REPORT

OF THE

CHEMICAL SECTION

BY

WILLIAM BEAM, M.A., M.D., F.I.C., F.C.S.
Research Chemist

REPRINT FROM

VOLUME B.—General Science

OF THE

FOURTH REPORT

OF THE

WELLCOME
TROPICAL RESEARCH LABORATORIES
GORDON MEMORIAL COLLEGE
KHARTOUM

PUBLISHED FOR
DEPARTMENT OF EDUCATION, SUDAN GOVERNMENT
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The following is a list of the samples received for examination since the issue of the Third Report of these Laboratories in 1908:—

Waters	389	Miscellaneous food and other products	34
Gums	52	Pathological chemical examinations	15
Toxicological examinations, drugs, etc.	42	Fuels	13
Soils	358	Clays and earths	30
Fertilisers	13	Limestones and limes	28
Oil seeds	17	Other minerals and ores	15
Grains and flours	33	Petroleum oils	13
Milk and milk products	10	Paints	4
Liquors and beverages	18		

Total, 1084

The period covered is from May, 1908, to December 30, 1910. The greater number of these samples were analysed or tested by the ordinary routine methods, but the list also includes samples secured for the purpose of research.

Research on Gum

A very great amount of time and labour was spent on gum research, the earlier results from which were most promising. It is all the more to be regretted, therefore, that one is forced to record, as in previous years, the entire failure of the Woods and Forests Department to effectively co-operate with us in this work. This Department is, however, now in process of reorganisation, and it is expected that we may count upon its aid in the future for the field work connected with research on forest products. Fortunately, too, the laboratories were able to secure for a second year the services of E. S. Edie, B.Sc., Carnegie Research Fellow, who spent the winter of 1908-9 in the forests near Taiara, Kordofan. Mr. Edie's researches were chiefly bacteriological, and his very interesting results appear to confirm those recorded by Greig Smith. The writer was also able to spend a short time in the gum forests of the Blue Nile (Sennar District), and a brief account of the observations there made will also be found below.

Toxicological work

In the course of its work, the chemical laboratory has been confronted with two very important problems, namely, the discovery of reliable tests for hashish and for "*ushar*" (*Calotropis procera*). The latter plant contains a milky juice which is extremely poisonous, and there is considerable evidence to show that it is not infrequently used by the native with criminal intent. It is gratifying to be able to record that what appears to be a reliable test for the former has now been found. As regards "*ushar*," Dr. Thompson has conducted a research on the latex of the plant and brought forward certain colour tests for it which may prove to be of value.

As will be seen from the list of samples tested, a very considerable number of soil examinations has been made in the past two years. At present the laboratories are largely engaged in a study of that section of the Gezira district which it has been proposed to put under perennial irrigation, when funds for the purpose become available. The cost of such irrigation works will be very great, and it is obviously necessary that some knowledge be secured of the character of the prevailing types of soil, before embarking upon a venture of such magnitude.

Soil examinations

Attention has been called, by this section of the laboratories, to the paramount importance of a study of the subsoil as well as the surface conditions, since the questions of drainage, resistance to drought and root penetration will depend largely upon the nature of the substrata. Mechanical analyses of these soils and their subsoils (*i.e.* the determinations of the proportions of sands, silt and clay) are therefore being made, and estimations of the proportions of essential plant constituents as well. These results, taken in conjunction with the observations made in the field, should yield sufficient evidence to enable one to form at least a reasonably accurate judgment as to the results which may be expected from irrigation, if the cultivation is carried out on suitable lines.

We have been fortunate in securing the aid of Mr. S. C. Dunn, Government Geologist, for field work in connection with these investigations, and are greatly indebted to him for the able manner in which he has carried it out in spite of climatic conditions which must be experienced to be appreciated. The first series of 184 samples were collected during the month of May with the thermometer ranging as high as 120° F. in the shade, and almost daily sandstorms.

A Test for Hashish

A reliable chemical test for hashish has long been a desideratum. The material, when pure, is sufficiently easy of identification, by reason both of its appearance and characteristic odour. In the great majority of instances, however, it is encountered in admixture with such substances as cloves, pepper, cinnamon, etc. This is usually the case with the native aphrodisiacs which often contain a small proportion of opium as well. The detection of small quantities of hashish in these mixtures has been extremely difficult and usually impossible. The following simple method has been found to be most satisfactory, and if proper precautions be taken, quite delicate. It depends upon the fact that the resinous matter of hashish strikes a marked purple colour on treatment with potash or soda. The test may be applied as follows: the material suspected to contain hashish is treated with petroleum-ether, the liquid passed through a filter and the ether evaporated to dryness in a small porcelain crucible. In the presence of any considerable amount of hashish a marked amount of tar-like residue is left; but if only a small amount is present there may only be a light yellow stain. To this residue a few drops of alcoholic potash are added, and the mixture evaporated to dryness on the water-bath. In the presence of hashish a rich purple colour is gradually developed. On dilution with water the colour takes on a more bluish cast. It is very permanent.

Details of the test

The purple colour is due to an oxidation product. If the evaporation of the petroleum-ether extract and alkali be conducted in an atmosphere free from oxygen, only a brown colour results.

Any of the ordinary resin solvents, alcohol, ether, acetone, benzene, chloroform, carbon disulphide or petroleum-ether may be applied to the extraction. Petroleum-ether is perhaps the most satisfactory, but it might conceivably be of advantage in special cases to employ one of the others in order to avoid the solution of material with which the hashish is associated.

The richest purple colour is obtained by extraction and evaporation in the cold. If the hashish be completely exhausted by prolonged extraction with warm petroleum-ether, as in a Soxhlet apparatus, the extract may not respond to the test, or only with difficulty. The colour developed by an extract so obtained is reddish, being masked by the brown tint due to the effect of the alkali on the associated extracted matter. There appears to be evidence also that the active body in the extract is gradually destroyed by such treatment.

Extracts of this kind may be made to yield a more characteristic reaction by treating the residue, spread out in a thin layer on porcelain, with strong *aqueous* potash or soda, but the colour may not appear for some hours.

J. A. Goodson, who has carried out much of the investigation in connection with the test, suggests the following method of application, which may be found useful when the hashish is mixed with other highly-coloured bodies. The extraction is made in the usual manner, the petroleum-ether treated with alcoholic alkali and evaporated to dryness. The resin acids are then liberated by the addition of a few drops of dilute acid, brought on to a filter and dissolved by the addition of a small amount of petroleum-ether. The liquid is then underlaid in a test-tube with weak aqueous soda or potash. The purple colour appears at the junction of the two liquids and, if the alkali solution is not too strong, is distributed throughout it. The colour is developed at once, since the resin acids have already been exposed to the air.

Variants of the method, for special circumstances

The test may also be made by the direct addition of the aqueous alkali to the petroleum-ether extract, but in this case the colour may not appear for 36 hours or more. So applied, the test is not delicate.

The ordinary alcoholic extract of *Cannabis indica* of the pharmacopœia does not appear to respond to the above test; this at least was the case with the two samples examined up to the present. The explanation of this may be connected with the fact, mentioned above, that the extract yielded by prolonged exhaustion with the solvent does not strike the purple colour as readily as material obtained by a short extraction in the cold. Then, too, the alcoholic extract of the pharmacopœia is obtained from the entire flowering tops of the plant, and is therefore more complex and more liable to alteration in composition than is hashish, which is chiefly the resinous matter obtained by rubbing the plant tops between the hands, or by some similar method.

[Since the above was written our attention has been called to a note on a similar reaction for "cannabinol" described by Czerkis (*Pharm. Post.* 42, 794-5, through *Chem. Zentr.* 1909, II., 1880, and abstracted in *Chemical Abstracts* of the Amer. Chem. Soc., Vol. 5, No. 4, Feb. 20, 1911). The note made is to the effect that potassium hydroxide produces in alcoholic solutions of cannabinol an intense red colour which disappears on acidifying. The extraordinarily rich purple colour obtained by the method already detailed does not appear to have been obtained.

The method as described has been in use in these laboratories for the past two years.]

Khartoum Water-Supply

In the last Report[1] a note was made on the composition of the waters of the deep wells at Khartoum from which it had been proposed to take the town supply. In it were recorded the results of the bacterioscopic and chemical examinations, which indicated that the water was highly contaminated, and the untreated water was, in consequence, condemned for such purpose. Not only were *B. coli* found in very great numbers, but the water was found to contain notable proportions of iron and manganese, sufficient indeed to give rise to the growth of *crenothrix* and to be objectionable in other ways. Subsequent investigation indicated that it was possible to prevent the contamination of the water. The means by which this was effected are detailed in Dr. Balfour's fuller note on the subject (*vide* Vol. A., *page* 308). It is proposed here simply to give a short account of the chemical composition of the water, before and after the alteration in the wells was made, by which the desired end was attained.

Chemical notes on Khartoum water-supply

The original scheme of the Department of Works comprised the sinking of seven wells. These were all fairly close together—perhaps too close for efficient working. At the present time only three of these wells are in use, Nos. 1, 6 and 7. At the time the earlier tests were made it was not possible for us to obtain the water from each well separately, so that the comparison with the present state of affairs is not as complete as could be desired. Several examinations were made of the water of Well No. 3, the results from one of these being as follows:—

[1] *Third Report, Wellcome Tropical Research Laboratories*, p. 399

Date of Collection, January 1, 1908

	Parts per million
Total solids	265·00
Free ammonia ... ...(NH_3)	0·55
Albuminoid ammonia ... ...(NH_3)	0·06
Nitrites... ... ... (N)	traces
Nitrates ... ... (N)	0·10
Chlorides ... ... (Cl)	1·44
Sulphates ... ... (SO_4)	2·06
Carbonates ... ... (CO_3)	143·00
Calcium ... ... (Ca)	64·31
Magnesium ... ... (Mg)	17·64
Sodium ... ... (Na)	7·88
Potassium ... ... (K)	5·74
Iron ... ... (Fe)	1·33
Manganese ... ... (Mn)	0·17

The water was almost quite clear when it emerged from the pipe but became distinctly opalescent after a few minutes exposure to the air, and ultimately deposited a small amount of yellowish-red precipitate. The taste of the water was faintly chalybeate. Its temperature was fairly constant at about 29° C. Physical characters

The points specially to be noted are the high proportion of ammonia, of iron and manganese, and the presence of nitrites. The presence of an excessive amount of ammonia, and of nitrites, is usually an indication of serious pollution; but in the present instance such a conclusion might be erroneous since ammonia is not uncommonly found in deep wells known to be pure, and such ammonia is often, as in the present instance, associated with iron. There could be no doubt, however, as to the objectionable nature of the iron and manganese found, and the prediction made at the time that *crenothrix* would sooner or later appear in the pipes was quickly verified. *Crenothrix* predicted

The mixed waters from Wells Nos. 1, 2, 4, 5 and 6 were next tested, on February 23, after 72 hours' continuous pumping. The water was found to have a distinct odour as it emerged from the pipe and was more turbid than the water from Well No. 3 examined formerly. It contained masses of flocculent matter coloured by iron. The interior of the pipe and the tin in which the water impinged at its exit were markedly coated with a fungoid growth coloured by iron. The proportions of iron and manganese found in this water were:—

	Parts per million
Iron	1·20
Manganese	0·22

After 192 hours' continuous pumping, the water was again tested. It was found to be in practically the same condition. The flocculent masses were examined under the microscope and found to be *Crenothrix polyspora* or closely allied species. Iron and manganese were present as follows :—

	Parts per million
Iron	1·12
Manganese	0·10

The pipes having been cleaned and scraped, another sample was taken on March 1. The odour of the water at its exit had disappeared, but the results of the chemical examination were unaltered.

During my absence on leave in July, 1908, samples from Wells Nos. 2 and 3 were taken by Dr. Todd, Bacteriologist to the Public Health Department, Cairo. These were examined by Mr. Goodson with results as follows :—

	Parts per million	
	Well No. 2	Well No. 3
Total solids	291·2	274·8
Free ammonia ... ... (NH_3)	0·379	0·489
Albuminoid ammonia ... ... (NH_3)	0·047	0·012
Oxygen consumed ... ... (O)	1·48	2·00
Nitrates... ... ... (N)	0·01	0·02
Nitrites... ... ... (N)	nil	nil
Chlorides ... ... (Cl)	1·72	2·48
Sulphates ... ... (SO_4)	1·64	1·38
Carbonates ... ... (CO_3)	134·05	132·84
Calcium... ... ... (Ca)	58·98	58·08
Magnesium ... ... (Mg)	18·11	19·25
Iron ... ... (Fe)	0·81	0·85
Manganese ... ... (Mn)	0·50	0·33

These showed still higher proportions of manganese than the samples examined before, but the sum of the iron and manganese was much the same.

Two long series of determinations of the manganese were also made during pumping trials on Wells Nos. 3 and 6. These showed the manganese practically constant at 0·3, and 0·55 parts per million, respectively.

Two more complete analyses of Well No. 7 were also made by Mr. Goodson, at Dr. Todd's suggestion, and one of a small surface well, the depth of which was 18 metres only. The results were as follows :—

	Parts per million		
	Well No. 7		Surface Well
Total solids	222·4	220·4	335·60
Free ammonia ... ... (NH_3)	0·622	0·800	0·411
Albuminoid ammonia ... ... (NH_3)	0·017	0·023	0·017
Oxygen consumed ... ... (O)	0·92	0·78	1·60
Nitrates .. .. (N)	0·055	0·040	0·046
Nitrites ... ... (N)	none	none	none
Chlorides ... ... (Cl)	1·33	1·71	0·95
Sulphates ... ... (SO_4)	2·80	4·11	6·25
Carbonates ... ... (CO_3)	112·12	110·00	168·00
Calcium ... ... (Ca)	44·23	42·64	68·14
Magnesium ... ... (Mg)	17·06	17·94	20·04
Iron ... ... (Fe)	0·33	0·13	0·20
Manganese ... ... (Mn)	0·20	0·18	1·11

As pointed out by Dr. Todd, it is evident from the foregoing analyses that the quantities of manganese show considerable differences in the different wells tested—the water from the small surface well containing the highest amount, and that from the deep well (No. 7) the lowest. Thus :—

	Depth	Manganese
Small surface well ...	18 metres	1·11
Well No. 2	75 ,,	0·50
,, No. 3	75 ,,	0·27–0·33
,, No. 6	75 ,,	0·55
,, No. 7	176 ,,	0·18–0·20

(These figures refer only to the analyses made during the month of July, as the results of analyses made at different seasons might not be comparable).

Dr. Todd further pointed out that the above results showed a certain parallelism with the following results of rough tests for manganese made at his request by Mr. Goodson, of the boring samples of Well No. 7 down to a depth of 80 metres :

Depth of Stratum	Proportion of manganese found	Depth of Stratum	Proportion of manganese found
6 to 15 metres	large	37 to 47 metres	nil
18 to 19 ,, ...	moderate	47 to 50 ,, ...	nil
19 to 23 ,, ...	,,	50 to 52 ,, ...	moderate
23 to 26 ,, ...	trace	52 to 54 ,, ...	,,
26 to 27·5 ,, ...	fairly large	54 to 56 ,, ...	small
27·5 to 28·5 ,, ...	moderate	56 to 61 ,, ...	nil
28·5 ,, ...	,,	61 to 62 ,, ...	moderate
28·5 to 31 ,, ...	fairly large	62 to 71 ,, ...	trace
31 to 37 ,, ...	large	71 to 80 ,, ...	nil

The analyses as a whole, it was found, seemed to prove that "the best water from a chemical point of view is that of Well No. 7, which is fed mainly from the deeper layers." The recommendations made by Dr. Todd and Mr. Abel, the engineer called in consultation, were, among others, to deepen certain of the wells and to cut off the upper strata by the method detailed by Dr. Balfour in his note on these wells (*loc. cit.*). The wells in use at the present time are Nos. 1, 6 and 7. Many examinations of these have been made in the last year, the most recent results being as follows. They are from Wells Nos. 1, 6 and 7, the others having been abandoned as unnecessary.

	Parts per million		
	Well No. 1	Well No. 6	Well No. 7
Collected	Dec. 29, 1910	Nov. 9, 1910	Nov. 9, 1910
Total solids	208·00	227·60	195·20
Free ammonia ... ...(NH_3)	0·50	0·60	0·48
Albuminoid ammonia ... ...(NH_3)	0·02	none	0·02
Nitrites ... ... (N)	none	none	none
Nitrates ... ... (N)	0·01	0·01	0·01
Chlorides ... ... (Cl)	1·44	2·20	1·90
Sulphates ... ... (SO_4)	3·79	3·80	3·90
Carbonates ... ... (CO_3)	109·80	117·60	103·20
Calcium ... ... (Ca)	44·80	45·60	40·40
Magnesium ... ... (Mg)	12·28	13·84	12·97
Sodium ... ... (Na)	5·82	8·18	5·97
Potassium ... ... (K)	2·21	4·70	5·48
Iron ... ... (Fe)	0·18	0·32	0·12
Manganese ... ... (Mn)	0·18	0·16	0·20

Further improvement on storage

The above analyses represent the water not as supplied to the town, but directly it emerges from the air-lift. A further very marked improvement is effected by storage in a large cement-lined reservoir. As a result of the very efficient aeration, due to the use of the air-lift, not only is the iron oxidised and precipitated, but, what was entirely unexpected, the manganese is carried down as well. The precipitation of the iron and manganese probably also aids the direct oxidation of the small amount of organic matter present, the effluent water attaining a remarkable degree of organic purity. The following is a comparison of the water as it emerges from the air-lift pipes with that taken from the tap in the laboratories, *i.e.* after it has been allowed to stand in the reservoir for 48 hours or over.

The water at the time was the product of Wells Nos. 6 and 7.

	From air-lift	From tap in laboratory
Free ammonia ... ... (NH_3)	0·54	none
Albuminoid ammonia ... ... (NH_3)	0·01	none
Nitrites ... ... (N)	none	none
Nitrates ... ... (N)	0·01	0·36
Iron ... ... (Fe)	0·22	0·05 to 0·80
Manganese ... ... (Mn)	0·18	none or trace

The following determinations of iron and manganese in the tap water were made at various times.

Date	Taken from tap at	Iron	Manganese
Jan., 1909	Medical Mess...	0·06	none
May, 1909	Military Hospital	0·20	none
Nov., 1909	Dr. Balfour's House...	0·45	none
,, 1909	Sudan Club	0·22	none
Oct. 31, 1910	Chemical Laboratory	0·12	none
Nov. 1, 1910	,, ,, ...	0·80	trace
,, 2, 1910	,, ,, ...	0·20	0·01
,, 3, 1910	,, ,, ...	0·50	none
Jan. 4, 1911	,, ,, ...	0·06	trace
,, 5, 1911	,, ,, ...	0·05	none

The iron present in the tap water is largely in suspension. It is apparently due to a slight corrosion of the pipes, since the surface water of the reservoir, after only eight hours settling, contains as a rule a smaller amount. There is also the fact that if it were that originally present, it would be associated with a more appreciable proportion of manganese. (*See below*, the analysis of sediment from the reservoir.)

The cause of the corrosion is doubtless, in part at least, galvanic action, the result of Corrosion
the deposition of a small amount of manganese and iron oxide in the pipes. The absence of manganese and presence of iron in the tap water was at first thought to be the result of a slight growth of *crenothrix* in the pipes, but no growth of this kind has been detected since the deepening of the wells and the cutting off of the contaminated water of the surface strata.

An analysis, by Dr. Thompson, of the sediment deposited in the storage reservoir gave results as follows :—

Loss of ignition		17·46 per cent.
Iron oxide	(Fe_2O_3)	29·40 ,, ,,
Manganese protosesquioxide	(Mn_3O_4)	18·07 ,, ,,
Alumina	(Al_2O_3)	3·97 ,, ,,
Lime	(CaO)	6·25 ,, ,,
Magnesia	(MgO)	2·57 ,, ,,
Silica	(SiO_2)	21·48 ,, ,,
Sulphates	(SO_4)	trace
Total		99·30

Plumbo-solvency. The solvent action of the water on lead was tested by means of a section of new lead pipe, about 2 metres long and 1·3 centimetres bore. The water of Well No. 7 only was taken for the test, but as the waters of these wells differ but slightly in composition, the results, I think, may safely be taken as representative of the supply as a whole.

The lead pipe having been fitted with a stop-cock, it was filled with the water which was allowed to remain for twenty-four hours. It was then run off and tested, and the pipe refilled. The tests were carried out in this way for a month. In the beginning, the amount of lead was approximately 0·7 part per million. The amount dissolved gradually diminished, but at the end of the month the proportion found was still considerable, being about 0·44 part per million.

Action on lead

Sobat River Water

In 1908, an attempt was made to carry out an investigation of the composition of the water of the Sobat River, and Mr. Walsh, then of the Sudan Irrigation Service, kindly undertook to collect the samples for the purpose. It was intended to make a series of monthly examinations for an entire year, but Mr. Walsh, by reason of the press of other work, was unable to secure more than nine samples. These were nevertheless well distributed throughout the year and the results probably represent fairly well the usual composition of the water and its variations.

The results of the examinations are stated in the table on the next page. As will be seen by comparison with those from the Blue Nile and White Nile, which have already been recorded,[1] the Sobat water contains, on the whole, lower proportions of dissolved solids than do any of the branches of the Nile examined up to the present. The proportions of sodium carbonate and potassium carbonate are very markedly lower than is found in the other tributaries of the White Nile or in the White Nile itself, and the Sobat water should therefore be superior to these for irrigation purposes. One may also reasonably expect the soil of the district through which this river flows, and which may be subjected to inundation by it from time to time, to be of better quality than that flooded by the White Nile.

Suitability for irrigation purposes

[1] *Third Report, Wellcome Tropical Research Laboratories*, pp. 386 to 395

ANALYSES OF SOBAT RIVER WATER

Date of Collection		Dec. 31, 1907	Jan. 26, 1908	March 2	March 24	May 23	June 21	July 18	Sept. 16	Oct. 29
Suspended matter		25·40	26·60	15·60	30·60	18·60	122·60	49·70	34·80	22·80
Dissolved solids		77·8	78·60	97·20	107·80	96·90	72·00	82·50	70·40	79·80
"Free" ammonia	NH_3	0·023	0·020	not det.	0·038	0·015	0·018	0·015	0·026	0·007
"Albumenoid" ammonia	NH_3	0·274	0·165	not det.	0·143	0·174	0·320	0·323	0·125	0·209
Oxygen consumed in 10 minutes at 100° C.	O	4·07	2·86	2·20	2·01	3·85	5·42	4·68	4·05	4·17
Nitrates	N	0·28	0·22	not det.	0·16	0·466	0·32	0·39	0·12	0·06
Nitrites	N	none	none	none	none	none	none	none	none	none
Chlorides	Cl	0·80	0·96	1·90	1·71	1·90	1·42	1·42	0·78	trace
Sulphates	SO_4	none	none	none	none	none	none	none	none	none
Carbonates	CO_3	26·27	29·60	30·34	29·60	22·12	14·43	14·13	17·43	26·44
Calcium	Ca	—	11·71	11·08	11·16	7·47	7·57	7·97	9·97	7·17
Magnesium	Mg	—	—	6·21	6·82	4·37	2·84	3·15	4·46	4·73
Potassium	K	4·93	3·15	0·35	0·23	1·53	traces	0·06	2·98	3·70
Sodium	Na	1·41	0·23	7·25	4·73	1·40	0·47	1·46	2·75	3·94
Silica	SiO_2	11·20	10·00	18·40	22·80	not det.	16·60	18·40	7·80	13·00

The Mechanical Analysis of Arid Soils

The mechanical analysis of soils, that is to say the division of their particles into groups according to size, is perhaps of greater importance than any other single determination which the soil analyst is called upon to make. These analyses would undoubtedly be made more frequently than is done at present were the methods suggested more satisfactory and, especially, less laborious. That recommended by Hall,[1] which appears to be the only one practised in Great Britain, is so tedious and often requires so long a time for its completion as to very seriously impair its usefulness. Its application to arid soils offers a still more serious objection in that it entails a treatment with acid, which is not permissible with arid soils, the larger particles of which may be, and usually are, concretions of calcium carbonate. Hilgard's method, depending upon the use of successive currents of water of velocities adjusted to carry particles of the required size, offers several objections, perhaps the least of which is that, requiring special and expensive apparatus, it is, to quote from Hall (*loc. cit.*), suited only to laboratories devoted entirely to soil analysis. Osborne's method, which, like that of Hall, is carried out by a series of sedimentations in beakers, proves in our hands, working with arid soils, to be capable of yielding results of the most varying character. It leaves very much to be desired on the score of ease and rapidity, especially when a number of samples are to be treated at the same time. Indeed, the multiplication of vessels alone renders it quite inapplicable in such cases. The method advocated by the U.S. Bureau of Soils appeared to us to be the most promising. It consists in breaking up the soil agglomerations—puddling the clay—by agitation in a mechanical shaker with water and a few drops of ammonia. The separation of the clay from the other groups of particles is then made by means of a centrifuge.

Various methods of mechanical analysis

Given the appliances suited to the purpose the above method would seem to leave little to be desired on the score either of rapidity or accuracy. Our experience with it, as applied to arid soils, has been most disappointing. It, as do most of the other methods, fails to separate a very considerable proportion of the clay, which goes therefore to swell the silt and other fractions. That the entire amount of clay should be taken into consideration has been abundantly shown by the results of observation on partially water-logged soils, inefficiently drained, and lacking oxygen. Under these conditions sodium carbonate is formed in notable proportion, one of the results being the deflocculation of the clay with its attendant disastrous effect on production.

Importance of ascertaining the total "clay"

In the analytical work carried out recently it has been noted that even when so little as two per cent. of clay remains associated with the residue of silt and sands, the binding effect on the soil is very marked.

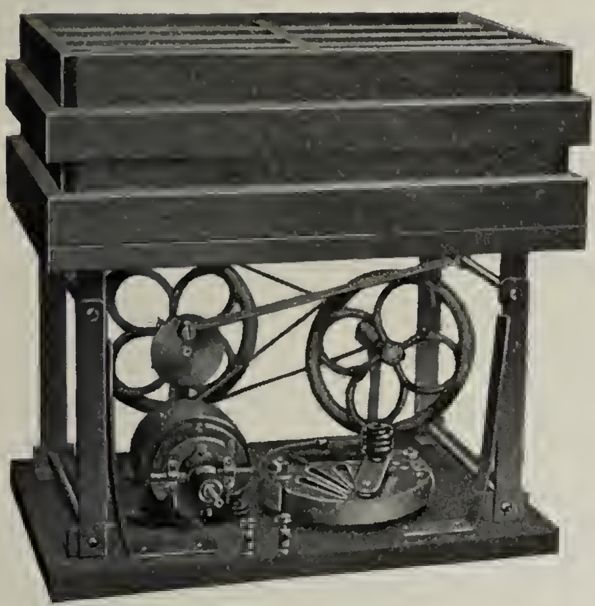
Clay aggregates in arid soils are known to be held together much more firmly than in those of humid regions. There is evidence that this condition is associated with the intense baking which these soils receive during the season of drought. (See below.)

In the tests which were made by the U.S. Bureau of Soils[2] on the effect of length of time of agitation in the mechanical shaker on the proportion of clay found, no marked additional change appeared to take place when the time was increased beyond six hours, except in the case of samples shaken as long as 77 hours. After such prolonged action

[1] *The Soil*, p. 51

[2] *Bureau of Soils Bulletin*, No. 24

there was usually an increase in the amount of clay and this was taken to mean that the soil was being unduly broken down. Six hours was therefore taken as a sufficient length of time to subject the soil to the action of the shaker.



W. B & E., PHILADA.
Fig. 3.—Mechanical Shaker for Soil Tubes

The form of electrically-driven mechanical shaker adopted by the U.S. Bureau of Soils is shown in Fig. 3. At the time soil work was begun in these laboratories a machine of this type was not at hand, and the ordinary form of end-over-end rotary shaker was used for the purpose. The following results were obtained on a sample of "cotton soil" known to contain about 54 per cent. of clay. Five grammes of the soil were, in each case, treated with 75 c.c. of water to which ten drops of strong ammonia were added. For the sake of simplicity the proportion of clay only is given, though in many cases complete analyses were made. Mechanical "shaker"

Length of shaking in rotary shaker	Clay
6 hours	24·8 per cent.
7 hours	26·1 ,, ,,
14 hours	23·5 ,, ,,
24 hours	29·6 ,, ,,
48 hours	35·1 ,, ,,

Later, a machine of the horizontal type was secured, and a short series of experiments was carried out with it. These were not carried very far since it was soon evident that while the agitation was more violent, the results were not sufficiently improved to render the method practicable. Thus:—

Length of shaking	Clay found
30 minutes	25·3 per cent.
1 hour	21·4 ,, ,,
2 hours...	26·5 ,, ,,
6 hours...	33·4 ,, ,,

The actual amount of clay present was, as in the former experiments, 54 per cent.

The machine was run at the speed prescribed by the U.S. Bureau of Soils, namely, 100 impulses per minute. By shaking more violently the amount of clay separated in six hours was increased to 38·2, a figure still far below the truth.

As will be seen, even after 48 hours' shaking in the rotary machine, the proportion of clay separated was only about two-thirds the total amount.

No attempt was made to carry the agitation in the horizontal shaker beyond six hours, since it was considered that this length of shaking is as long as can be conveniently carried out, a longer one entailing either two or more periods of shaking, or its continuance during the absence of the analyst, which always introduces an undesirable uncertainty into the determination.

Soils of arid regions usually contain notable proportions of calcium and magnesium compounds, especially calcium carbonate and sulphate. It had already been noted by Briggs, Martin and Pearce[1] that ammonia, when applied to the treatment of such soils, appears rather to flocculate the clay than to break up the flocculations, and its addition in such cases is therefore not desirable. They further note that certain soils (containing an excess of magnesium and calcium carbonate) and which presumably were shaken with water only, were badly flocculated at the beginning of the mechanical analysis; but that after two or three decantations had been made, the tendency to flocculate disappeared and the final separation was made without difficulty. These soils were found to contain as much as 25 and 42 per cent. respectively, of carbonate, calculated as calcium carbonate.

Deflocculation assisted by the presence of sodium carbonate

Although Sudan soils rarely, if ever, contain as much as ten per cent. of carbonates, calcium sulphate is frequently present, more especially in the subsoils, and the two together cause these soils to flocculate persistently in spite of the absence of ammonia. We have found, however, that trouble of this kind usually disappears on the addition of sodium carbonate. As we have abandoned the needlessly laborious and no more accurate method of determining the clay by direct weighing, the presence of sodium carbonate introduces no difficulty. Deflocculation is so effectually aided by the sodium carbonate that only moderate agitation in the mechanical shaker is required, and either of the two forms of machine mentioned above may be applied to the purpose, the one figured on *page* 35 being, however, preferable by reason of its far greater convenience in use.

The use of sodium carbonate in the analysis of these soils is, it appears to us, all the more indicated in view of the fact that it may be formed in the soil as the result of inefficient drainage. The indications furnished by its use in the laboratory are of direct practical bearing aside from the fact that it appears to be the only agent which will enable us to obtain an idea of the true mechanical constitution of the soil, without the use of acids which, for the reason already given, are wholly inadmissible.

A number of experiments was made in order to determine the effect of varying amounts of sodium carbonate. From fifty to one hundred milligrammes to 100 c.c. of water appears to be a suitable proportion. If the amount of sodium carbonate be materially increased, the reverse effect of flocculation results. The yield of clay with the higher proportion of carbonate was nevertheless, in the few experiments made, slightly lower; which is satisfactory in that it goes to show that there is no danger of solvent action on the fine siliceous silt in the soil. The results were as follows:—

Form of shaker	Time of shaking	Sodium carbonate	Clay found
Rotary	6 hours	1 gramme	48·6 per cent.
,,	,, ,,	0·1 ,,	48·9 ,, ,,
Horizontal	,, ,,	1 ,,	47·7 ,, ,,
,,	,, ,,	0·1 ,,	49·1 ,, ,,

[1] U.S. Bureau of Soils, Bulletin 24, *p.* 24

A slightly more effective disintegration of the soil aggregates is had by simple heating with the dilute sodium carbonate solution. The soil tested above gave the results as follows:—

Time of heating	Sodium carbonate	Clay found
15 minutes in steam bath	·2 in 100 c.c. water	50·9 per cent.
30 ,, ,, ,,	,, ,, ,, ,,	51·4 ,, ,,
5 ,, boiling	,, ,, ,, ,,	51·7 ,, ,,
15 ,, ,,	,, ,, ,, ,,	51·8 ,, ,,
35 ,, ,,	·1 ,, ,, ,,	51·8 ,, ,,

The above results were obtained by the use of the centrifugal machine. If the method of sedimentation in beakers is employed, the boiling method offers the great disadvantage that the number of decantations is very much increased. It is possible that while the clay particles are disintegrated by the boiling, they gradually combine again to a certain extent after the liquid cools.

We have found that by far the most effective agent in bringing about the deflocculation of the clay is an ordinary camel-hair brush. It is employed as follows: The weighed portion of soil is placed in a beaker (or enamelled iron cup) and water cautiously added, sufficient to form a thick paste. The mixture is then stirred with the brush. The clay is rapidly puddled and the mixture becomes so tenacious that a further addition of water is required. This is made very carefully, a few drops at a time, and the puddling continued for from five to ten minutes.

Use of a camel-hair brush in puddling the clay

There appears to be no objection to carrying out the puddling in a beaker. One of these, used for several successive operations, was found not to have lost even a milligramme.

For arid soils, which contain considerable calcium carbonate (and, not infrequently, calcium sulphate) it is essential that all water used should contain sodium carbonate in about the proportion already indicated.

The further treatment of the soil, after the above operation, depends upon the method to be employed. If one of sedimentation, the mixture is made up to a height of say ten centimetres and allowed to stand for a length of time depending upon the size of soil particles which is taken as limiting the clay (*vide infra*). We have adopted what is practically the 8-hour subsidence, which includes, in the clay division, particles up to about 0·002 millimetre. After, usually, the third decantation, the residue, from which most of the water should be removed on the water-bath, is again puddled for about a minute, after which no further puddling is required, the residue being simply mixed with successive portions of water (containing sodium carbonate) and allowed to stand for the specified time until the liquid becomes practically clear at the end of that time.

As already stated, the brush method of puddling has been found to be more effective than any that we have tried. No matter what be the method of analysis adopted, its use at one or more stages of the process is strongly recommended. Its efficiency as compared to that of the rubber pestle recommended by Hall and others is most striking. Using the rubber pestle and employing the Hall method (of acid treatment followed by ammonia) we have frequently had to decant as often as 20 to 30 times before the water came away clear. The analysis carried out in this fashion may take more than a month for its completion. By the aid of the brush and the use of sodium carbonate, the whole or practically the whole of the clay may usually be removed in five decantations.

Great acceleration of analysis by the brush and sodium carbonate method

The following experiments were made in order to determine the rate at which the clay is removed :—

	Clay, per cent. of total present	
	Soil No. 1	Soil No. 2
1st decantation	60·5	76·0
2nd ,, ...	23·5	12·6
3rd ,, ...	9·9	5·4
4th ,, ...	4·1	3·6
5th ,, ...	2·0	2·4
Total	100·0	100·0

These results were compared with those of the method by boiling with dilute sodium carbonate solution. It was found that when boiling was adopted, not only was more than double the number of decantations required, but the sum total of the clay removed was 51·5 per cent. as against 54 per cent. by the use of the brush. Examination of the soil particles under the microscope shows the particles of sand and silt to be quite clean when the brush is used, which is not the case with the method by boiling.

Technique for using the brush

As the camel-hair brush picks up and retains a considerable quantity of the soil, care must be taken to remove this by agitation in successive portions of distilled water in a small beaker, the whole of the separated sand being washed out of the beaker after each washing. Usually four or five washings are sufficient. Tapping the bottom of the beaker with the brush submerged in the water, has been found the most efficient method of dislodging the sand.

In order to avoid the frequent washing of the brush, which, while it need only be employed twice in each determination, is nevertheless advantageously applied to bring the clay into suspension after each decantation, it is best to use a separate brush for each soil operated on, and to wash out only once at the end of the process. The brush is conveniently kept in the small beaker in which the operation of washing is carried out at the end.

Any form of camel-hair brush may be applied to the above purpose. We have found the flat form about half an inch broad, bound to a wooden handle by a strip of tin, to be very convenient. Paraffin wax should be applied to the tin junction in order to fill the interstices and prevent the entrance of soil.

The round form of brush may also be used, a glass rod being inserted into the quill, (which is cut rather short) and fastened by wrapping with thin copper wire. The junction should be protected by wax as noted above.

Cleaning of the brush after each puddling is more readily accomplished if the hairs be cut moderately short.

Where a great number of soils are to be operated upon, the labour of the preliminary puddling may be avoided by substituting agitation with water and sodium carbonate in the mechanical shaker, as described above. After the fourth decantation the residue (from which some of the water should be removed on the water-bath) need be puddled by the aid of the brush for about one minute only. The results obtained in this way have been, in our hands, identical with those in which the five or ten minutes preliminary puddling was carried out, but the clay comes away more slowly.

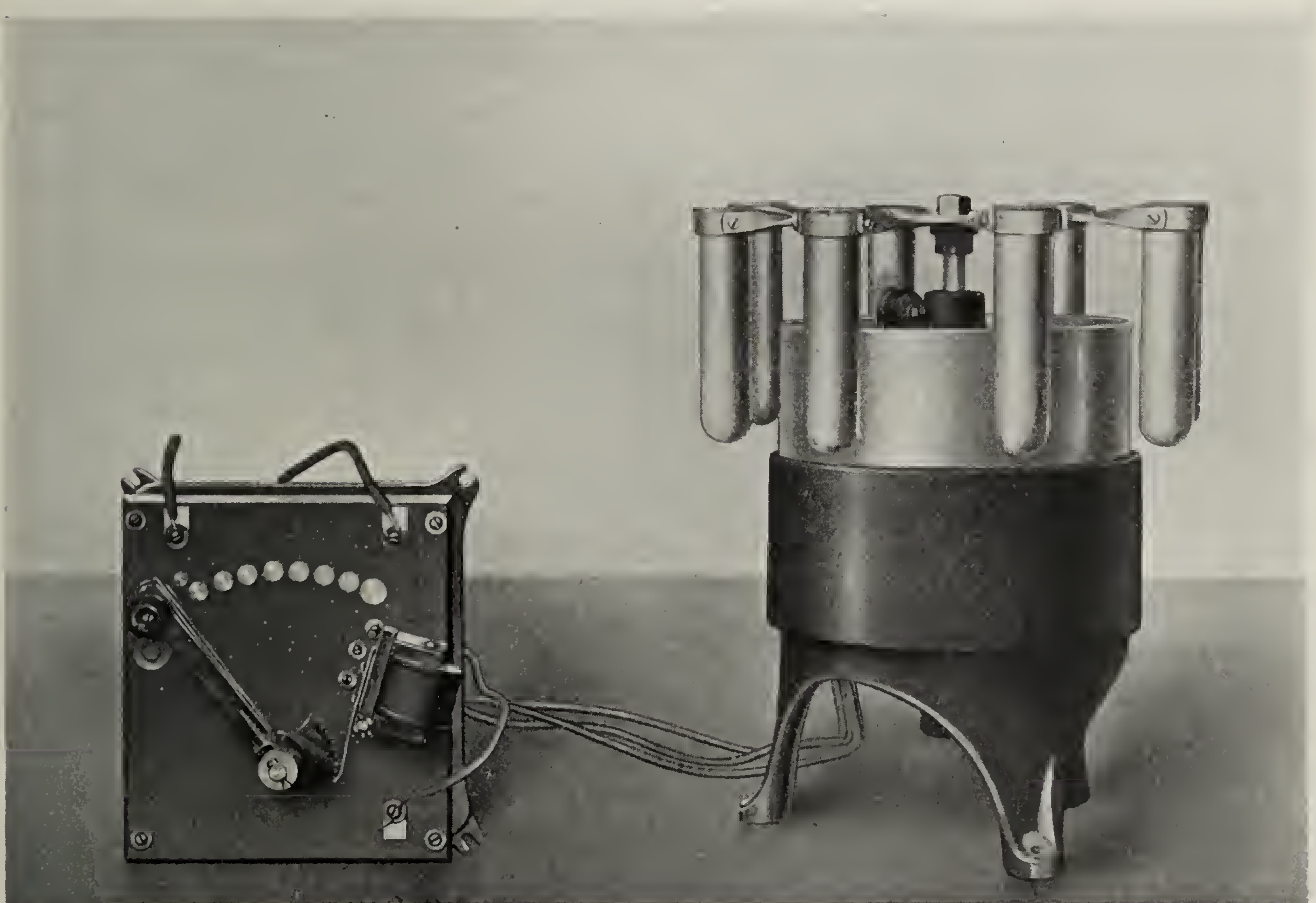
The soil need not usually remain in the shaker more than about an hour, as will be seen from the results of the following experiments with a soil containing about 54 per cent. of clay.

Time of agitation in the mechanical shaker (Water 10 c.c. Na_2CO_3 0·1 gramme. Brush not used)	Clay found
1 hour	47·4 per cent.
3 hours	47·2 ,, ,,
5 ,, ...	48·8 ,, ,,
6 ,, ...	49·1 ,, ,,

With the majority of soils little appears to be gained by continuing the operation beyond an hour, since the small amount of clay which remains unaffected at the end of that period is easily brought into suspension by the short puddling mentioned.

Centrifugal Method

While the method of separating the clay, as outlined above, is rapid and generally satisfactory, the operation may be performed still more quickly by means of the



W. B. & E., Phila.

Fig. 4.—Centrifuge for Soil Analysis

centrifugal machine. Against this must be stated the fact that the centrifugal method entails much more of the operator's attention, though the use of an alarm clock which may be set accurately to the minute will enable him to devote a little time to other work during the whirling. We have found an electric alarm the most reliable for the purpose. One of the forms of centrifuges used in America is shown in Fig. 4. The machines are well known and need no special description. It is desired simply to call attention to the method of controlling the results. It is usually stated that this must be carried out by the use of the microscope. While this is, in a measure, true, it would be useless to expect to obtain results exactly comparable with those from sedimentation, in such a manner. The slightest variation in the size of the particles from the standard which has been adopted would, in many soils, make a marked difference in the results. It must be recollected that the particles are never spherical, so that exact measurement by means of a micrometer is practically impossible, and no two observers could be expected to get precisely the same result. The plan we have adopted is to treat several soils of different character by the sedimentation method and then to determine the length of time of whirling in the centrifuge, run at a known speed, to obtain the same result.

Centrifugal method

If the soil has been sufficiently puddled at the start we have found that the number of whirlings required is much lessened, almost the entire amount of clay being removed after the sixth decantation. In the machine at hand, 6 minutes has been fixed upon as the period of whirling, the number of revolutions being about 840 per minute. The machine figured runs at a much higher speed and the length of whirling would be materially reduced.

It has been found that after the 6th or 7th whirling, when nearly all the clay has been removed, the remaining soil packs so loosely at the bottom of the tube that the swirling of the liquid, due to the arresting of the machine, causes some of the fine silt to be drawn up into it. As the result of this the water never becomes quite clear, and the end of the clay removal is difficult to judge. This may be avoided by increasing the time of whirling, after the 6th or 7th, to 10 minutes, so that the soil residue packs more closely. The error introduced by the longer whirling at this stage of the process is negligible. The difficulty mentioned would probably not be experienced with machines adapted to higher speed.

Size of the clay particles

The size of the clay particles. Different workers have adopted various limits for the size of the particles taken to represent the group designated "clay." The most common upper limits are ·002 mm. and ·005 mm. Hall[1] employs the first mentioned and separates the clay by 24 hours' subsidence from a column of water $8\frac{1}{2}$ centimetres in height. Kilroe, Seymour and Hallisy[2] employ a method which is attributed to Hall and in which the height taken is 15 centimetres, the particles being stated to have a maximum diameter of ·005 mm. Hilgard[3] describes a method of subsidence of 24 hours' duration, the column of water being 20 centimetres in height "whereby all grain sizes of and above 0·01 mm. diameter are removed from the turbid liquid." Atterberg[4] recommends either the limit ·003 mm. obtained by a 4 hours' subsidence from a column of 10 centimetres, or of ·002 mm. from a column of the same height but with the time of subsidence increased to 8 hours.

It is obvious that the above statements as to the size of the particles are highly discordant. We have made many measurements, all the results of which point to the fact that the figures given by Hilgard and by Kilroe, Seymour and Hallisy and many others, are not even approximately correct. Our measurements agree more nearly with those

[1] *The Soil*, 2nd Ed., p. 51.

[2] *The Geological Features and Soils of the Agricultural Station of the Dept. of Agriculture at Ballyhaise*, 1910.

[3] *Soils*, p. 89.

[4] *Über die Klassifikation der Bodenkörner*, A. Atterberg, Kalmar.

of Hall and of Atterberg, but it is evident that to obtain a separation up to about ·002 mm. it is not necessary to carry the time of subsidence as far as prescribed by Hall. Many of our results were obtained by the use of a column of 20 centimetres height, but we have abandoned this method for the reason that the shortening of the number of decantations was not what was expected. It would appear that the longer the column the more the particles which subside carry others with them. A better result is had by employing two vessels with columns one half the height (10 cm.) the liquid being divided equally beween them; but such a multiplication of vessels does not appear necessary if the soil be properly puddled as described.

Influence of height of column

An examination of the particles deposited from the 20 centimetre columns proved them to be but very slightly larger than those of the 10 or 8½ centimetre columns, provided always that the time of subsidence be carried to 24 hours. The following figures show how small is the effect of the height of the liquid on the results obtained from the mechanical analysis of Sudan soils. The duration of subsidence was, as stated, 24 hours.

	HEIGHT OF COLUMN OF WATER		
	8½ cm.	10 cm.	20 cm.
Azaza soil	36·1 per cent.	not determined	38·0 per cent.
Bardobe soil	52·6 ,, ,,	53·1 per cent.	54·2 ,, ,,
Mixture of 10 typical *bardobe* soils ...	51·0 ,, ,,	not determined	52·4 ,, ,,

Determination of the "Silt"

When a number of soils have to be examined at the same time, we have found the use of the apparatus shown in Fig. 5 to effect a great saving of time and trouble. The residues from the clay determinations (made by difference) are washed into the cylindrical beakers (or museum jars) with distilled water containing the usual small amount of sodium carbonate.[1] After standing for a length of time dependent upon the size of the particles adopted as representing the "silt" division, the liquid is poured away and rejected. This preliminary treatment should be made with distilled water, since the soil still contains particles in size bordering on those of the clay division. The subsequent operations may, as a rule, be carried out with clear tap water.

"Silt"

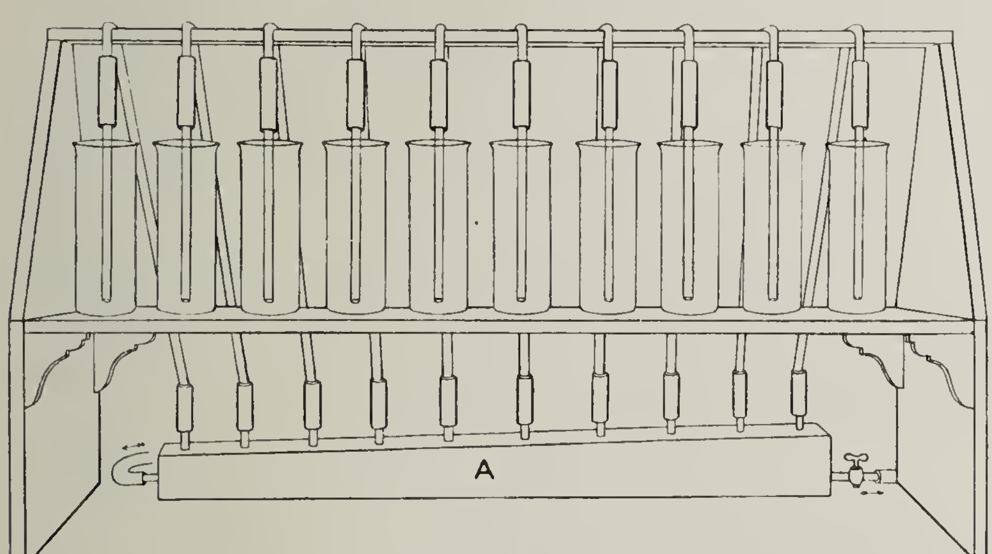


Fig. 5.—Apparatus for the determination of silt

[1] Since the heating of the soil residue in the oven usually causes it to cake together, it is advisable to add to it a small amount of water containing sodium carbonate and bring almost or quite to boiling. It is then treated as described above.

The beakers are placed in position and, the vent-cock having been closed, the water tap is turned on very cautiously until the water is seen to appear in the glass tubes. If the level rises equally in all, thus indicating that no air is included, the flow is allowed to continue until the water reaches the bend in the glass tube. At this moment the full force of the water is quickly turned on. If the operation is not carried out as indicated some of the siphons may begin to act too quickly, with the result that their pull on the water may be so great as to prevent entirely the filling of the others. When the beakers are about half filled, the pressure is greatly reduced so that the level of the water rises very slowly. By operating in this fashion even very considerable differences in the diameters of the tubes and beakers will cause no trouble, since the back pressure in those in which the flow is more rapid acts as a check on the incoming water. If the filling is performed with care there will be an almost absolute equality in the level throughout.

Technique of determination of "Silt"

In order to secure the above equality of level the supply tubes should not be too small. Those in the apparatus in use have a bore of 0·5 cm. If the distributing vessel (A) is made as shown, with the top inclined at a slight angle, and the tubes are cut off flush with its under-surface, the inclusion of air with the water in the tubes very rarely takes place. The same result may be attained by substituting for the distributing vessel A, a metallic tube tilted at a slight angle.

During the time the water level is slowly rising in the beakers there is ample opportunity to mix the soil well with the water by stirring with the glass inlet tubes which, as shown in the cut, are connected with the supply tubes by means of flexible rubber tubing.

At the end of the period fixed upon for subsidence of the larger particles, the vent-cock is opened and the supernatant water siphoned off. When this operation has been completed, the water is again turned on (the vent-cock being still open) and a small amount of water is run through in order to wash out the last of the turbid water. The vent-cock is then closed and the entire operation repeated, as described, as often as may be necessary.

The Classification of Soil Particles

The want of uniformity in the system of classification of soil particles no less than the diversity in the methods of separation, is greatly to be deplored. Much of the value of the results is lost by reason of the impossibility of comparison with those of other observers. In a paper presented to the International Agro-geological Congress held at Stockholm in August, 1910, Dr. Atterberg of Kalmar suggested the following limits, with a view to their general adoption:—

Classification by size

Coarse sand (unretentive of moisture)	3	to ·3	*or*	2	to ·2
Fine sand (water-retaining)	·3	to ·03	*or*	·2	to ·02
Silt	·03	to ·003	*or*	·02	to ·002
Clay	·003	to —	*or*	·002	to —

The times of subsidence (in a 10 centimetre column) prescribed for the separation of the two series of silts and clays were:—

Silts		Clays	
·03 mm. ...	$3\frac{3}{4}$ minutes	·003 mm. ...	4 hours
·02 mm. ...	$7\frac{1}{2}$ minutes	·002 mm. ...	8 hours

In the paper referred to, Dr. Atterberg rather favoured the first series of limits from the point of view of the shortening of the times of subsidence. In a more recent communication, however, he states that against this should be counted the fact that the limit of ·002 mm. for clay has already been rather widely adopted and, further, that the limit of ·2 mm. for the water-retaining sand is more nearly correct than is that of ·3 mm. Our own experience with Sudan soils leads us very greatly to prefer the limits ·02 and ·002 mm., the latter especially, as it differentiates more sharply the soils with which we have to deal. We have therefore adopted these limits, provisionally, with the hope that a general agreement on these lines may be effected. As already noted the figures given are only approximate, the clay being more accurately defined by the time required for its subsidence. Limits of ·02 and ·002 mm. preferred

Résumé of the Method used for the Mechanical Analysis

The following is a short description of the method of mechanical analysis as carried out in these laboratories.

The separation is made, as has been stated, into particles as follows:—

(*a*) *Stones and gravel* above 2 mm.

(*b*) *Fine soil*, less than 2 mm.

The latter is further subdivided into:

Coarse sand (non-retentive of water)	2 mm. to 0·2 mm.
Fine sand (water-retaining)	·2 mm. to ·02 mm.
Silt	·02 mm. to ·002 mm.
Clay	·002 mm. and below

The air-dry soil is well mixed, the larger masses being crushed by means of a wooden rolling-pin. One hundred grammes are weighed out on a rough balance and passed through a sieve with round holes, 2 mm. in diameter. The portion, if any, which remains on the sieve is washed with water to separate the adhering sand and soil, dried on the water-bath and weighed. This constitutes the "stones and gravel."

The portion passing the 2 mm. sieve is passed through a sieve with round holes 1 mm. diameter. (The material which passes is taken for the chemical examination and for the further mechanical analysis.) In the above operation the larger masses of soil are treated with the rolling-pin, and also, if not too hard, by rubbing with a cork bung. When most of the soil has been passed through the sieve the remainder is washed on the sieve by a current of water aided by a camel-hair brush, the small quantity of soil washed away being disregarded.

When a number of soils are being examined at the same time, the residues on the sieves are not treated with water at once, but are put aside, in marked beakers, the washings being performed later. In this way the sieves are kept dry during the operations of sifting the soils.

The moisture having been removed by several hours' drying in the air-oven at 110° C., a quantity of the fine dry soil is taken, less than 5 grammes in proportion to the amount of particles between 2 mm. and 1 mm. known to be present in the original soil. This plan of excluding the larger particles is adopted in order more safely to secure an average sample when the small quantity (less than 5 grammes) is weighed out. Résumé of technique

The weighed portion of fine soil is either puddled by the aid of the brush, as described on *page* 37 or, if a number of soils are to be treated at the same time, it is placed in a shaker bottle, 100 c.c. of water containing ·2 gramme of sodium carbonate added, and shaken in the machine, for 2 hours, as described on *page* 35. The soil and water are then transferred to a cylindrical beaker marked at 10 centimetres, distilled water added up to the mark, mixed and allowed to stand for not less than eight hours. In the case of heavy clay soils so much clay is brought into suspension by this method that the first sedimentation is allowed to continue over night in order to ensure that the silt may not be held up by the thick liquid. The subsequent subsidence is of eight hours' duration followed by one over night. In this manner the entire amount of clay may usually be removed in three days. The water used for each operation should contain about one half gramme of sodium carbonate per litre. It sometimes happens that clay is present is such large proportion that the usual volume of water is not sufficient to hold it in suspension for the necessary 8 hours. In the case of flocculation due to this cause, it is necessary either to employ a more capacious beaker, or to divide the turbid liquid between two or more beakers of the usual size (8 centimetres diameter).

Entire amount of clay removed in three days

Flocculation, if it takes place, is more usually due to the presence of soluble salts. This is especially the case with subsoils. It may, as a rule, be avoided by using a smaller proportion of sodium carbonate in order to reduce the total amount of salt present. Two tenths of a gramme per litre may be used for the first two decantations, after which it is advisable to increase to the usual proportion.

If flocculation has occurred, the excess of water, after decantation, should be removed on the water-bath and the soil puddled with the brush. Once the floccules are formed they do not readily break up again in spite of the fact that the salt may have been almost entirely removed by decanting the more or less clear supernatant liquid.

Flocculation due to excess of salts occurs less frequently if the centrifugal method be employed, since it usually takes place very slowly in the presence of the sodium carbonate.

After, usually, the third or fourth sedimentation and decantation, the residue is puddled with the camel-hair brush as described on *page* 37.

When almost the entire amount of clay has been removed, the soil is washed into a weighed beaker of about 200 c.c. capacity, using distilled water (in this case without sodium carbonate). After standing for the usual period (*i.e.* not less than eight hours) or until clear, the water is poured away and the beaker and residue dried by heating in the air-oven for 2 hours at 110° C. From the weight of the soil residue may be calculated the percentage of clay, which is determined by difference. The figure so obtained should be corrected for soluble salts if present in notable quantity. A "correction" for organic matter in the mechanical analysis of a soil is, in the opinion of the writer, neither necessary nor desirable. In any case the amount present in soils even of semi-arid districts, rarely amounts to one per cent. The determination of humus should, of course, be made, but separately, as a part of the chemical analysis. If desired, however, practically the whole of the humus may be removed by using a larger proportion of sodium carbonate in the shaker bottle (·5 to 1 gramme) and, its proportion being determined on another sample by the usual method, the necessary correction may be made.

"Correction" for soluble salts

When it is desired to carry out the separation of the clay more rapidly, the centrifugal machine is used, as already described.

The residue in the beaker, consisting of sands and silt, is treated as detailed on *page* 41. The silt having been removed, the residue is washed back into the original weighed beaker, dried as before and weighed. The silt, like the clay, is determined by difference.

The remaining sand in the beaker is separated into two portions, by means of an appropriate wire sieve.[1] To the portion remaining on the sieve is added that which was retained by the 1 mm. sieve in order to obtain the entire proportion of coarse sand, 2 mm. to ·2 mm. in diameter. The fine sand is determined by difference.

All figures should, obviously, be expressed on the dry soil.

In concluding these notes it is desired to call attention to the fact that while the above method is especially recommended for arid soils, it is equally suitable for those of humid regions. Further, it is held that a method of this kind should invariably be used since otherwise the comparison of humid with arid soils becomes impossible. It must be recollected also that the treatment by acid not only results, at times, in the complete solution of the larger particles, but invariably, in the extraction of material from the finer constituents, so that as a method of "mechanical" analysis it cannot but be considered scientifically unsound.

Soils of the Gezira

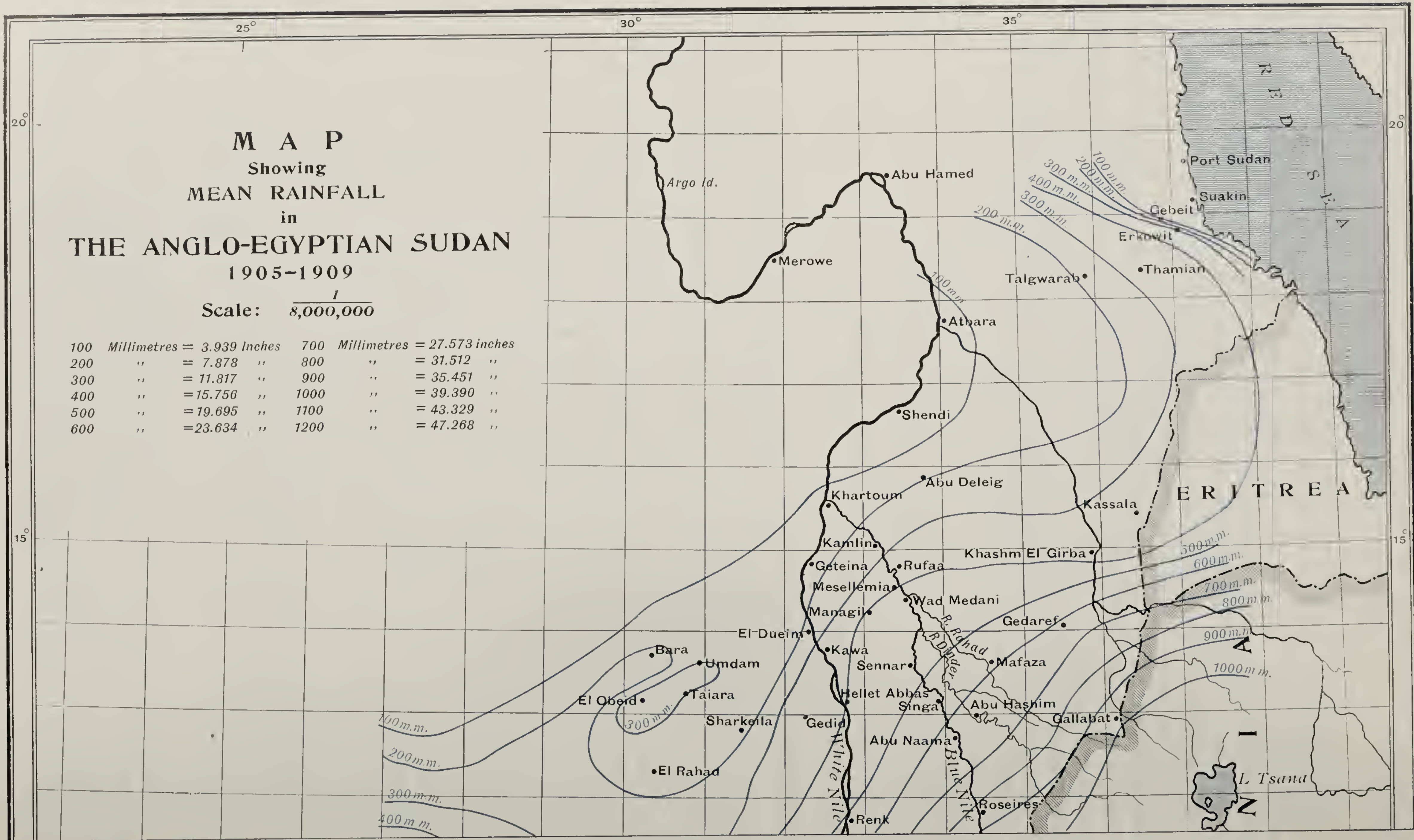
A Preliminary Note

The "Gezira" or "island" is that roughly triangular section of the Sudan which lies between the White Nile and Blue Nile, with Khartoum at its apex, at the junction of these two rivers. It has long been held that the main hope of agricultural development of the Sudan lies in the irrigation of this district. The writer takes a more sanguine view, but, in any case, it appears evident from a study of the rainfall map on *pages* 46 and 47 that the portion south of, say, the 15th parallel, may be capable of profitable development by rainfall cultivation, and there is no little evidence to indicate that even so valuable a product as Egyptian cotton may be successfully grown, as a rain crop, if modern methods of cultivation be applied. Very good crops of dura are now produced, even with the primitive methods of the natives, and it appears likely that wheat may displace this largely when the native cultivator has learned to realise the advantage to be gained. The newly established Gezira railway is already having a marked effect on the output of rain-grown grain from the Gezira, and while this is at present largely dura there is also a certain amount of other grain and of cotton, as well. The latter is grown from native seed and therefore of poor quality, but experiments have been made with Egyptian seed, with most promising results.

Since many appear to be slow to believe in the possibilities of the Gezira from the point of view of rainfall cultivation, a comparison with similar semi-arid districts in other countries may not be out of place. In these districts of low rainfall a method of so-called "dry soil farming" is practised, the distinguishing features of which are (*a*) deep ploughing to ensure the entrance of the rain into the soil, and (*b*) frequent harrowing in order to preserve a loose mulch on the surface and thereby check excessive evaporation. It is obvious that *season* of rainfall in such dry climates is more important than its actual amount.

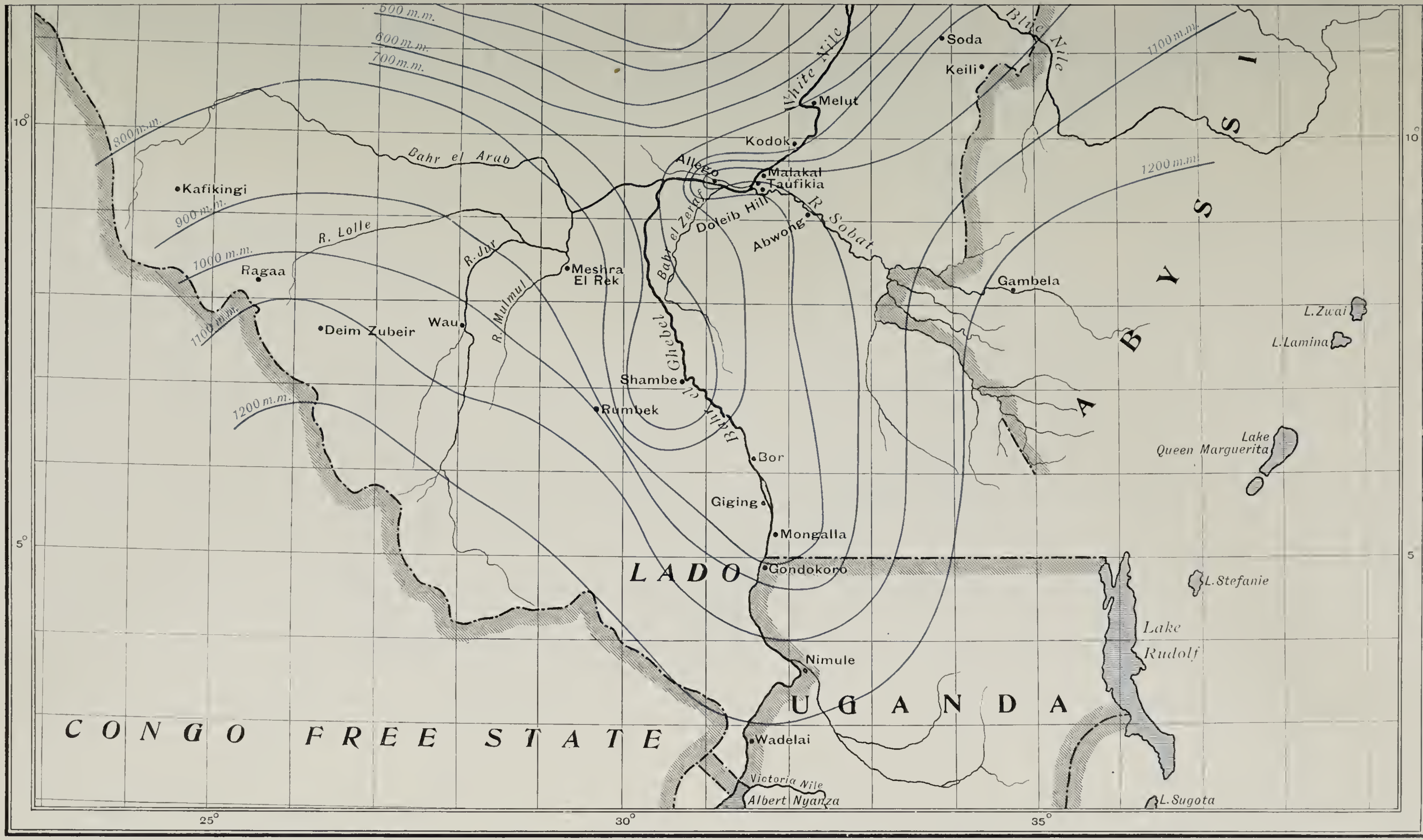
In the United States (Utah and California), 590 kilogrammes of wheat per acre are stated to have been obtained with a total annual rainfall of about 10 inches. The *average* annual rainfall over the whole of these wheat-producing districts is only about $14\frac{1}{2}$ inches.

[1] The sieve found to pass particles most nearly approximating 0·2 mm. in diameter was of 80 meshes to the linear inch. This will, of course, depend in part upon the size of wire used.



The continuation of this Map to the South is shown on the opposite page

The continuation of this Map to the North is shown on the opposite page



From a map compiled by the Sudan Irrigation Department

Fig. 6.—Map showing Mean Rainfall in the Anglo-Egyptian Sudan, 1905-1909

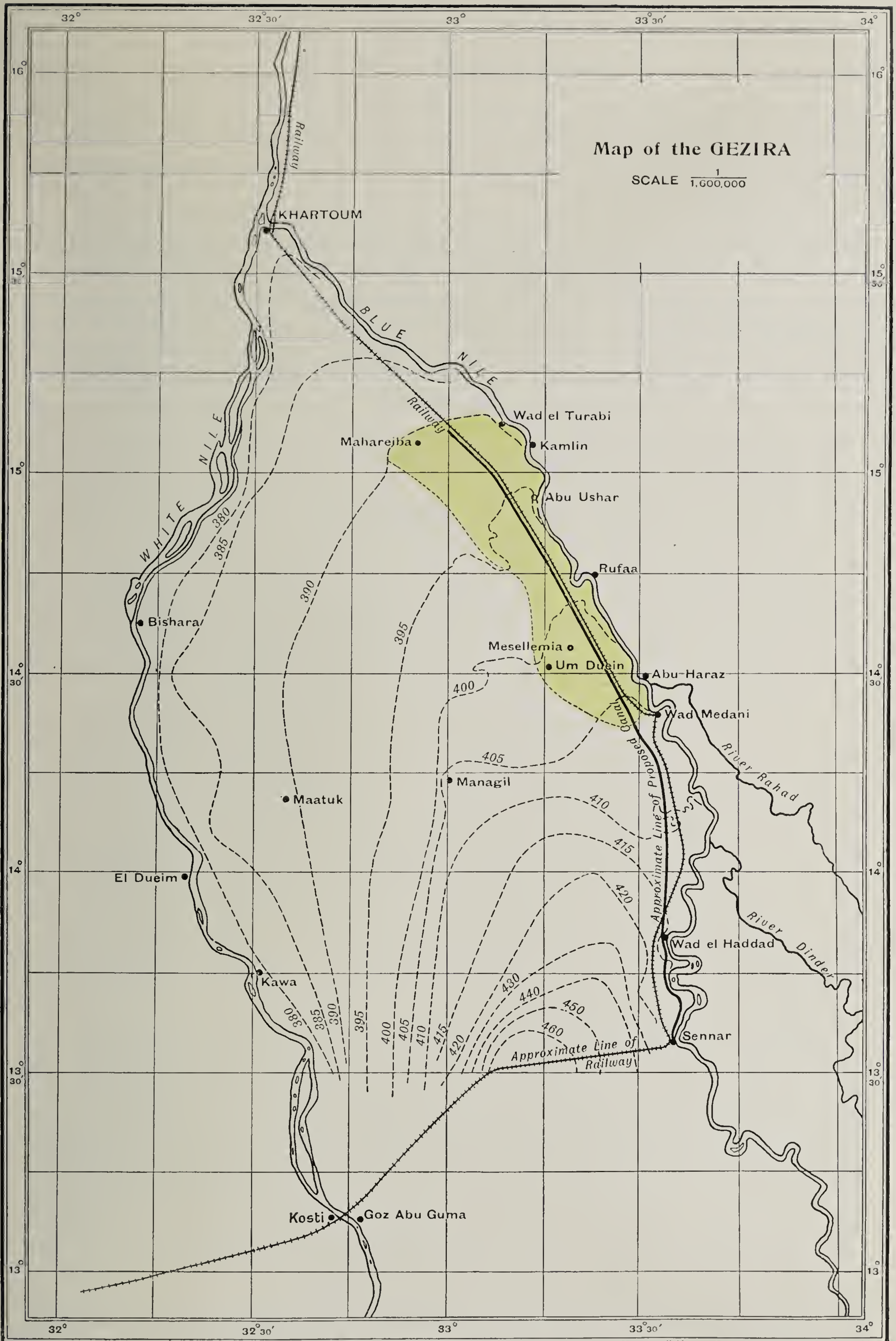
In the Gezira, at Wad Medani, the rainfall is officially stated to be 400 mm. (about 16 inches). This is slightly greater than the average in the dry farming districts in the United States. Even half-way between Wad Medani and Kamlin, as reference to the map on *pages* 46 and 47 will show, the rainfall is greater than that prevailing in Utah and California where wheat is successfully grown. That the season of rainfall, more especially in the latitude of Wad Medani and south of it, is suitable for cotton, is proved by the fact that it has been extensively grown in the past, in spite of the unscientific methods practised by the natives. Improvement of seed and more modern methods of cultivation would appear to be all that are required to make this enterprise a financial success.

Up to the present but little work has been done on the soils of the Sudan, and especially on those of the Gezira. In 1903 a few samples collected by Sir W. Willcocks[1] were examined by Mr. Hughes, of the Egyptian Department of Agriculture, but no mechanical analyses were made, and, as Mr. Hughes was not supplied with samples of the subsoil, the results, *e.g.* as regards soluble salts, are not only incomplete, but even misleading. Further, the two samples of which more complete chemical examinations were made and which are described by Sir W. Willcocks as "typical Gezira soil," one collected on the Blue Nile and the other on the White Nile side, were taken only 10 miles and 2 miles, respectively, from Khartoum. A comparison with the results in the tables on *page* 54 *et seq.* will show that these soils are not correctly designated as typical of the Gezira generally, since the soils of that district vary greatly, both their mechanical and chemical characters being dependent upon the location—that is to say, upon the climatic conditions, rainfall especially.

At Khartoum, the rainfall is a little over 10 centimetres. At the southern end of the Gezira, it is approximately ten times as great; and while Sudan soils, like those of Egypt, are chiefly river-borne silt of Abyssinian origin, the deposit has suffered very material change in those places in which the rainfall has been more abundant. There is also evidence of change as a result of the alkaline water of the White Nile, some of the soils on this side of the Gezira having their clay in a more puddled condition, and therefore less permeable.

The natives of the Gezira distinguish two main classes of soil. The better of these, from the point of view of suitability for cultivation under ordinary conditions (*i.e.* rainfall cultivation), is termed by them *bardobe*. This is the typical so-called cotton soil, characterised by the deep cracks which form when the soil dries. The other chief variety cracks but little, if at all, on drying. It is called *azaza* and is said to be uncultivable, or, at best, to return inferior yields. Another variety of soil, and the one most esteemed by the native, is termed *fud* or *fuda*. This appears to be merely *bardobe* in a good state of tilth. On drying, it cracks to a less extent than does ordinary *bardobe* soil, and remains friable and permeable. In view of the proposed irrigation of a section of the Gezira a very great number of soils, with subsoils down to four feet, have been collected for us by Mr. S. C. Dunn, the Government Geologist, and examined in the laboratory. A sketch map prepared by Mr. Dunn, showing the points of collection, is found on *page* 51. It is evident from the results of the mechanical analyses that while *azaza* soils are, generally speaking, lighter than *bardobe* the difference in composition is not nearly so great as estimated by the native. The inferior returns under present conditions are due in great part to scanty rainfall. The porous nature of the soil is also a result of this same condition, so that the effect of low rainfall on crop production is doubly felt. *Bardobe* soils,

[1] *The Nile in* 1904, p. 100



Sudan Irrigation Dept.

Fig. 7.—Map of the Gezira showing approximate line and scope of proposed Irrigation Canal
The area coloured green represents that under consideration, with a view to irrigation
Contour lines show height in metres above sea level
Proposed Canal ———— Railway

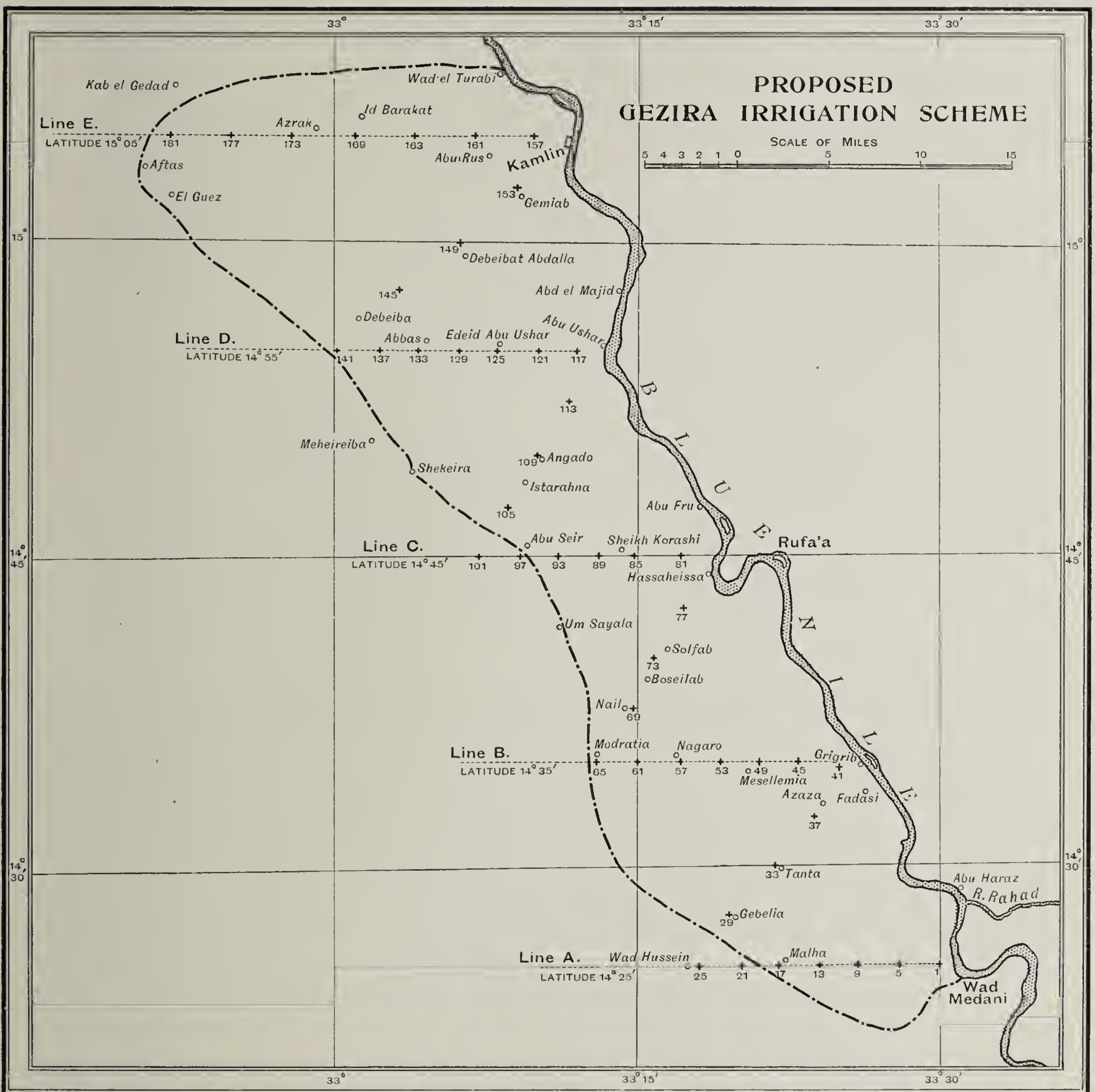
from their geographical position, not only receive more moisture, but, by reason of their higher proportion of clay resulting from this condition, are better able to retain the moisture received. *Azaza* soils, here considered very light, would in a country of normal rainfall be held to be rather heavy than otherwise.

Near Khartoum, where the rainfall is only a few inches, the prevailing type of soil is a light *azaza*. This statement does not include the soils directly bordering on the river, which may be subjected to flooding from time to time. These, as a rule, are distinctly heavier. South of Khartoum, as the rainfall increases, the decomposition of the silt and the formation of clay take place to an increasing extent, until, in the neighbourhood of Wad Medani, with an average rainfall of about 16 inches, the proportion of clay amounts to 50 per cent. and even, in some cases, to as much as 60 per cent. Soils in humid regions containing such a high proportion of clay would be considered almost impervious and extremely difficult to work; but the fact that in arid countries even higher proportions may exist in good arable soils has already been pointed out. Thus Means[1] calls attention to a sample from Egypt in which the clay (below ·005 mm.) amounted to about 75 per cent. and the silt (·005 to ·05 mm.) above 12 per cent., making a total of 87 per cent., of heavy material. This "according to the mechanical analysis should be an almost impermeable clay; but in the field the soil was found to be easily drained, perfectly amenable to cultivation and favourable to plant growth." The same remarks apply to Gezira soils and to Sudan soils generally, *provided they are properly drained*. Good drainage is essential to all soils; but the disastrous effect of inefficient drainage on heavy soils has been especially evident in certain lands, improperly worked, near Khartoum, and in the irrigation basins in Dongola Province, in course of construction.

Means (*loc. cit.*) explains the ease with which these essentially heavy soils may be worked by the "cementing action of lime and magnesia and iron compounds which join together the fine grains of silt and clay and form larger aggregates, thus giving the soil a lighter appearance than a mechanical analysis would indicate. The fact," he states, "has been very clearly brought out in mechanical analyses of soils from American desert lands where calcium and magnesium carbonates were abundant. In New Mexico, certain soils were classed in the field as sandy loams, but upon subjecting them to mechanical analysis, when water acts upon the soils for several days, the cementing material was dissolved, the aggregates broken down, and the soil was found to contain enough clay to be classed as a loam or clay loam. The field examinations of Egyptian soils show this cementing process to be developed to a high degree, and soils in the field seem lighter than would be indicated by the mechanical analysis."

The writer was formerly of the same opinion as to the cause of the above effect, but recent experience has shaken his belief in this respect. It has been found, for instance, that the extent to which the clay particles are held together appears to be independent of the amount of earthy carbonates present. It has already been mentioned that the attempt to apply the United States Bureau of Soils method to Sudan soils had not met with success, disintegration of the clay aggregates not being effected by the prescribed agitation with water, and often still less so when ammonia was added. It was found, however, that subsoils often gave results more nearly approximating the truth, and yet the proportion of earthy carbonates in these was not appreciably less—in some cases, in fact, it was even greater. The following are instances of such a condition:—

[1] "The reclamation of alkali lands in Egypt." *Bulletin of U.S. Bureau of Soils* No. 21. *Dept. of Agriculture.*



S. C. Dunn

Fig. 8.—Map showing points at which Samples of Soil were collected for Analysis

	Clay separated by 7 hours shaking with water	Earthy carbonates expressed as $CaCO_3$
Sample No. 1 (1st foot)	27·3 per cent.	2·36 per cent.
,, ,, 2 (2nd ,,)	47·0 ,, ,,	2·26 ,, ,,
,, ,, 3 (3rd ,,)	45·3 ,, ,,	2·57 ,, ,,
,, ,, 4 (4th ,,)	38·9 ,, ,,	1·74 ,, ,,
,, ,, 5 (1st ,,)	25·5 ,, ,,	1·85 ,, ,,
,, ,, 6 (2nd ,,)	43·9 ,, ,,	2·14 ,, ,,
,, ,, 7 (3rd ,,)	17·9 ,, ,,	2·17 ,, ,,
,, ,, 8 (4th ,,)	26·7 ,, ,,	2·22 ,, ,,

The actual amount of clay in the above soils was approximately :—

1st foot	58 per cent.
2nd ,, ...	56 ,, ,,
3rd ,, ...	61 ,, ,,
4th ,, ...	64 ,, ,,

It is not held that the above is proof that cementation of the clay particles by calcium and magnesium carbonates does not occur. It doubtless does occur to a certain extent, but it is felt that some more potent cause is active in the majority of cases. In the regions of no rainfall, *e.g.* Dongola Province, the soils were at first thought to contain practically no clay whatever. Agitation with water, or with water and ammonia, resulted in the bringing of a quantity of material into suspension, but practically the whole of this settled out at the end of a few hours. It was at first assumed that this was due to soluble salts, but the absence of these in the majority of cases was soon proved. It was then concluded that the material present was fine silt, its preservation from decomposition being the result of the total absence of rainfall. Later, these soils were treated with water containing a small amount of sodium carbonate, and were also puddled by the aid of a camel-hair brush as described on *page* 37, with the result that a large amount of clay was separated. The results of the mechanical analyses carried out in this way at once explained the behaviour of the soil in the field.[1] It should be stated that the proportion of calcium carbonate in these soils was usually low—in one case only 0·36 per cent.—so that the explanation of the behaviour of the soil to water by its cementing action does not appear to be tenable.

In the writer's opinion, the intense baking which these heavy soils receive during the hot season plays a very important part, in that it coagulates the clay and renders the soil more permeable and productive. This is in addition to the well-known fact that the

[1] These soils puddle very rapidly when not sufficiently drained

heating of soil even to a moderate degree results in a greater solubility in water of the constituents essential to plant life.

The fact that a treatment so far from drastic as the simple puddling of the soil by means of a soft camel-hair brush, in the presence of an extremely dilute cold solution of sodium carbonate (not sufficient to dissolve the humus), suffices at once to disintegrate the clay aggregates and bring the former into suspension, points rather to the conclusion that the clay has simply been flocculated by the heat and dryness, and that, in the soil, it is usually not held together entirely, or even to any very great extent, by cementing material such as calcium carbonate. It is for this reason that the treatment by puddling in the preparation of the sample for mechanical analysis is held to be a sound one and the substitution of the very small amount of sodium carbonate for the ammonia usually employed, entirely unobjectionable.

There is further evidence that it is not necessary to assume cementation of the clay in the soil aggregates. It has already been noted (*vide page* 44) that when subsoils containing rather high proportions of salts are treated for the mechanical analysis, flocculation of the clay occurs; and that when the excess of salt is removed, these floccules do not readily break up on the addition of water, even in the presence of sodium carbonate. The floccules may appear to do so at first, but if the liquid be allowed to stand for some hours, precipitation of the clay usually recurs.

It is obvious that the intense baking and drying to which arid soils are subjected may cause a similar flocculation of the clay, and the aggregates so formed may be expected to be much more resistant to disintegration than those obtained by precipitation from suspension in water.

Chemical composition of Gezira soils. Extended chemical examinations have as yet only been made of the tract in the Gezira which it has been proposed to irrigate, and which is indicated in the sketch map on *page* 51. The results of examination of individual samples are detailed in the tables on *pages* 56 to 59. The variations in chemical character are more clearly shown in the table of averages on *page* 55, which should be studied in connection with the rainfall map.

As would be expected, the proportion of water-soluble salts in the surface soil, and especially in the subsoils, is greater towards the northern end of the tract where rainfall and consequent leaching are least. The same is true of the proportion of calcium carbonate. Organic matter, as expressed by the content of humus and of nitrogen, is, on the other hand, greater towards the southern end where there has been a greater amount of cultivation and of plant residues left in the soil. Phosphates readily soluble in acid are also less where there has been least rain and where, consequently, rock decomposition has taken place to the least extent. Acid-soluble potash compounds are found to vary but slightly, but in the same direction.

Speaking generally, the soils, both *bardobe* and *azaza*, in this tract may be said to be fairly well supplied with potash and with phosphates. They are, however, like most Egyptian and Sudan soils, markedly deficient in organic matter and in nitrogen, and the results from their cultivation will be largely dependent upon treatment with respect to this deficiency. Rotation with a leguminous crop such as berseem and the ploughing of a fair proportion of the crop into the soil is what is especially indicated. Without such a rotation, rapidly diminishing crops may be predicted with confidence. Since such leguminous crops have not been grown on most Gezira soils, inoculation of the seed first planted should make a very marked difference in the yield. This experiment was tried on a small scale near Khartoum, with results which exceeded all expectations.

GEZIRA SOILS. AVERAGES. MECHANICAL ANALYSES

		First foot	Second foot	Third foot	Fourth foot
Line (A)	Stones, etc., above 2 mm.	3·0	2·1	1·5	0·7
Lat. 14° 25′	*Fine soil below 2 mm.*				
	Coarse sand 2 to ·2 mm.	14·6	12·0	12·2	9·9
	Fine sand ·2 to ·02 mm.	23·4	21·4	22·0	20·7
	Silt ·02 to ·002 mm.	13·0	13·3	14·0	14·6
	Clay ·002 to 0 mm.	49·0	53·3	50·8	54·8
Line (B)	Stones, etc., above 2 mm.	3·0	1·6	3·1	1·0
Lat. 14° 35′	*Fine soil below 2 mm.*				
	Coarse sand 2 to ·2 mm.	13·5	14·0	12·5	15·2
	Fine sand ·2 to ·02 mm.	19·7	19·9	19·3	16·6
	Silt ·02 to ·002 mm.	14·0	14·2	13·9	13·8
	Clay (1) ·002 to 0 mm.	52·8	51·9	53·8	54·4
Line (C)	Stones, etc., above 2 mm.	2·5	1·4	1·4	0·9
Lat. 14° 45′	*Fine soil below 2 mm.*				
	Coarse sand 2 to ·2 mm.	16·9	20·9	15·0	14·8
	Fine sand ·2 to ·02 mm.	24·8	21.8	22·8	22·6
	Silt ·02 to ·002 mm.	10·7	10·2	13·0	12·6
	Clay ·002 to 0 mm.	47·6	47·1	49·2	50·0
Line (D)	Stones, etc., above 2 mm.	2·4	1·4	0·9	1·9
Lat. 14° 55′	*Fine soil below 2 mm.*				
	Coarse sand 2 to ·2 mm.	17·0	18·5	13·6	18·0
	Fine sand ·2 to ·02 mm.	25·6	22·7	23·5	26·3
	Silt ·02 to ·002 mm.	12·2	13·6	14·6	12·6
	Clay ·002 to 0 mm.	45·2	45·2	46·3	43·1
Line (E)	Stones, etc., above 2 mm.	2·4	1·9	1·7	1·8
Lat. 15° 05′	*Fine soil below 2 mm.*				
	Coarse sand 2 to ·2 mm.	21·1	24·4	20·7	19·4
	Fine sand ·2 to ·02 mm.	25·0	22·1	22·1	21·5
	Silt ·02 to ·002 mm.	12·1	10·0	13·1	14·5
	Clay ·002 to 0 mm.	41·8	44·1	44·1	44·5

[1] Clay separation made by subsidence of 8 hours' duration. If increased to 24 hours the average result would be 2·6 per cent. less clay, the silt being increased in proportion.

GEZIRA SOILS. AVERAGES. CHEMICAL ANALYSES

		First foot	Second foot	Third foot	Fourth foot
Line (A)	Potash, soluble in hydrochloric acid[1] ... (K_2O)	0·53			
Lat. 14° 25′	,, insoluble ,, ,, ... ,,	0·57			
	Phosphoric acid[1] ... ... (P_2O_5)	0·19			
	Humus	0·67			
	Humus nitrogen	0·015			
	Total nitrogen	0·036			
	Carbonates, expressed as calcium carbonate ...	3·5			
	Water-soluble salts	0·08 [2]	0·14	0·33	0·51
Line (B)	Potash, soluble in hydrochloric acid... ... (K_2O)	0·46			
Lat. 14° 35′	,, insoluble ,, ,, ... ,,	0·68			
	Phosphoric acid ... ... (P_2O_5)	0·20			
	Humus	0·62			
	Humus nitrogen	0·012			
	Total nitrogen	0·018			
	Carbonates, expressed as calcium carbonate ...	3·2			
	Water-soluble salts	0·08	0·10	0·28	0·60
Line (C)	Potash, soluble in hydrochloric acid ... ... (K_2O)	0·32			
Lat. 14° 45′	,, insoluble ,, ,, ... ,,	0·74			
	Phosphoric acid... ... ... (P_2O_5)	0·15			
	Humus	0·59			
	Humus nitrogen	0·013			
	Total nitrogen	0·022			
	Carbonates, expressed as calcium carbonate ...	3·4			
	Water-soluble salts	0·10	0·31	0·58	0·49
Line (D)	Potash, soluble in hydrochloric acid ... ... (K_2O)	0·45			
Lat. 14° 55′	,, insoluble ,, ,, ... ,,	0·49			
	Phosphoric acid... ... ... (P_2O_5)	0·10			
	Humus	0·52			
	Humus nitrogen	0·013			
	Total nitrogen	0·017			
	Carbonates, expressed as calcium carbonate ...	4·9			
	Water-soluble salts	0·10	0·43	0·57	0·54
Line (E)	Potash, soluble in hydrochloric acid... ... (K_2O)	0·42			
Lat. 15° 05′	,, insoluble .. .. ,,	0·58			
	Phosphoric acid ... ... (P_2O_5)	0·15			
	Humus	0·51			
	Humus nitrogen	0·011			
	Total nitrogen	0·020			
	Carbonates, expressed as calcium carbonate... ...	5·7			
	Water-soluble salts	0·10	0·30	0·57	0·58

[1] 10 hours' extraction with acid of 1·115 Sp. Gr.

[2] Excluding No. 1 which was exceptionally high

GEZIRA SOILS

Surface 12 inches except where otherwise stated — *Figures represent per cent. of dry soil*

Point of collection ...	Lat.	14° 25′	14° 25′	14° 25′	14° 25′	14° 25′	14° 25′	14° 25′	14°27′30″	14°30′	14°13′30″	14°35′
	Long.	33° 30′	33° 28′	33° 26′	33° 24′	33° 22′	33° 20′	33° 18′	33°19′30″	33°22′30″	33°24′	33°24′45″
Sample Number ...		No. 1	No. 5	No. 9	No. 13	No. 17	No. 21	No. 25	No. 29	No. 33	No. 37	No. 41
MECHANICAL ANALYSIS												
Stones and gravel above 2 mm. ...		3·0	3·4	3·9	3·6	1·9	2·9	2·0	4·4	3·6	2·3	0·9
Analysis of fine soil, below 2 mm.												
Coarse sand, 2 to ·2 mm. ...		10·2	18·6	11·6	17·2	13·9	15·2	16·1	17·7	18·3	9·5	7·9
Fine ,, ·2 to ·02 mm. ...		16·4	22·2	21·5	23·0	33·3	24·0	22·5	22·0	20·0	24·2	17·1
Silt ·02 to ·002 mm. ...		14·9	12·2	13·9	12·7	12·6	12·2	12·6	12·6	12·1	13·9	14·4
Clay[1] ·002 to 0 mm. ...		58·5	47·1	53·4	47·1	40·2	48·6	47·8	47·7	49·6	52·4	60·6
CHEMICAL ANALYSIS												
Potash, soluble in hydrochloric acid[2] ...	(K_2O)	0·43	0·55	0·70	0·31	0·35	0·42	0·99	0·35	0·47	0·50	0·44
,, insol. ,, ,, ,, ...		—	—	0·52	—	—	0·63	—	—	—	—	0·68
Phosphoric acid ...	(P_2O_5)	0·24	0·16	0·20	0·13	·0·15	0·21	0·26	0·18	0·20	0·19	0·19
Humus ...		—	—	0·62	—	—	0·72	—	—	—	—	0·62
Humus nitrogen ...	(N)	—	—	0·01	—	—	0·021	—	—	—	—	0·013
Total nitrogen ...	(N)	0·055	0·028	0·039	0·027	0·04	0·044	0·024	0·018	0·016	0·018	0·016
Carbonates ...	($CaCO_3$)	4·8	3·9	3·9	4·6	3·9	2·4	2·2	2·0	2·90	2·5	2·6
Water-soluble salts ...	1st foot	0·88	0·13	0·08	0·08	0·08	0·08	0·06	0·08	0·08	0·06	0·08
	2nd ,,	1·96	0·25	0·09	0·12	0·15	0·14	0·11	0·22	0·11	0·08	0·11
	3rd ,,	1·28	0·44	0·15	0·15	0·66	0·45	0·15	0·56	0·22	0·23	0·27
	4th ,,	1·25	0·55	0·45	0·76	0·49	0·37	0·60	0·89	0·61	0·54	0·64

[1] Determined by a subsidence of 8 hours. If increased to 24 hours, the average result would be 2·6 per cent. less clay, the silt being increased in proportion.
[2] Ten hours' extraction with acid of 1·115 Sp. Gr.

GEZIRA SOILS—*continued*

Surface 12 inches except where otherwise stated — *Figures represent per cent. of dry soil*

Point of collection — Lat.	14° 35′	14° 35′	14° 35′	14° 35′	14° 35′	14° 35′	14° 37′30″	14° 40′	14° 42′30″	14° 45′	14° 45′
Point of collection — Long.	33° 23′	33° 21′	33° 19′	33° 17′	33° 15′	33° 13′	33°14′30″	33° 16′	37° 17′	33° 17′	33° 15′
Sample Number	No. 45	No. 49	No. 53	No. 57	No. 61	No. 65	No. 69	No. 73	No. 77	No. 81	No. 85
MECHANICAL ANALYSIS											
Stones and gravel above 2 mm.	3·6	3·0	4·9	2·9	2·4	3·1	3·3	2·9	3·4	2·5	3·4
Analysis of fine soil, below 2 mm.											
Coarse sand, 2 to ·2 mm.	7·6	11·8	8·9	14·0	12·8	31·0	14·2	23·2	17·6	13·8	16·4
Fine „ ·2 to ·02 mm.	18·7	25·9	21·0	18·3	20·9	21·8	25·7	21·7	24·0	19·8	23·1
Silt ·02 to ·002 mm.	15·1	12·0	15·0	15·6	12·4	11·0	11·9	10·2	11·6	12·2	11·1
Clay[1] ·002 to 0 mm.	58·6	49·3	56·1	53·1	53·9	36·2	48·2	44·9	46·8	54·2	49·5
CHEMICAL ANALYSIS											
Potash, soluble in hydrochloric acid[2] ... (K_2O)	0·45	0·55	0·49	0·46	0·51	0·33	0·47	0·47	0·64	0·36	0·45
„ insol. „ „ „	—	—	—	—	—	—	0·56	—	—	—	—
Phosphoric acid ... (P_2O_5)	0·25	0·14	0·25	0·25	0·20	0·15	0·12	0·13	0·18	0·14	0·19
Humus	—	—	—	—	—	—	0·67	—	0·42	—	—
Humus nitrogen ... (N)	—	—	—	—	—	—	0·012	—	0·013	—	—
Total nitrogen ... (N)	0·014	0·019	0·018	0·016	0·016	0·031	0·024	0·037	0·026	0·017	0·030
Carbonates ... ($CaCO_3$)	1·7	2·5	2·1	2·0	3·2	9·1	6 3	3·3	4·3	3·4	4·0
Water-soluble salts — 1st foot	0·07	0·06	0·08	0·08	0·08	0·09	0·09	0·16	0·08	0·10	0·09
Water-soluble salts — 2nd „	0·09	0·08	0·08	0·08	0·11	0·17	0·12	0·92	0·16	0·11	0·11
Water-soluble salts — 3rd „	0·46	0·15	0·41	0·17	0·28	0·23	0·63	1·74	0·87	0·35	0·83
Water-soluble salts — 4th „	0·80	0·90	0·54	0·53	0·61	0·22	0·80	1·30	0·25	0·50	0·80

[1] See note on *page* 56 [2] Ten hours' extraction with acid of 1·115 Sp. Gr.

Gezira Soils—*continued*

Surface 12 inches except where otherwise stated — *Figures represent per cent. of dry soil*

Point of collection — Lat.	14° 45′	14° 45′	14° 45′	14° 45′	14° 47′	14° 50′	14° 52′ 30″	14° 55′	14° 55′	14° 55′	14° 55′	14° 55′
Point of collection — Long.	33° 13′	33° 11′	33° 9′	33° 7′	33° 8′ 30″	33° 10′	33° 11′ 30″	33° 12′	33° 10′	33° 8′	33° 6′	33° 4′
Sample Number …	No. 89	No. 93	No. 97	No. 101	No. 105	No. 109	No. 113	No. 117	No. 121	No. 125	No. 129	No. 133
MECHANICAL ANALYSIS												
Stones and gravel above 2 mm.	3·1	2·9	2·1	1·0	0·7	6·4	2·8	0·5	1·2	2·1	3·2	2·9
Analysis of fine soil, below 2 mm.												
Coarse sand, 2 to ·2 mm.	19·2	20·0	10·7	21·5	21·8	20·1	22·4	17·9	8·1	19·9	19·4	16·9
Fine sand ·2 to ·02 mm.	24·2	31·1	23·9	27·0	31·4	31·9	29·5	28·3	19·2	24·4	28·6	27·8
Silt ·02 to ·002 mm.	10·3	9·3	9·6	11·9	10·4	10·8	10·3	13·9	13·0	12·0	11·3	11·3
Clay [1] ·002 to 0 mm.	46·3	39·6	55·8	39·6	36·4	37·2	37·8	39·9	59·7	44·7	40·7	44·0
CHEMICAL ANALYSIS												
Potash, soluble in hydrochloric acid [2] … (K_2O)	0·36	0·33	0·52	0·25	0·46	0·25	0·30	0·45	0·59	0·30	0·38	0·40
,, insol. ,, ,, ,,	—	0·74	—	—	—	0·43	—	—	—	—	0·49	—
Phosphoric acid … (P_2O_5)	0·16	0·14	0·16	0·14	0·14	0·15	0·09	0 13	0·13	0·09	0·09	0·10
Humus …	—	0·59	—	—	—	0·65	—	—	—	—	0·52	—
Humus nitrogen … (N)	—	0·013	—	—	—	0·014	—	—	—	—	0·013	—
Total nitrogen … (N)	0·031	0·033	0·024	0·021	0·029	0·032	0·021	0·025	0·019	0·012	0·013	0·019
Carbonates … ($CaCO_3$)	6·6	3·8	2·4	3·9	2·5	6·9	6·1	2·7	3·4	5·6	6·3	5·2
Water-soluble salts — 1st foot	0·13	0·10	0·08	0·10	0·07	0·11	0·09	0·09	0·09	0·10	0·10	0·15
Water-soluble salts — 2nd ,,	0·79	0·13	0·08	0·68	0·07	0·26	0·72	0·12	0·13	0·57	0·40	1·28
Water-soluble salts — 3rd ,,	0·67	0·78	0·13	0·64	0·09	0·56	0·78	0·12	0·41	0·54	0·74	1·19
Water-soluble salts — 4th ,,	0·37	0·34	0·13	0·78	0·11	0·33	0·51	0·12	0·54	0·34	0·74	1·14

[1] See note on *page* 56

[2] Ten hours' extraction with acid of 1·115 Sp. Gr.

GEZIRA SOILS—*continued*

Surface 12 inches except where otherwise stated — *Figures represent per cent. of dry soil*

Point of collection	Lat.	14° 55′	14° 55′	14° 58′	15° 0′	15°2′30″	15° 5′	15° 5′	15° 5′	15° 5′	15° 5′	15° 5′	15° 5′
	Long.	33° 2′	33° 0′	33° 3′	33° 6′	33° 9′	33° 10′	33° 7′	33° 4′	33° 1′	33° 58′	33° 55′	32° 52′
Sample Number		No. 137	No. 141	No. 145	No. 149	No. 153	No. 157	No. 161	No. 165	No. 169	No. 173	No. 177	No. 181
MECHANICAL ANALYSIS													
Stones and gravel above 2 mm.		2·9	3·9	1·2	3·3	3·0	2·9	2·6	3·9	4·1	0·5	0·8	2·4
Analysis of fine soil, below 2 mm.													
Coarse sand, 2 to ·2 mm.		15·4	21·6	14·3	19·5	20·9	18·3	15·5	25·6	24·5	18·8	23·1	22·0
Fine sand ·2 to ·02 mm.		26·9	24·8	28·0	24·8	24·5	29·2	28·4	22·0	24·9	21·2	25·2	24·9
Silt ·02 to ·002 mm.		13·6	10·8	14·5	12·7	11·0	13·4	12·8	10·0	12·5	11·6	11·1	13·7
Clay[1] ·002 to 0 mm.		44·2	43·8	43·2	43·0	43·6	39·1	43·3	42·4	38·1	48·4	40·6	39·4
CHEMICAL ANALYSIS													
Potash, soluble in hydrochloric acid[2] ...	(K_2O)	0·57	0·45	0·58	0·60	0·47	0·36	0·51	0·46	0·39	0·53	0·36	0·36
,, insol. ,, ,, ,, ...		—	—	—	—	—	—	0·53	—	0·54	—	—	0·66
Phosphoric acid	(P_2O_5)	0·10	0·09	0·10	0·10	0·10	0·12	0·16	0·17	0·13	0·16	0·17	0·16
Humus		—	—	—	—	—	—	0·53	—	0·50	—	—	0·51
Humus nitrogen	(N)	—	—	—	—	—	—	0·010	—	0·013	—	—	0·010
Total nitrogen	(N)	0·019	0·015	0·018	0·015	0·022	0·021	0·018	0·029	0·018	0·011	0·014	0·026
Carbonates	($CaCO_3$)	6·6	4·8	4·0	5·4	5·7	4·3	4·5	6·2	7·0	5·4	4·8	7·8
Water-soluble salts	1st foot	0·11	0·08	0·22	0·15	0·34	0·14	0·16	0·11	0·08	0·08	0·04	0·06
	2nd ,,	0·47	0·08	0·46	0·23	0·43	0·16	0·16	0·69	0·19	0·13	0·54	0·23
	3rd ,,	0·93	0·18	1·06	0·83	0·91	0·29	0·95	0·70	0·78	0·25	0·55	0·49
	4th ,,	0·75	0·13	1·13	0·87	1·04	0·26	0·85	0·68	0·87	0·40	0·54	0·46

[1] See note on *page* 56

[2] Ten hours' extraction with acid of 1·115 Sp. Gr.

Gypsum as a Fertiliser for Sudan Soils

The beneficial effect of lime on soil has long been known and its application in one form or another is a common practice, especially in humid regions. In arid regions like those of the Sudan, the removal of the lime originally present as a soil constituent, by the leaching effect of infiltrating rain water, takes place only to a very limited extent, and the soils in such regions are usually so rich in lime that its application as a fertiliser is rarely if ever practised. There is, however, evidence to show that under certain conditions a soil may be benefited by lime even when the analysis indicates that there is already present a proportion much above that usually laid down as amply sufficient. Thus in certain heavy, difficultly permeable, soils, lime, existing as small nodules of calcium carbonate, may be so enveloped by clay as not to be available, and the application of lime in a soluble form may be distinctly beneficial.

The chief beneficial effect of lime, in the form of calcium carbonate, is usually stated to be in connection with the growth of nitrifying organisms. Nitrification, the conversion of the nitrogen of the soil into nitrates directly available for plant food, will not take place except in slightly alkaline solutions such as that furnished by the action of water on calcium carbonate. There are many other effects of lime equally important, and these are shared by other compounds of calcium, more especially calcium sulphates. It is especially with a view to call attention to this latter substance and the possible benefits which may result from its use on Sudan soils that the following notes have been gathered together. It is hoped that they may induce agriculturists in the Sudan to make a trial of gypsum on their lands. If the results obtained are sufficiently favourable, the extensive deposits of gypsum which are known to exist in the Red Sea Province may possibly be worked on such a scale as will enable the material to be secured at comparatively low cost.

Before going into the details of the effects of gypsum in the amelioration of undesirable soil conditions, a glance at the figures in the following table[1] may not be without interest. They show the results of a very great number of fertiliser experiments on cotton soils carried out between 1887 and 1907 and reported in the official bulletins of the United States Department of Agriculture and of the State Experiment Stations. The actual experiments were performed on one tenth or one twentieth acre plots, but the results are uniformly stated in pounds of cotton per acre. The value assigned to the cotton was only 10 cents (2 piastres) per pound, but the present value in Egypt is nearly twice that figure.

Experiments were carried out both with single fertilisers and with mixtures. The table given includes the trials made with single fertilisers alone, since it is only in this series that gypsum figures.

It will be seen that the total area treated with gypsum was 11 acres. Since the trials were made on one tenth and one twentieth acre plots, the number of different experiments carried out with this fertiliser was between 110 and 220. The proportion of cases of success to cases of failure was as ten to one, and the *average* gain per acre over the cost of gypsum was \$18 (about P.T. 360.) or, at the present value of cotton, nearly double that figure. This is six times greater than the average gain from the use of any other form of single fertiliser.

It is fully realised that such a comparison as this is far from scientific; but, as noted by Whitney,[2] owing to the generally inadequate description of the soils in the reports of experiments, it was not found practicable to group and to analyse the data with relation to

[1] Taken from "Fertilizers for Cotton Soils," M. Whitney, *U.S. Dept. of Agriculture, Bureau of Soils, Bulletin* No. 62.

[2] Whitney, *loc. cit.*

RESULTS OF FERTILISER TESTS WITH COTTON SOILS

Kind of Fertiliser used	Total area	Increase to no increase	Range of crop increase	Fertilisers per acre		Average crop increase per acre		Average gain per acre
				Used	Cost			
	Acres	Ratio	Pounds	Pounds	Dollars	Pounds	Dollars	Dollars
Nitrate of soda...	73	3·5 : 1	— 60 to 492	160	4.00	64.0	6.40	2.40
Sulphate of ammonia	17	4·7 : 1	— 82 to 234	128	3.97	58.2	5.82	1.85
Acid phosphate...	181	9·6 : 1	—108 to 363	286	1.90	69.8	6.98	5.08
Ground bone	14	13·0 : 1	—235 to 283	279	3.63	92.8	9.28	5.65
Rock phosphate	6	1·0 : 1	— 70 to 50	706	3.18	— 4.0	0.40	— 3.58
Floats	25	1·6 : 1	— 96 to 89	201	.80	16.7	1.67	0.80
Basic slag	4	·3 : 1	— 48 to 104	230	1.42	— 1.0	.10	1.52
Boneblack	3	3·0 : 0	20 to 290	500	5.50	132.7	13.27	7.77
Muriate of potash	36	3·0 : 1	— 27 to 180	98	2.16	34.5	3.45	1.29
Sulphate of potash	6	·5 : 1	— 30 to 149	112	3.36	21.2	2.12	— 1.24
Kainit	161	3·9 : 1	—108 to 201	292	1.75	32.3	3.23	1.48
Wood ashes	3	2·0 : 1	— 18 to 206	1,667	4.17	68.0	6.80	2.63
Cotton-seed-hull ashes...	12	1·0 : 1	— 47 to 250	271	4.61	41.6	4.16	— .45
Lime	3	2·0 : 1	— 42 to 127	1,333	4.00	33.3	3.33	— .67
Marl	3	2·0 : 1	— 20 to 64	900	.23	19.0	1.90	1.67
Salt	1	—	— 8	200	.80	— 8.0	— .80	— .88
Gypsum	11	10·0 : 1	— 27 to 360	195	.78	197.4	19.74	18.96
Total	559	4·1 : 1	—	—	2.33	54.0	5.40	3.07

the chemical and physical differences in the soils. The results are nevertheless interesting and suggestive. Whether anything like the same benefit will accrue from the application of gypsum to Sudan soils, can only be determined by trials on a practical scale; but it may be mentioned in passing that a number of pot cultures in the laboratory, with heavy soils, showed marked improvement to result from the addition of moderate amounts of gypsum.

The following is a brief account of the various effects which have been noted as resulting from the application of gypsum to soils, and which may account for the increased yields which have been recorded in the table given on *page* 61.

(*a*) The harmful action of sodium carbonate on soils and on plant life is well known. It appears to be the most injurious mineral ingredient found in otherwise good arable soils. Its action is both direct, on the plant, and indirect, on the soil. On the plant it acts by corroding the root, crown or stem and in some cases the latter is girdled, the bark being completely destroyed. This effect is especially liable to take place when the salt accumulates near the surface as the result of evaporation of the soil water. The effect on the soil is no less injurious, a proportion less even than one tenth per cent being sufficient to destroy the tilth of the soil and to render it unproductive. The effect is due to the deflocculation (puddling) of the clay, with the result that the soil becomes almost or quite impermeable to water.

In cases like the above, gypsum acts as a veritable specific. The impermeability of the soil renders the simple washing out of the salt impossible; but the addition of a small amount of gypsum to the soil water suffices to convert the sodium carbonate into comparatively harmless sodium sulphate, the clay being coagulated and rendered permeable at the same time.

The fact that too little attention has commonly been paid to the drainage of irrigated lands is a truism. When this lack of drainage results in the stagnation of the soil water—*i.e.* insufficient aeration—sodium carbonate is almost invariably formed. Treatment with gypsum should be the first step in the correction of such a condition.

(*b*) The harmful effects of ordinary salt—in fact of practically all soluble salts, even those employed as fertilisers—when present in any but very small proportions, are only too well known. The case of one of these, sodium carbonate, has just been discussed, and its destruction by the use of gypsum noted. The effect of gypsum in this case is usually explained by a consideration of the chemical change which takes place when these two bodies are brought together. It has, however, been discovered that the inhibition of the injurious action extends to other salts as well, a fact all the more remarkable as no adequate explanation can as yet be given for it. In an investigation[1] of the effect of alkali soils on vegetation carried out in 1902 by Kearney and Cameron, of the United States Dept. of Agriculture, a very important fact was recorded in connection with calcium sulphate. It was found that while certain very small proportions of salts, such as common salt, sodium sulphate, magnesium chloride and sulphate, were distinctly injurious to plant life, in the presence of calcium sulphate these proportions may be greatly, in some cases even enormously, exceeded, without apparent injury. Thus, under the conditions mentioned, the maxima of concentration of the salts endurable by the plant were increased as follows:—

Magnesium sulphate	480 times
,, chloride	80 ,,
Sodium sulphate	66 ,,
,, chloride	10 ,,

[1] "Some mutual relations between alkali soils and vegetation." Bulletin No. 71, 1902

In other words, if, in ordinary soil, one part of magnesium sulphate was found to be sufficient to prevent plant growth, in the presence of calcium sulphate the proportion of magnesium sulphate could be increased to 480 parts before the same poisonous effect was manifest.

The experiments mentioned were carried out with wheat seedlings. The results obtained in 1902 have been confirmed by later investigations. Kearney and Harter in a bulletin[1] which appeared in 1907 have detailed the results obtained with four varieties of dura, two of oats and two species of cotton (the Jannovitch Egyptian and an American variety). The results establish the fact that different genera and species differ greatly in their power of resistance to the salts of so-called alkali soils, and that in the presence of salts of calcium, especially calcium sulphate, these differences are much less pronounced. They, however, still exist to such a degree as to leave no escape from the conclusion that some species and varieties of these plants are better adapted than others to grow in soils containing a relatively large amount of these salts.

The extent to which gypsum neutralises the poisonous effect of salts, thus increasing the resistance of the plant to the same, varies with the nature of the salt. In the case of sodium chloride the resistance of the plant was increased as follows:—

Lupine (white)	5 to 10 times
Wheat	5 to 10 ,,
Dura	about 10 ,,
Oats	,, 9 ,,
Cotton (*G. barbadense*)	,, 32 ,,
Beet	,, 8 ,,

These experiments were carried out with solutions saturated with gypsum. It was found, further, that when the latter was present even in very small amount, its effect was still marked. Thus, when present to the extent of only one sixteenth part of that required for saturation, the neutralising effect was more than one half that observed for the concentrated solution. It may be stated here that very little calcium sulphate is required to form a saturated solution in pure water—approximately two parts in one thousand parts of water.

The experiments detailed above were all on a small scale, in the laboratory. A very interesting series of field experiments on a larger scale was made at the Experiment Station of the Hawaiian Sugar Planters' Association.[2] These were directed to the determination of the effect of salt in the irrigation water of sugar plantations and the extent to which neutralisation might be effected by the addition of calcium carbonate (in the form of ground coral) and of gypsum. Very large amounts of salt were used in those experiments (200 grains per gallon of irrigation water, amounting in all to over 30 tons of salt per acre) so that the effect on the yield of cane was very marked.

It was found that when gypsum or ground coral were employed, the effect of the salt was to a certain extent neutralised, the yield of sugar being increased by about 46 per cent. The quality of the juice was also slightly improved, the sugar being associated with less impurity.

(*c*) The importance of maintaining a good "tilth"—that loose friable condition of the soil in which the clay exists, not in the puddled state, but agglomerated into small aggregates, thus permitting the free access of moisture and air—is so well known as to

[1] Bulletin No. 113. Bureau of Plant Industry, U.S. Dept. of Agriculture

[2] Report of the work of the Experiment Station of the Hawaiian Sugar Planters' Association, Division of Agriculture and Chemistry, Bulletin No. 11.

require no special discussion here. A fact which is, however, very generally overlooked in the Sudan, is that the *penetrability to roots should extend as far below the surface as possible.* Gypsum, like other soluble lime compounds, has a marked effect in loosening heavy clayey soil. Being more readily soluble than, *e.g.*, calcium carbonate, it is more quickly removed in the drainage water and the effect is, therefore, less lasting. At the same time it must be remembered that once the soil is made more penetrable and the roots have reached a greater depth, the fact of their presence, and the introduction of more organic matter into the soil, renders the penetrability easier to maintain.

The effect of clay in lessening the cohesion of heavy soils was clearly shown by the results of trials made recently in this laboratory. Several soils were made into bricks, in the one case with pure water, and in the other with water containing gypsum. The clay in the soil was, of course, partially puddled in the operation. After these bricks had thoroughly dried, their transverse breaking strain was determined. In three out of four cases the breaking strain of the bricks which contained gypsum was very markedly less than that of those made from the untreated soil. It is evident, therefore, that a plant root would usually find a gypsum-treated soil more readily penetrable than the original soil.

(*d*) Gypsum shares the effect, exhibited by certain other soluble compounds, of rendering the potash of the soil constituents more available. The gypsum, being comparatively soluble, easily penetrates the soil and acts upon the potassium compounds, especially the hydrosilicates (zeolites) formed as the result of rock decomposition under atmospheric influences. The result of this action is a partial substitution of calcium for potassium, the latter being set free in soluble form, available as plant food.

(*e*) It has already been mentioned that lime (or magnesia), in the form of carbonate, is essential to nitrification, and that these act by neutralising the nitric acid as fast as it is formed, thus preventing its accumulation and the consequent inhibition of the growth of the nitrifying micro-organisms. Calcium sulphate has been found to have a remarkably stimulating effect on the growth and multiplication of these bacteria. In this respect it has been stated by Pichard[1] to be more effective than any other substance known. Taking the effect of gypsum as the maximum, he found that, other things being equal, the amounts of nitrates formed were as shown in the table below—

Gypsum	100
Sodium sulphate	47·9
Potassium sulphate.	35·8
Calcium carbonate	13·3
Magnesium carbonate	12·5

Hilgard has noted that the above results are confirmed by his observations on the soils of California. The explanation of the increased nitrification in the presence of gypsum appears to be due to the fact that the latter acts as a food for the micro-organism.

The importance of this effect of gypsum in the treatment of many Sudan soils may be very great. There is considerable evidence to show that certain of them are, from one cause or another, markedly deficient in nitrifying power. The application to these of gypsum is well worthy of a trial from this point of view alone.

(*f*) The partial exhaustion of soils by the continuous removal of the same variety of crop, without rotation, cannot be explained simply as the result of abstraction of plant food. Several causes are probably at work and there is evidence to show that among

[1] Quoted in *Soils* by Hilgard

them may probably be included the accumulation of products excreted by the plant, these (like all excretory products) being poisonous to the organism producing them.

The beneficial effects of fertilisers has been thought by some to be due, in part at least, to their direct action on these harmful excretory products. It is not impossible that gypsum may have an action of this kind. Be this as it may, the sterility of some soils has been shown by Shreiner and Shorey of the United States Department of Agriculture to be connected with the presence of certain organic compounds among which is, *e.g.*, dihydroxy-stearic acid. An interesting point in this connection is that while some of the combinations of this acid with bases are as harmful as the acid itself, the potassium and *calcium* salts are apparently without injurious action. Soils containing this or similar bodies might therefore, it appears to the writer, reasonably be expected to be made more productive by the application of gypsum as a fertiliser.

(*g*) Lastly, gypsum has long been known to act favourably in promoting the growth of leguminous crops, notably the clovers. The rationale of its action in this case appears not to be fully understood. It may be due to effects not yet discovered or to a combination of those already detailed.

Amount to be applied.—The usual dose of gypsum is about 200 pounds to the acre. In special cases, where there is a notable proportion of sodium carbonate present and the soil well puddled in consequence, 500 pounds or even more may have to be employed.

It should be remembered that lime either as such or in the form of gypsum is not a plant food in the ordinary sense but that it acts rather as a "tonic." It would not be good practice to continually fertilise with gypsum since the effect might be to impoverish the soil too rapidly. The gypsum should, in most cases, simply be added to aid in bringing the soil into good working condition, and its maintenance in this state can be effected only by having regard to the requirements of each special case.

Gum Research

The disadvantages under which the laboratories have been labouring in connection with research on gum products have already been mentioned. Many lines of investigation have had to be abandoned for lack of efficient aid in the field work. Some advances have nevertheless been made, and it may not be without interest to state, briefly, some of the points which appear to have been established, as well as to indicate the lines along which investigation should be directed in future work.

Origin of gum. Mr. Edie's researches, both those detailed in the Third Report, and those carried out during the winter of 1908-9 (*vide page* 73), appear to confirm the earlier work of Greig Smith, which indicated that gum production is the result of the activity of a specific micro-organism. The mode of infection probably varies in different cases, but there is evidence to show that ants, and possibly other insects, frequently act as carriers. During the course of some experimental tappings of *talh* trees *(Acacia seyal)* in the Sennar Province, the freshly exuded sap was observed to attract streams of ants to the cut surface, and it seemed extremely likely that this fact was directly connected with the infection of the tree by the gum-producing microbe.

Microbial origin of gum

The attention of Mr. E. S. Edie, who was at this time at work on *hashâb* trees *(A. senegal)* in the Kordofan forests, was called to this point, and his observations (*vide page* 81) appeared to amply confirm the conclusion arrived at. Such a view would explain the results which were obtained from the attempted inoculations of *hashâb* trees in 1907.[1] The experiments made at that time were as follows:—Tapping was performed by making a series of gashes with an axe, no bark being stripped off, and (as it was thought that the chances of efficient inoculation might thus be lessened) an attempt was made to ensure the entrance of the microbe by rubbing a moist rag over the bark, in which the microbe was presumed to reside, and subsequently into the cut.

"Tapping" experiments

A series of trees tapped in the usual native fashion, by stripping the bark, were also treated in the same manner for comparison. The number of trees operated on in each case was twenty-five. The following table exhibits the results obtained:—

Method of tapping	Treatment	Yield of gum per tree per season
Ordinary	No attempt to inoculate	0·9 rotl
,, ...	Attempted inoculation	0·55 ,,
Short gashes	No attempt to inoculate	0·28 ,,
,, ...	Attempted inoculation	0·14 ,,

When the results were reported it was suggested that possibly the lower yields were due to the fact that in place of increasing the extent of infection, the procedure adopted had, on the contrary, lessened it, since the sap exuded was, in great part, removed by the wet cloth. If we accept the view that ants are the chief carriers of infection the results become still more comprehensible. A portion of the sap having been removed (and the amount exuded is usually very small) there was no longer sufficient present to attract the insects, in the usual number, before the cut had healed.

Another point which is of interest in this connection is the effect of cold at the time of tapping. No further experiments have been made since those already reported on, but these appear to show conclusively that cold at the time of tapping has a marked retarding effect on gum production. Should the weather remain cold for several successive days after tapping, the operation may even be entirely fruitless. It seems reasonable to conclude from this that the growth of the microbe is inhibited by the low temperature, and that the wound heals before the tree has become sufficiently infected.

It should be stated here that the exact determination of the quantitative effect of any given condition on gum production is far from easy by reason of the difficulty in securing a reliable standard for comparison, *i. e.* a tree of the same age and size, perfectly sound, to the sap of which the microbes are unable to gain access. Small cracks or fissures at one point or another are almost sure to be found during the dry season, and a certain indeterminate amount of infection appears to be inevitable.

Methods of tapping

Methods of tapping. The native method of tapping *hashâb* trees is to remove a strip of the bark, from 2 to 3 feet in length and 1 to 3 inches broad, according to the size of the branch operated upon. Trials have been made to improve upon this method by removing shorter strips, or by simply gashing the tree, but up to the present, the native method appears to yield the best results.

Tapping of gum trees is only a comparatively recent practice in Kordofan, and is said to date from about 30 years ago. Previous to this, only such gum was collected as was found exuding from natural fissures in the bark. Tapping by the present method was found to increase the yield to something like five times the former amount.

[1] *Vide Third Report, Wellcome Tropical Research Laboratories*, p. 422

Varieties of hashâb gum. The gum found exuding naturally is called by the natives "wady" gum and is usually held by them to be stronger than that resulting from tapping. This is not borne out by the result of examination. Indeed, wady gum is, on the whole, of inferior quality, since it is usually darker in colour than the gum of tapped trees. Varieties of *Hashâb* gum

After tapping, the first collection of gum is usually made at the end of several weeks, more or less, depending in part at least upon the temperature, which has a marked influence upon the rate of exudation. There are usually seven or eight collections in the season, which terminates when the rains begin to fall.

The gum of the earliest exudation is usually not completely soluble. On treatment with water, a glairy, mucus-like liquid results, from which there separates, after a time, a greater or less amount of true solution. This effect is usually less marked in weak solutions. Fortunately it has been found that storage of the gum for a short period is sufficient to correct this defect, the gum becoming completely soluble in solutions even of the highest concentration. Senegal gum has been found to behave in a similar manner.

The change which takes place in the gum on storage has not yet been worked out, but it is doubtless connected with the presence of certain enzymes[1] which have been found to be present.

Hashâb (*A. senegal*) gum is found to be a mixture of two markedly different varieties, one hard, and the other soft. These may be separated by exposing the mixed gum to the sun. The harder variety remains glass-like and transparent, whereas the softer becomes more or less rapidly covered with innumerable small fissures which make it appear almost quite white. This bleaching of the gum is more apparent than real, and if the gum is originally appreciably coloured it will remain so in the interior. A certain amount of true bleaching does, nevertheless, take place, but it is not very marked. The solution of this variety of gum is less viscous than that of the harder variety.

The usual range of viscosity of 20 per cent. solutions of the two varieties is as follows, the figures expressing degrees of retardation in the torsion viscosimeter.[2]

Hard gum	60 to 70 degrees
Soft gum	28 to 33 ,,

The two gums exhibit no apparent differences as regards their proportion of ash and acidity.

The origin of the hard gum, that is to say, the special conditions which determine its formation, has not yet been determined. A great deal of work has been attempted with this end in view, but the investigation had to be abandoned for a time for the reasons stated above.

If tested shortly after exudation, gum of the six or more successive collections in a given season exhibits a more or less regular decrease in apparent viscosity strength of solutions. This is not due to a higher proportion of the hard, transparent, strong gum in the earlier collection but to the presence of the less soluble, constantly changing variety to which reference has already been made. If the gum is stored for some months before testing, the change to complete solubility will usually be found to have taken place, and all the collections will exhibit approximately the same viscosity strength.

The typical hard, strong, gum suffers but little change in viscosity strength, on storing.

Effect of coppicing. A considerable proportion of *hashâb* gum is derived from coppiced trees. As such gum might show marked difference in quality or quantity from that Effect of coppicing

[1] *Vide* F. Reinitzer, *Zeit f. Physiolog. Chem.* 1909, p. 352

[2] *Vide Second Report, Wellcome Tropical Research Laboratories*, p. 232

exuded by ordinary trees, the Forestry Department was urged to furnish us with samples of the two, collected at the same time, and from the same district, for purposes of comparison. This request has not been complied with, but a sample from a single coppiced tree, kindly collected for us by Mr. E. S. Edie, was found to weigh only about one-half of that exuded by an ordinary tree of about the same size. As only a single tree has been tested the result must be taken merely as suggestive. The chemical examination of the two gums yielded results as follows:—

	Gum from coppiced tree	Gum from ordinary tree
Moisture, per cent.	8·29	8·41
Ash, per cent.	2·40	2·67
Acidity (mmgs. KHO required to neutralise one gramme) ...	3·57	3·38
Viscosity of 20% solution (degrees of retardation in torsion viscosimeter)	19·0	17·1

There is no marked difference in quality between the two gums, but both were exceptionally weak as regards the viscosity of their solutions.

As has been noted in previous Reports, *hashâb* gum is only formed when the tree is reduced in vitality, usually as a result of the dryness of the soil. It might be expected, therefore, that in the case of coppiced trees the greater root development in proportion to the size of the tree would result in increased vitality during the period of drought, and consequently in lessened gum production. The single instance mentioned above would appear to bear out this assumption, but many collections will have to be made and examined before a reliable conclusion to this effect may be drawn.

Talh gum

Talh gum. This gum, which is the product of two varieties of *Acacia seyal*, is of much less importance, commercially, than that of *A. senegal*, to which it is inferior in several respects; the solution of the gum is less viscous than that of the hard variety of *hashâb* gum, and further, on standing exposed to the air, it becomes dark in colour, usually depositing a brownish-black precipitate. The gum is also more acid than is *hashâb* gum.

A gum of much better quality may be had by selecting only the colourless pieces. These yield a solution less acid and having little or no tendency to darken on exposure to air. Colourless *talh* gum is found only in very small proportion in the product as ordinarily collected.

Tapping of *talh* trees

Tapping of talh trees. *Talh* trees are not tapped by the native gum collectors. At our request an experimental tapping of these trees was carried out by Mr. S. A. Wood, Inspector of the Woods and Forests Dept., with a view to determine whether the quality or quantity of the gum was naturally improved. From the report made by this official it appeared that the quantity of gum exuded could be very considerably increased in this way; and, from the sample of such gum sent us, it appeared also that the quality was even more markedly improved. In the Third Report of the Laboratories, *page* 436, is found a comparison of the results of examination of this sample with that of ordinary gum collected in the same district from untapped trees. Later investigations disclosed the fact that for some unaccountable reason the sample furnished as gum from tapped trees had been picked, all the darker particles being rejected. The comparison of results referred to above was, therefore, rendered not only useless but misleading.

A second attempt was made to determine the effect of tapping *talh* trees but the forestry official to whom the work of tapping and collection was confided again failed to carry out the work in a satisfactory manner, and the results were useless except to confirm the conclusion that the sample first furnished was not reliable.

A third attempt was made, the operations of tapping being carried out under the supervision of the writer. The trials made and their results are detailed below.

Red *Talh* Trees. *Tapped November* 18

Red *talh* trees

Series A. Ten trees tapped by a clean cut with a sharp spoke-shave, removing both bark and liber. The strips removed were about 10 × $1\frac{1}{2}$ inches. They were taken from the trunk alone, since the branches were too high to be accessible.

Nov. 24. No appearance of gum.

Dec. 18. No appearance of gum.

The cut appeared to have healed when observed on Nov. 24.

Series B. Strips, of outer bark only, removed by means of the spoke-shave. Five trees operated upon.

Nov. 24. No appearance of gum.

Dec. 18. No appearance of gum.

Series C. Simple horizontal gashes, to the number of about six on each tree, made with a small native axe. Six trees operated upon.

Nov. 24. Gum just beginning to exude.

Dec. 18. All the trees but one (C 4) showed exudation of a small amount of gum at each gash. The gum was dark coloured except in the case of tree (C 5) which had apparently been less affected by fire.

Series D. Two horizontal clean cuts, so made as to remove a wedge-shaped piece of the bark and liber, and exposing the wood. Six trees operated upon.

Nov. 24. Gum beginning to appear.

Dec. 18. Nos. 1, 2 and 3 showed a slight exudation, No. 4 a large blob of gum of rather dark colour. No. 5 tree, markedly less affected by fire, yielded no gum.

Series E. Six trees treated as in D. but the bark adjoining the cut bruised by blows with blunt end of the axe.

Nov. 24. Gum beginning to appear in most cases, but of dark colour.

Dec. 18. In four cases gum was found to be exuding in fair quantity but rather dark in colour, especially where it had passed through the cracks in the bruises.

Two of the trees, which were larger and less affected by fire, showed no exudation at all.

Series F. Simple vertical gashes made by blows of a small sharp axe. Six trees operated upon.

Nov. 24. Gum beginning to exude in some cases.

Dec. 18. Two trees showed practically no result from the tapping. One of them was almost completely shaded by a large tree with heavy foliage. The remaining four trees showed gum either at some or at all of the gashes.

Tapping experiments

Series G. Bark and liber removed and an auger hole made in the denuded wood. In this case the removal of the bark was effected by making a horizontal cut and loosening the bark beneath it by bruising slightly with the blunt end of the axe. In this way a strip of the bark may be pulled off by hand, an operation which is otherwise sometimes effected with difficulty. Six trees operated upon.

Nov. 24. No appearance of gum.

Experiments *continued*

Dec. 18. In the case of one fairly large sound tree, no gum was found at the point of tapping. In all the other cases there exuded a fair, and usually quite considerable, amount of gum which was dark in colour, especially in the case of the trees most injured by fire.

SERIES H. An auger hole, about $\frac{1}{4}$-inch in diameter, made through the bark and into the wood. Six trees treated.

Nov. 24. Slight exudation of gum, from between the bark and the wood. None from the wood itself.

Dec. 18. A small quantity of gum—usually of dark colour—exuding from most of the holes.

SERIES J. Holes made by "pecking" with a sharp-pointed axe. Six trees operated upon.

Nov. 24. Gum beginning to exude at each point.

Dec. 18. In five out of the six trees, gum of fair colour was found exuding from nearly all the "pecks." In one case, when the exposed roots of a large tree had been much affected by fire, but the rest of the tree practically uninjured, there was an extremely large amount of gum yielded at one of the "pecks."

SERIES K., L. AND M. These trees were tapped by removing the bark and liber in the manner detailed for Series G, and the cut surface was treated with strong antiseptics in order to determine whether such treatment would prevent inoculation and gum production.

SERIES K. A solution of corrosive sublimate rubbed into the freshly denuded surface and the neighbouring bark. Three trees operated on.

Nov. 24. Gum appearing in greater quantity than in the previously detailed experiments.

Dec. 18. Considerable exudation of gum, of rather lighter colour than the average yielded in the former series of experiments.

SERIES L. Diluted formalin applied, under the same conditions, to three trees.

(*Note.* The roots of these trees had been considerably injured by fire.)

As in the case of Series K, all three of the trees exuded a large amount of gum. In one case there was not less than a pound, partly hanging from the tree and partly lying on the ground.

SERIES M. Three trees taken. The treatment in this case was with a solution of sodium metabisulphite. The results yielded were in the main similar to those in the case of experiments K and L. One of the trees yielded practically no gum, but the remaining two yielded much larger amounts than in the case of simple tapping without the use of chemicals.

The gum, in all three cases of chemical treatment, was evidently exuded much more quickly than is usually the case, and it was spread over the tree to such an extent that it could not be removed without great loss.

White *talh* trees

White *Talh* Trees

These trees were tapped on November 19 and the observations made on December 17.

SERIES A. Ten trees. Simple tapping by removing a strip about 8 inches long, including both bark and liber. The removal of the bark was effected as in Series G of the Red *Talh* trees.

When examined on December 17 most of these trees, fairly sound, showed little or no appearance of gum. Several trees which had obviously been injured by fire exuded a fair amount of gum of dark colour.

SERIES B. Eight trees, tapped as above, but, in addition, an auger hole made into the denuded wood.

In most cases no gum was found exuding from between the bark and the wood, and in no case was any trace of gum found exuding from the hole in the wood itself.

SERIES C. Six trees treated by boring holes with an auger, through the bark and into the wood.

In the case only of one tree was gum found exuding, and from one only of the several auger holes in it.

SERIES D. Five trees treated by removing a wedge-shaped piece of the bark and liber, and bruising the adjoining bark by blows of the blunt end of a small axe.

Three of these trees yielded no gum at the point of tapping. The remaining two yielded a fair amount, but very dark in colour, especially where it exuded from the cracks in the bruised bark.

No further reliable observations were made on the above experimental tappings. It was intended when they were instituted that observations be made periodically—once every two or three weeks—in order to watch the course of the exudations. It appears, however, that the forest officer in charge of the district did not visit them until three months after the date mentioned above, when he reported the practical absence of gum from any of the trees except those which had been chemically treated. We were therefore left somewhat in the dark in this connection; but, in view of the fact that the apparently sound trees, both of *White Talh* and of *Red Talh*, did not yield gum when tapped in the ordinary way, there seems to be strong evidence that, at least in the immediate district in which these experiments were performed, the conditions were not naturally favourable for gum production. Taken altogether the results appear to justify the following conclusions:—

(*a*) In the district in question sound *white talh* and *red talh* trees—*i.e.* trees which have not been injured by fire or which have not suffered marked mechanical injury—are not susceptible to the action of the gum-producing microbe, and will not, therefore, yield gum on simple tapping in October and November. It appears evident Conclusions that at this time the ground is still sufficiently moist, from the lately fallen rains, to keep the trees in a resistant condition.

Such trees would probably yield gum if tapped at the end of February or, better, in March, when the weather is hot again and the soil contains less moisture. On the other hand, the soil itself appears to be of rather good texture and fairly rich, which, again, is unfavourable for gum production under ordinary conditions.

(*b*) Trees which have been injured by fire are more susceptible and yield gum fairly readily; but such gum is very frequently coloured to an objectionable degree. Even in the case of these fire-injured trees, it would seem preferable to perform the tapping as late as possible after the rains, so that the exudation may not be checked by the colder weather of December, January and February.

(*c*) Tapping by cuts with a sharp instrument, such as a spoke-shave, will probably be least effective, since such cuts appear to heal too quickly. This method, has, however, not yet been tested on trees known to be in a low state of vitality, and therefore most suitable for gum production.

(*d*) Bruising of the bark around a cut allows freer outlet to the gum and increases its production; but the resulting gum, especially if it exudes through cracks in the bruised bark, is coloured to an objectionable degree.

(*e*) If found feasible it would appear preferable to tap lightly, but in a considerable number of places, on each tree, in order that the gum may form separate tears, instead of running down the trunk in a thin layer. It is probable that this latter condition would be less likely to obtain if the tree were tapped, as suggested, towards the end of the dry season, when the gum might be expected to exude in a less liquid condition. Such gum might form tears less contaminated by bark and more easy of collection.

(*f*) As regards the marked effect of the application of chemical agents to the freshly tapped surface, it seems reasonable to conclude that these act, not by inciting gum formation, but rather as irritants, stimulating the flow of gum-containing sap to the part. In other words, it seems likely that the gum already existed in the sap, the trees having previously become infected by the entrance of the microbe at other points. This conclusion is supported by the fact that, of a further lot of twenty trees, treated in the same way by the forest officer, a few failed to respond.

The above results, obtained in Sennar, were communicated to Mr. E. S. Edie, who was working at the same time on similar lines in Kordofan, but on the *hashâb* tree. As will be seen from his report (*page* 73), Mr. Edie's observations led him to the same conclusions.

To conclude these notes, the fact that in the neighbourhood of Saoleil, only such trees as had been injured by fire yielded gum readily on tapping, is a point of obvious importance. As already noted, it still remains to be determined whether the sounder trees could be made productive if tapped towards the end of the hot dry season. If not, we would be compelled to rely upon injured trees for gum production, and, in this case, a method of reducing vitality more under control than a chance forest fire, is obviously desirable. Girdling some of the roots of the tree, or, more simply, partial girdling of the trunk near its base would seem to be a promising method. Objection may be raised that it is not advisable to carry the injury to such an extent, but since these trees are at present put to no use and have cost the Government no inconsiderable sum for fire protection, such an objection does not appeal to one as sound.

The method, if found to answer, might be advantageously used to secure at the same time a cheap wood fuel which is even more desirable than an increased output of *talh* gum. The trees might be utilised for gum as long as the work appeared profitable, after which they could be felled for use as fuel.

Experiments on Gum Production in Kordofan

BY

E. S. Edie, M.A., B.Sc., Carnegie Research Fellow, 1908-9

On being awarded a renewal of the Carnegie Fellowship held by me during 1907–8, I discussed with Dr. Balfour and Dr. Beam the best way in which I might be able to throw some more light on the subject of gum production, the principal questions at issue being the causes affecting the amount of gum exuded and the quality of the gum. It was decided that the best way would be for me to study the problems in one of the gum-producing districts, instead of having to get material sent to Khartoum to be worked up there.

Selection of site for experiments

I arrived at Taiara, the principal centre of the gum industry in Kordofan, in the first week of November, 1908, and was fortunate enough to find that two gum gardens suitable for experimental work had been partly cleared of grass and fenced in by the Woods and Forests Department in the previous season. One garden consisted entirely of young *hashâb (Acacia senegal)* trees which had never been tapped. These were all in a good state of health and free from accidental injuries. The other garden contained principally large trees, probably none being less than ten years old.

Twenty trees in each of these gardens had been tapped in the ordinary manner before my arrival at Taiara, about October 15. It will be of interest to consider the gum produced by these trees before entering into the question of the influence of artificial conditions on the yield of gum.

Gum from twenty small trees.—These trees, tapped for the first time, were among the largest of those in the first-mentioned garden, being probably from five to seven years old, judging from comparison with trees of known age elsewhere. On the whole they were considerably smaller than the average trees tapped by the natives in their own gardens. In order to show the fluctuations in the yield of gum throughout the season, it will be useful to give the complete figures for these trees, and afterwards to give a similar table in the case of the large trees.

It will be seen that the collections, after the first, were made at intervals of about 16 days.

Variation in yield of individual trees

On looking at the table on the next page, one is immediately struck with the enormous variation in yield of the individual trees. From an examination of the latter I think that the variations could not be entirely accounted for by differences in the size of the trees or the extent of the tapping. Tree No. 10, for example, was one of the largest of these trees, and was as well tapped as any, but yet it only yielded a very small amount of gum. The trees from which only a small amount of gum was obtained may not have been so well infected as the others.

Of special interest is the amount of gum obtained at the last collection. From the way in which the exudation was gradually falling off, one would have expected very little gum at this time, instead of which not only was there a considerably greater total yield on this occasion than on the one immediately preceding, but several trees actually gave more gum at the last than at any previous collection. The reason for this is probably as follows:—Between March 29 and April 8 about an inch and a quarter of rain fell, as a result of which many of the smaller trees came into leaf, and the renewed exudation was

Increase in gum after the first rains

probably caused by the sudden increase in the amount of sap from which the gum is produced. The increase was principally in the first ten trees, which were, on the whole, smaller than the rest. The amount of rain at this time was probably not sufficient to affect the larger trees as they did not come into leaf as a consequence. This increase, after the first rains, is of greater interest, as it is nearly always stated that the exudation of gum stops when the rain begins. It may quite probably be that more or less gum is produced until the edges of the wounds caused by tapping are entirely healed up. There was no sudden change of temperature for any prolonged period, nor any other exceptional circumstance of any kind to account for this increased yield. The average yield from these young trees is 900 grammes, considerably higher than is usually supposed to be the case. From the amount exuded by individual trees, however, it will readily be seen how difficult it is to reach definite conclusions from experiments with a few trees only, even though these may be to all appearances under similar conditions of health, age, etc.

YIELD OF GUM FROM SMALL TREES DURING SEASON 1908-9 (IN GRAMMES)

Tree No.	Dec. 17 1908	Jan. 2 1909	Jan. 19	Feb. 3	Feb. 17	Mar. 4	Mar. 19	Apr. 4	Apr. 22	Total
1	31	55	53	30	36	50	28	18	37	338
2	50	47	50	27	3	33	7	39	81	337
3	64	42	37	0	10	22	8	44	38	265
4	144	179	190	151	129	169	103	25	42	1132
5	351	239	153	19	27	52	37	38	18	934
6	98	16	32	27	10	6	0	11	29	229
7	186	137	130	97	11	101	56	10	22	750
8	36	55	61	14	24	63	74	45	86	458
9	33	25	35	3	5	34	28	25	82	270
10	59	28	23	0	0	34	16	5	23	188
11	308	214	244	195	206	196	174	39	16	1592
12	131	125	90	50	29	15	3	18	21	482
13	524	385	278	187	53	110	26	17	14	1594
14	770	536	536	388	226	242	81	51	26	2856
15	145	159	178	135	90	144	73	21	7	952
16	524	395	390	245	65	125	17	9	43	1813
17	498	318	269	238	48	227	84	32	47	1761
18	94	79	67	34	14	46	4	0	16	354
19	133	133	96	100	16	90	26	13	38	645
20	238	198	166	117	125	119	24	41	39	1067
Total...	4417	3365	3078	2057	1127	1878	869	501	725	18017

This garden was much more densely covered with trees than any ordinary garden which I saw belonging to the natives, which leads one to the conclusion that the amount of

Prospect of benefit from increasing the number of trees on a given area

gum produced in the country could easily be very much increased without even the necessity of opening up new areas which are not at present developed at all. Mr. Bisset, of the Woods and Forests Department, has shown that clearing the grass away carefully has a marked beneficial effect in increasing the number of trees by allowing them to obtain a good hold in the first year or two of their life, where they would otherwise simply be killed off. I have seen fair-sized tears of gum, an inch and more in diameter, produced by trees three years old, but the natives do not appear to tap their trees until the latter are about six years old. Of course, by tapping the trees at an earlier age, there may be a considerable risk of prematurely shortening the gum-producing life of the trees.

Gum from twenty large trees.—These trees varied considerably more in size than the small trees described above, and were not all equally well preserved. From the general appearance of the trees, however, I should say that they represented an average garden. The following table shows the yield of gum from these trees throughout the season :—

Tree No.	Dec. 18 1908	Jan. 2 1909	Jan. 20	Feb. 4	Feb. 18	Mar. 4	Mar. 20	Apr. 5	Apr. 23	Total
1	351	322	375	231	327	344	138	104	57	2249
2	241	198	177	99	47	3	2	15	8	790
3	243	156	171	118	112	43	31	135	72	1081
4	614	258	176	97	43	37	6	32	27	1290
5	239	311	434	350	301	447	268	147	68	2565
6	173	99	74	40	32	30	13	81	47	589
7	174	141	104	67	60	36	15	41	29	667
8	450	458	553	459	349	411	224	226	138	3268
9	437	509	705	822	1041	1212	936	677	415	6754
10	817	829	892	812	890	888	557	336	107	6128
11	304	336	341	260	146	141	29	124	51	1732
12	368	228	131	45	29	11	0	2	6	820
13	952	835	920	606	520	379	135	54	11	4412
14	38	82	140	165	173	248	147	108	42	1143
15	342	109	93	73	91	65	24	66	23	886
16	80	276	218	281	335	493	426	206	95	2410
17	299	236	251	198	157	175	90	141	56	1603
18	177	261	339	339	282	188	107	40	3	1736
19	308	138	279	145	111	64	24	37	19	1125
20	128	102	54	24	19	10	3	31	8	379
Total...	6735	5884	6427	5231	5065	5225	3175	2603	1282	41627

The average yield of gum from these trees for the season is over two kilogrammes, which again is much higher than the general estimate. Trees Nos. 9, 10 and 13 are remarkable for the exceptionally high yield, and the continued increase in exudation throughout nearly the whole season noticed in No. 9 is very interesting. Individual trees vary enormously in this garden also, not only in their total yield of gum, but also in the relative amounts produced at the beginning and towards the latter half of the season. For these differences, as in the case of the younger trees, there was no apparent cause, trees which gave only a small amount of gum being in many cases as large and, so far as one could see, as healthy as others from which a very much larger amount was obtained.

Production from large trees unaffected by early rains

It will be seen that the rain at the beginning of April was followed by no increase in the amount of gum exuded by these large trees. Probably the rain was not sufficient to cause any increased flow of sap, and no new leaves appeared in consequence of it. It might be of interest to tap a few trees about the middle of the rainy season, when they are in full leaf, with a view to seeing if any gum was exuded before the wounds had time to heal up.

Dr. Beam has pointed out in the Third Report of these Laboratories that it is usually considered inadvisable to tap trees on a cold day, and has given the results of some experiments confirming this. It does not seem to be the case, however, that the exudation of gum has a tendency to increase as the season advances and the days become warmer.

Temperature records

Near the end of December Mr. Bisset was kind enough to send me a maximum and minimum thermometer, readings of which I took every day, and it may be of interest to state briefly the variations in temperature for the four succeeding months. A convenient method of doing this, without tabulating the whole figures, will be by giving the absolute and also the average maximum and minimum temperatures during each interval between the collections of gum. This is sufficient to give a fair idea of the weather for each period, as apart from differences of temperature, the conditions remained the same the whole time with the exception of about ten days at the beginning of April when the weather was rather cloudy.

TEMPERATURE AT TAIARA, JANUARY TO APRIL, 1909

Period	Max.	Min.	Average Max.	Average Min.
January 2 to January 19...	97·5° F.	45° F.	86° F.	54° F.
January 20 to February 3	96·5° F.	51° F.	90° F.	58° F.
February 4 to February 17	103° F.	48·5° F.	94° F.	60° F.
February 18 to March 4	104·5° F.	57·5° F.	96° F.	63° F.
March 5 to March 19	110° F.	59° F.	102° F.	64° F.
March 20 to April 4	109° F.	63° F.	104° F.	71° F.
April 5 to April 22	109° F.	65·5° F.	106° F.	71° F.

There was thus a gradual but regular increase in the temperature during these four months, but in spite of this the amount of gum produced declined nearly as steadily. The explanation of this lies probably in the fact that there was a continuous decrease in the amount of sap available for the production of gum.

Dr. Beam has mentioned the fact that the natives are first of all agriculturists, and therefore do not trouble to tap their gum trees until they have secured their crops. If these trees described above be taken as a fair average, however, it would probably pay the owners of gum gardens to take the trouble of tapping them as soon as possible after the rains, an operation which need not take up very much of their time, and in that way it is reasonable to suppose that a considerably larger amount of gum per tree would be obtained, while the money value of the gum from an acre of well stocked gum garden would well repay any extra labour spent in clearing the ground or sowing seed where necessary. The question of increasing the amount of gum produced in a district is comparatively simple, as the factors on which the yield of gum depends are to a considerable extent under control, such as increasing the number of trees and removing those which are too old to produce gum. In view of this it becomes a much more important point to be able to increase the proportion of hard, strong gum which fetches a much higher price than that of lower grades. Unfortunately, the factors which underlie the production of this hard gum are but little understood. Dr. Beam has made a special study of this problem, but failed to find any of this hard, strong gum in a series of collections made in several gardens at Taiara. This may have been due to lack of favourable conditions of temperature and rainfall, wrong season of tapping, or other causes mentioned by Dr. Beam in his article on this subject in the Third Report of these Laboratories. I examined the gum from these two sets of trees above-mentioned, but also failed to find any of this strong gum.

Desirability of producing a hard and strong gum

The following table shows the viscosity and acidity of the gum from the two sets of trees, so far as determined :—

GUM FROM SMALL TREES

Date of Testing	Viscosity of 20 % solution (grammes of sugar in 100 c.c.)	Acidity (milligrammes of KOH)
1st collection, January 21	62·1	2·58
2nd „ January 30	61·4	2·98
3rd „ February 14	66·7	2·80
4th „ February 26	65·3	3·17
5th „ March 18	62·5	2·60
6th „ April 2	61·6	2·95

GUM FROM LARGE TREES

Date of Testing	Viscosity of 20 % solution (grammes of sugar in 100 c.c.)	Acidity (milligrammes of KOH)
1st collection, January 21	61·5	2·24
2nd „ January 30	61·7	2·60
3rd „ February 16	65·8	2·58
4th „ February 28	62·3	2·80
5th „ March 18	61·8	2·43
6th „ April 2	62·4	2·64

An attempt was made at first to test the samples immediately after collection, but the tears of gum were then so tough that they could not be pounded up, and consequently it was not possible to obtain a fair sample. The mixed gum from each collection was therefore allowed to dry in the air for several weeks, and a fair sample of sufficient size taken for examination as soon as it was found to be dry enough to powder. The

Technique for determination of acidity and viscosity

gum then usually contained about 10 per cent. of moisture. The acidity was determined by titrating a weighed amount (about 3 grammes) with decinormal sodium hydrate, using phenol-phthalein as an indicator. The results are expressed as milligrammes of potassium hydrate required to neutralise one gramme of gum. The acidity was always a little higher in the case of the gum from the small trees, but this is unimportant.

The viscosity was determined by using Ostwald's viscosimeter as described by Dr. Beam in the Third Report of these Laboratories. The solutions used contained 20 grammes of dry gum in 100 c.c., allowance being made for the percentage of moisture in the particular sample under examination. The determinations of viscosity were made at 32°C., and the results are expressed in terms of the amount of pure cane-sugar in 100 c.c. required to give the same viscosity. The gum of the third collection from the 20 small trees was slightly ropy when first tested, but in the course of another month it had become completely soluble. All the other samples tested gave a homogeneous solution. The gum in all cases compared favourably with good commercial samples, giving an almost white powder, and a 20 per cent. solution had usually a very pale straw colour.

As a rule, the gum from the small trees had a higher viscosity than that of the same collection from the large trees, but this was not invariably the case. I tested the gum of the earlier collections at intervals during the season, and found a gradual falling off in the viscosity, this being most marked in the gums of the third and fourth collections. On being kept in the sun for a short time a large proportion of all the gum took on the "bleached" appearance of the commercial grade of gum which is exposed to the sun in large quantities at Omdurman. As Dr. Beam has previously remarked, this is not a real bleaching, the appearance being due to the presence of a very large number of minute cracks and fissures on the surface of the tears. This does not occur in the case of the hard, strong gum of high viscosity. Dr. Beam mentioned in his last report that this strong high-grade gum was said to occur more in the collections made very early in the season, about November or December. In the year 1908, however, there was no gum brought into Taiara in the former month, and only a small quantity in December. I was given to understand also that this was the usual condition of affairs there. It may be that in other districts of Kordofan the collection of gum begins at an earlier date, and Dr. Beam, I believe, arranged for a series of collections to be made in different parts with a view to determining whether the presence of hard, strong gum depended on local conditions, such as soil, height and water level in the ground, etc.

"Bleached" appearance due to cracks and fissures of surface

The Effects of Treatment of *Hashâb* Trees on the Yield of Gum

In the *Third Report of the Wellcome Tropical Research Laboratories, Khartoum, page* 422, Dr. Beam gives the results of experiments carried out by him in which he tried the effect of rubbing a moist rag over the bark and then into a cut which was made in the tree instead of the bark being removed. This was done in view of Greig Smith's work on the production of gum by bacteria, the object being to facilitate the entrance of the bacteria to the wound. The result was a complete surprise, however, the yield of gum being considerably less in the case of the trees thus treated than in the control trees. Dr. Beam concluded from this that the rubbing had washed away much of the sap containing the bacteria and therefore rendered infection less complete. This would probably be the effect of such treatment in those cases where only a few bacteria were already present in the tree, and in other cases, as Dr. Beam has also pointed out, the effect would be to wash away the sweet sap, after which there would be less attraction for the ants and flies which carry the infection. At the same time it must be remembered that trees vary enormously

Paradoxical result of attempts to infect the site of tapping in their yield of gum under ordinary circumstances, even though to all appearance they are under similar conditions of health and size, and though they are sufficiently infected to produce a considerable quantity of gum.

Experiments with antiseptics

With a view to supplementing Dr. Beam's experiments in this direction I treated a number of trees both before and after tapping with a number of solutions, and observed the effect of this on the exudation of gum. The trees chosen for this purpose were young trees never previously tapped, in the garden already described. They were nearly uniform in size, neither the smallest nor the largest being used. To make the results more comparable also, the trees were not tapped heavily, as would be the case if a large yield of gum was desired, but a strip of bark about 30 inches long by an inch and a half wide was removed in each case.

It was thought that treatment of the wound with strong antiseptics such as formalin and mercuric chloride would, by killing the bacteria, prevent the exudation of gum. At Dr. Beam's suggestion I also treated the bark of a number of trees with the same solutions before tapping, with a view to finding whether killing the bacteria on the outside of, or near the surface of, the bark would have the effect of preventing the formation of any gum.

Method of Treatment	Dec. 28 1908	Jan. 22 1909	Feb. 13	March 6	March 22	April 13	Total
Control trees	57	83	156	118	95	62	571
Bark treated—							
(*a*) with 10% Formalin	72	106	139	142	121	78	658
(*b*) with 1% Mercuric Chloride	65	98	117	108	84	91	563
(*c*) 5% Potassium Carbonate...	69	102	97	123	128	82	601
(*d*) 5% Acetic Acid ...	58	72	165	127	111	74	607
Wound treated—							
(*a*) 10% Formalin ...	107	218	341	345	293	187	1491
(*b*) 1% Mercuric Chloride ...	41	52	38	31	44	23	229
(*c*) 3% Hydrochloric Acid	112	153	237	228	265	140	1135
(*d*) 5% Acetic Acid ...	76	95	130	132	147	86	666
(*e*) 5% Potassium Carbonate...	93	116	147	153	101	89	699
(*f*) 3% Cane-sugar ...	84	73	109	127	96	114	603

In testing the effect of each solution used, six trees were employed. In those cases where the tree was to receive preliminary treatment, the bark where tapping was to take place was thoroughly rubbed with cotton wool saturated with the solution used, on each of the three days preceding the tapping. In the other cases the wounded surface was rubbed with the solution immediately before tapping and also on the two succeeding days. It was hoped that the whole wound would thus be thoroughly impregnated with the substance in question.

The trees of which the bark had previously been treated were tapped on November 19 and the others on the next day, the temperature on both of these days being about the same, and not too low.

The principal results of these experiments are shown in the table on the previous page, the dates being those on which the different collections of gum were made, while the figures represent the total yield of gum (in grammes) from the set of six trees in each case.

The control trees were not treated in any way either before or after tapping. The formalin solution was made by diluting one volume of "Formalin" (40 per cent.) with three volumes of water. The hydrochloric acid contained one volume of the strong acid to ten of water. The sugar solution was used as it was thought that the bacteria might increase in number much faster if the wounded branch was treated with a suitable medium for their growth.

Increase of sap as response to irritation

The first effect noticed was that exudation of gum began much more quickly from the trees which had been treated after tapping. This is probably due to the fact that these solutions acted as irritants, causing an increased flow of sap to the wounded part. The gum already present in the sap was there exuded within the first week after the trees were tapped, and then the production of gum went on more slowly. The treatment of the bark before tapping cannot be held to have had much effect on the yield of gum. This was probably due to the fact that even strong antiseptics such as formalin and mercuric chloride failed to kill the bacteria in the inner layers of the bark, and they also had little action on the tissues of the tree when merely rubbed on the outside of the bark. The most interesting results are seen in the after-effects of the treatment. Contrary to expectation, the yield of gum was not increased by rubbing the wound with a solution of sugar. There were, most probably, sufficient bacteria in these trees at the beginning of the experiment, or the sap itself was quite suitable as a medium without the addition of any extra constituents. Probably, also, the mere question of sufficient infection has not alone to be considered, as the sap ceases to flow in some trees much sooner than in others, speaking at least from the much longer time which some trees keep their leaves.

Mercuric Chloride proved to inhibit gum-production

It will be noticed that treatment with mercuric chloride almost entirely prevented the further production of gum. This is specially interesting in view of the bacterial origin of gum. When the solution had dried up, the tissues would still remain impregnated with the antiseptic, in consequence of which any bacteria brought to that part would immediately be killed, and would therefore be unable to produce any gum in spite of the lessened resistance of the tissues to bacterial action through wounding. Later in the season I tapped a number of trees on two branches, treating one branch only with mercuric chloride. As a result the branches thus treated exuded no more gum, while the control branches kept on doing so. The trees treated with formalin after tapping continued to give a much larger yield of gum than the control trees. In this case, while the formalin would at first kill any bacteria present, this solution would soon entirely evaporate, and fresh bacteria would be brought to the spot in the sap. The increased flow of sap to an injured branch probably continues until the injury is repaired, which would account for the large yield of gum after formalin treatment. This would account for the increase after treatment with hydrochloric acid. The other solutions used would probably have less effect in injuring the branches, and therefore the flow of sap to these parts would not be markedly increased, thus to some extent explaining the fact that the exudation of gum was not greatly affected in those cases.

Formalin leads to an increase

It must be remembered that the explanations given above of the action of formalin, etc., are largely tentative, owing to the difficulty of being certain that all the trees under observation were exactly comparable at first, and that the flow of sap would have been the same in each set of trees under ordinary conditions.

Dr. Beam has dealt fully with the question of the yield of gum when trees are tapped in various ways. At his suggestion I tapped several by making a series of cuts with an axe, these cuts being arranged spirally around the tree from the ground upwards, and also along the branches. Only a piece of bark about eight inches long by an inch and a half wide was removed. These trees, however, did not exude any more gum than a similar set tapped in the ordinary way at the same time.

Production of Gum by Bacteria

As mentioned in the *Third Report of the Wellcome Tropical Research Laboratories, Khartoum*, the question of the bacterial origin of gums was first investigated by Greig Smith in Australia. I described briefly in that Report a few experiments carried out in Khartoum with a view to confirming Greig Smith's conclusions in the case of *Hashâb* gum. Being unable, in the time at my disposal in Khartoum, however, to reach conclusive results, I took the opportunity of pursuing the matter further at Taiara. The procedure was the same as already described, twigs from which gum was exuding being passed through the flame in order to kill any bacteria accidentally adhering to the outside of the bark, and from these cultures were made in tubes of glucose gelatine. After about 24 hours' cultivation at 37° C. the growths were plated on media containing cane-sugar, asparagin, potassium citrate and agar. No potato extract was used in these media, as was done in the earlier experiments. A large number of twigs was treated in this manner at different times of the season, and in every case the predominant bacterium showed the same habit of growth and the bipolar staining of the bacterium which I had already isolated in my experiments in Khartoum. In a number of cases, particularly where the gum had been exuding from a small puncture in the bark only, the original plate culture showed this bacterium with no contamination, while in the other cases, by sub-cultivation on the same medium, a pure culture was readily obtained. From these and my previous experiments, it seems justifiable to assume that this bacterium is always present in gum-bearing branches of *hashâb* trees. I also succeeded in isolating it free from contamination from branches showing no wound, and from which no gum was exuding. It seems improbable, however, that any trees in a gum-producing district are absolutely free from gum, as it was noticed especially towards the latter half of the season that nearly all the trees, even those which had never been tapped, were exuding a small amount of gum. This was very often in the form of thin rods or spirals of gum, and an examination of the spot showed the presence of a slight wound, caused in many cases by the accidental breaking of a small twig, or again, by the borings of small beetles or other insects. With respect to this latter point it may again be stated that Zimmermann connects the formation of gum in the case of *Acacia decurrens* with the borings of Ambrosia beetles, mentioning also that in all cases of gum production the essential point is, in the first place, some injury to the tree.

Bacteriological technique, and discovery of the probable bacterial cause

On tapping the trees in the early part of the season I noticed that within a few hours a large number of ants were usually to be seen swarming over the wounded surface of the branches, attracted, no doubt, by the sweetness of the sap. Dr. Beam also called my attention to the fact that he had observed the presence of large numbers of ants after tapping some trees in connection with a series of experiments carried out by him up the Blue Nile. Besides the ants, flies of several kinds were observed on the wounded surfaces soon after the trees had been tapped.

Presence of ants where trees have been tapped, and their possible rôle as "carriers"

These facts at once suggested a means by which this particular bacterium might readily be transmitted from one tree which had been tapped to another, or, indeed, a wound of any kind might serve as a point from which ants or other insects could pick up infection, or on the other hand bacteria conveyed by insects to a wounded surface could readily obtain a hold in the tissues of the tree at that point. It was important, therefore, to find whether such an infection was thus capable of being conveyed from tree to tree under ordinary circumstances. Some flies were caught after being seen apparently feeding on the recently tapped surface of a branch. These were killed and introduced into sterile test-tubes, a few c.c. of sterile water being then added. After being left thus for a few hours, a loopful of the water was introduced into sterile tubes of gelatine media containing sugar. These were then cultivated at 37° C. for a day. In some cases the flies were put direct into the tubes of gelatine. In all cases, cultures were made from the gelatine on plates of saccharose agar, as was done with the gum-bearing branches. Among the colonies obtained from the flies in this way was a number showing the same appearance as those produced by the bipolar staining organism already isolated. A further examination of these colonies revealed the presence of this organism, which showed all the properties of that obtained from the twigs. An examination of some ants obtained from tapped branches also showed the presence of this bacterium. The method of transmission from tree to tree is probably simply mechanical, the legs and wings of the insects picking up small quantities of sap containing the organisms, some of which are conveyed to the exposed surface of the next branch on which the insect alights.

Recovery of implicated organism from flies and ants

Having proved the invariable presence of these bacteria in gum-bearing branches, and having also found a ready means for their transmission from one tree to another, the question of the production of gum from the sap of the tree by these organisms had next to be investigated. The best way to do this seemed at first sight to be by growing the organisms in the sterilised sap of the *hashâb* tree itself. It was found impracticable to obtain this in any quantity by pressure, so the following method was adopted. One or two young trees from which no gum was exuding were cut down and the branches chopped into lengths of about two inches. These pieces were bruised, put in a steriliser with water, and boiled for a short time. The water was then poured off and the extraction repeated, the two extracts being mixed and concentrated. The resulting liquid represented a somewhat diluted sap, but on filtering off the dirt, bark, etc., it was found also to contain a considerable quantity of gum. This liquid was therefore unsuitable as a medium for testing the gum-producing powers of the bacteria, as it would have been very difficult with the means at my disposal to estimate with any degree of accuracy the proportion of gum present before and after the experiment. An artificial medium was therefore used, which had been found suitable for the cultivation of the bacteria in tubes and on plates. This contained 4 per cent. levulose, 1 per cent. glycerine, 0·1 per cent. asparagin, and 0·1 per cent. potassium citrate in water. I preferred using a liquid medium to a solid one containing agar in addition to these constituents, as in the latter case there is a danger of some agar getting scraped off when removing the slime produced by the bacteria, and this may give, on hydrolysis, products resembling those derived from gum.

Production of a gum-like substance "in vitro" by action of bacteria

The above medium, after being sterilised, was inoculated from a pure culture of the bacterium and kept at 37° C. for about a month. The growth was then stopped by heating the flask in the steriliser for half-an-hour. The liquid was then concentrated to half its original volume over a small flame, a few drops of dilute sulphuric acid being added towards the end in order to precipitate any substances of a protein nature which might have been formed by the bacteria. The liquid was then filtered, and to the clear filtrate, on cooling, was added three times its volume of alcohol. The whole was well stirred up and allowed to settle, after which the supernatant liquid was poured off, the remainder being filtered and the precipitate washed with 75 per cent. alcohol. This precipitate was redissolved in a little water, brought down again with a large excess of alcohol, filtered off, washed with alcohol and dried.

The final product was nearly white and resembled gum in appearance. From the method of its separation described above it will be seen that this substance also resembled gum in being soluble in water and insoluble in 75 per cent. alcohol. Levulose is readily soluble even in alcohol of a much higher strength, and any of this sugar which had been unchanged by the bacteria would remain in solution when the product of bacterial action was precipitated at first. The same is true of the other constituents of the original medium, and, in addition to this, the amount of asparagin and potassium citrate used was so small that the new substance could only be accounted for by having been derived from the levulose, and perhaps to some extent from the glycerine, any products of a protein nature being removed in the treatment of the original solution with acid and afterwards with alcohol.

Properties of the gum-like bacterial product

The bacterial product did not reduce Fehling's solution, but on boiling a solution of the former in five per cent. sulphuric acid for twenty minutes and then neutralising this, a good reduction took place, showing another point of resemblance between this bacterial product and the gums exuded from tapped trees. Some of the ordinary gum tests were also tried, such as coagulation with basic lead acetate and ferric chloride, and these gave positive results. From the examination of this bacterial substance, therefore, we must assume that these bacteria, when grown in an artificial medium of suitable composition, produce, among other things, a substance of the same nature as the gum of the tree from which they have originally been isolated. The formation of gum from the sugars of the sap is thus, as Greig Smith pointed out, the result of pathological conditions. In the first place, exudation of gum does not take place from *Hashâb* trees in those districts where the rainfall is high compared with that met with in the gum-producing districts of Kordofan. In the latter case the tree as a whole is in a state of reduced vitality, and the tissues are therefore more susceptible to the effects of abnormal injuries. In those districts where the proportion of moisture in the soil is relatively high, the injury produced when the tree is tapped is repaired before the bacteria present have time to produce any appreciable amount of gum. The wounding of the tree through tapping causes a local weakness in the tissues next to the bark, and the cells of the tree are then unable to prevent the rapid increase of, and increased transformation of the sap by, the bacteria. This appears to go on until sufficient new bark has grown over the wound to form a protection for the exposed surface. In the case of a tree which was quite free from bacteria, it has already been shown how infection can readily be carried by means of ants or flies.

Effect of mechanical injury to the trees

Since my return from Taiara, I have confirmed my work there, both in obtaining pure cultures of this bacterium from gum-bearing branches of *hashâb* trees, and also in producing a substance of the nature of a gum by cultivating the bacteria on artificial media containing sugar as the principal constituent. I regret, however, that I have been unable up to the present to investigate the properties of these bacteria at all fully. They grow equally well on glucose and levulose media, but not so well on maltose and other sugars, and they do not appear to form a very adhesive slime. Greig Smith found his bacteria to produce slime more readily in presence of tannin, but the *hashâb* bacteria do not grow at all well in media containing tannin.

Acting on a suggestion made by Dr. Beam, I obtained, through the kindness of Mr. Tippetts, Inspector at Taiara, some gum-bearing branches of *talh* trees from Sherkeila, and made cultures from small portions of these in the manner already described. It is of great interest to note that by far the largest number of colonies obtained in this case also were those of the same bipolar bacteria isolated from *hashâb* branches. In this connection it is well to recall the fact that Greig Smith

Isolation of the characteristic bacteria from *Talh* trees states that the bacteria found responsible for gum-flux in *Acacia binervata* also caused production of gum (of a different kind) when made to infect peach trees. In other instances, also, he found that one species of bacterium could produce gum in the tissues of different species of trees.

In cases of this kind the differences in the chemical nature of the gums are probably due to the presence of different sugars or other constituents in the sap of the various trees.

In concluding this report, I wish again to express my thanks to Dr. Balfour and Dr. Beam for suggestions and advice which they have kindly given me in connection with my work.

Preliminary Notes on the Chemistry of the Latex of Calotropis procera

BY

James Thompson, Ph.D. (Heidelberg), F.I.C.

Senior Assistant Chemist, Wellcome Tropical Research Laboratories

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This investigation was undertaken, primarily, with the object of discovering a test which could be relied on in cases of suspected poisoning. *Calotropis procera*, a shrub belonging to the Nat. Ord. *Asclepiadaceæ*, is a common weed throughout the Sudan, and under the name of "ushar" is well known to the natives as a poisonous plant. When wounded, all parts of the plant exude considerable quantities of an acrid milky juice, possessing a nauseating odour, in some degree reminiscent of rhubarb. The leaves are used in the preparation of "merissa," the native beer, and it is possible that the presence of an excessive quantity, whether there by criminal intent or not, might account for cases of apparent poisoning, which had been investigated in these laboratories with negative results. In India, under the popular name of "madar," or "ákh," *Calotropis procera* has long been famous as a remedy in a variety of ailments, the milky juice, root-bark, and flowers being in use. A detailed description of the plant and its medicinal uses is to be found in the *Pharmacographia Indica*, Vol. II., *pages* 428–437. The attached photographs (Figs. 9 and 10) give a good idea of the plant, the first showing leaf, flower and seed-pod, and the second the entire plant.

Previous work on the subject

While considerable work has been done on the chemistry of the root bark,[1] the literature at my disposal records no similar examination of the latex, nor has communication with several sources revealed that any such examination has been made. In this connection, one is greatly indebted to Dr. Power and Mr. C. J. S. Thompson of the Wellcome Chemical Research Laboratories, London, for their kindness in furnishing valuable extracts of the literature on the subject.

So long ago as 1867, in consequence of the numerous cases of infanticide by the milky juice, Dr. McReddie, Medical Officer of Hurdur, India, suggested that an investigation should be made with a view to the detection of this poison by chemical analysis, but no record that his suggestion was acted on is to hand.

Dr. Duncan[2] (1829) made a chemical examination of the root-bark, and concluded that its medicinal activity was due to an extractive matter which he termed "*mudarine*." The authors of the *Pharmacographia Indica*,[3] repeating the work of Duncan, failed to obtain anything corresponding to his *mudarine*, but, instead, an acrid resin, with which was associated a bitter principle, probably the active constituent of the plant. Drs. Warden and Waddel,[4] after a lengthy research, concluded that a yellow, bitter resin, occurring to the extent of 0·093 per cent., was the active principle.

The resins and bitter principle described by these various investigators being in all probability derived from the dried latex present in the root-bark, a thorough examination of

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[1] *Pharmacographia Indica*, Vol. II., pp. 428–437

[2] Duncan, *Edinburgh Medical and Surgical Journal*, 1829, XXXII., 65

[3] *Pharmacographia Indica*, Vol. II., pp. 428–437

[4] Warden and Waddel, *Pharmaceutical Journal*, 1885, pp. 165–170

the latex itself may be expected to furnish valuable evidence as to the precise nature of the toxic principles of the plant. It is worthy of note that experiments carried out in India[1] indicate that, while the fresh leaves are extremely acrid, producing severe vomiting accompanied by much pain and distress, the cooked leaves are innocuous, and the writer has observed goats and sheep eating withered parts of the plant, while the natives affirm that they will not touch the fresh plant.

Uses of the juice for making an intoxicating liquor

The milky juice of *C. procera* is undoubtedly used in the preparation of an intoxicating liquor, both in India and in Central Africa, but it is impossible to gather whether the juice itself is directly fermented or is simply used as a ferment or bitter. Sir G. Birdwood (*Bomb. Prod.*, 208) says, "the intoxicating liquor *bar* is prepared from it by the tribes of the Western Ghâts," and Lisboa, in *Useful Plants of Bombay*, asserts that the tribes of Central Africa prepare from it their *giya*.

A Colour Reaction for the Latex of Calotropis Procera

When the latex is diluted with four volumes of water, and a few drops of acetic acid added, and the liquid boiled, coagulation readily takes place, and by straining off the coagulated gutta-percha and filtering, a clear, pale yellow liquid, of decidedly acid reaction to litmus, is obtained. To this liquid, and to the residue left on its evaporation, were applied the customary reagents giving colour reactions. Those having strong sulphuric acid as a basis—Erdmann's, Fröhde's, Buckingham's, Mandelin's, etc.—were found to give, with the liquid, green to blue colorations; of the many others tried, none gave any reaction worthy of note. When sulphuric acid, diluted with one half its volume of water to prevent charring, is carefully added to the liquid, a greenish-blue ring is formed, and, on carefully mixing the liquids, a bluish-green solution results. The addition of traces of oxidising agents causes a change of colour to a deep Prussian blue. Ferric chloride has been found the most suitable oxidiser, the blue colour produced in its presence being comparatively stable, lasting for two or three hours, and then changing slowly to a dark brownish-purple. The more energetic action of such oxidisers as hydrogen peroxide, nitric acid, chromic acid, and sodium persulphate, even when these are present only in minute traces, results in a quick change of the blue colour to dark green, then greenish-brown and finally deep yellow. In the presence of nitrates the blue colour rapidly changes, owing to the formation of nitric acid, while the presence of nitrites prevents its production, the deep yellow colour being at once developed.

Details of the reaction

The reagent found to give the most satisfactory results is prepared by diluting sulphuric acid with one half its volume of water, and adding sufficient ferric chloride to impart a faint yellow colour to the liquid. A mere trace of ferric chloride is not sufficient to develop the blue colour; on the other hand, excess is to be avoided, as any marked yellow colour of the reagent would interfere. The reagent is added carefully in equal volume to the liquid to be tested; a deep blue ring forms at the junction of the liquids, and, on mixing, a deep Prussian blue colour is developed. A decided blue colour is given by the reagent to 1 c.c. of a liquid containing one part of latex in 250 parts. Sulphuric acid alone gives no coloration when added to a latex solution of this strength, but the subsequent addition of a drop of ferric chloride solution brings up the blue colour.

The substance which gives rise to the blue colour on the addition of sulphuric acid and an oxidising agent, appears to be present in the latex in very minute quantity, and has not yet been isolated. The following facts regarding its properties have, however,

[1] Harvey, *Report on Medico-legal Returns, Bengal Presidency*, 1870–1872

W. Beam

Fig. 9.—*Calotropis procera* SHOWING LEAF, FLOWER AND SEED-POD

J. Thompson

Fig. 10.—*Calotropis procera* SHOWING ENTIRE PLANT

been established. It is not removed from its solution by ether, chloroform, or petroleum-ether, but is completely precipitated by basic lead acetate in the presence of ammonia, the lead salt being soluble in excess of lead acetate.[1] Neutral lead acetate, in the presence of acetic acid, does not precipitate the substance, nor does basic lead acetate when added to a solution faintly acid with acetic acid (the free acetic acid is, of course, neutralised by a portion of the basic lead acetate). After reduction with zinc and sulphuric acid, its solution gives no coloration with sulphuric acid; on reoxidation, the blue colour is produced. The substance may be removed from its solution by boiling with animal charcoal, and is dialysable.

Application of the test in cases of suspected poisoning

As regards the application of the test to cases of suspected poisoning, it is, of course, essential that a solution of the latex free from substances which would give colorations with the reagent, and so obscure the reaction, be obtained. Several experiments have been carried out, which have led to the adoption of the following method. The stomach contents, and, where emesis has occurred, the vomit, are digested in water slightly acidulated with acetic acid. To the strained liquid is added slight excess of neutral lead acetate, to precipitate albuminous matter, and the liquid filtered. The filtrate is carefully treated with basic lead acetate until no further precipitation results, and, after filtration, the liquid is made distinctly ammoniacal. The resultant precipitate is filtered off, carefully washed, and decomposed with dilute sulphuric acid. The liquid is filtered from lead sulphate, and the reagent applied to the filtrate, which may be concentrated if necessary.

Experiments have shown that, by following this method, 0·5 c.c. of the latex may be readily detected when mixed with stomach contents. In most cases it will be found that the treatment with basic lead acetate and ammonia may be omitted, and the reagent applied direct to the filtrate from the neutral lead acetate, after freeing it from lead by the addition of dilute sulphuric acid. In cases where the volume of liquid to be tested is considerable, the treatment with ammoniacal basic lead acetate is advisable, since concentration of the liquid is thereby rendered unnecessary, the resultant precipitate being decomposed by the addition of a small volume of dilute sulphuric acid. The addition of the latex to *merissa* (the native beer made from millet) is easily demonstrated by applying the reagent direct to the filtered liquid. Should the latter be coloured, the preliminary treatment with lead acetate, indicated above, would be necessary.

Addition of latex to native beer is easily detected by the reagent

Latex, which has been thoroughly dried by exposure in an open vessel, is found to respond to the test after digestion with water. The concentration of dilute latex solutions by boiling does not affect the production of the blue colour by the reagent, nor does digestion of the latex with pepsin and dilute hydrochloric acid.

The action of the stomach juices on the latex being of primary importance as regards the value of the test in cases of suspected poisoning, the following experiment was carried out. An artificial gastric juice was prepared by digesting the fresh stomach of a sheep in water, and adding to the strained liquid sufficient hydrochloric acid to give it an acidity of 0·2 per cent. hydrochloric acid. To 100 c.c. of this liquid was added 10 c.c. latex, and the liquid incubated at 37° C. Portions of 25 c.c. each were removed at intervals of 24 hours and the test applied. The treatment with lead acetate, etc., previously described, was employed, a control test being applied to the gastric juice itself. From the liquid, to which latex had been added, positive reactions were obtained in each case, while the gastric juice itself gave no coloration with the reagent.

[1] When this lead compound [(d.) Table A, seq.] is decomposed by sulphuretted hydrogen or dilute sulphuric acid, a strong solution of the colourable substance of the latex, to which test reagents may be advantageously applied, is obtained.

The possibility that plant juices, other than those of *C. procera*, may give a similar reaction, has not been overlooked, and special attention has been devoted to the examination of foodstuffs in common use among the natives, and which might, therefore, be present in the stomach contents of suspected cases. The test has been applied to between twenty and thirty varieties of *dura*, which is the staple food in the Sudan, and to as many common vegetables and fruits. The foodstuffs were crushed, macerated for several hours in 0·2 per cent. hydrochloric acid, and the reagent added to the strained and filtered liquids. The pale-coloured varieties of *dura* gave no ring or coloration on shaking. In the case of the red varieties, however, a pink ring was developed, and a deep crimson solution obtained on shaking. A strong extract of a red variety of *dura*, to which a small amount of latex had been added, gave with the reagent a purple coloration, as was to be expected. Further examination of the *dura* extract showed that the red colouring matter is entirely removed by basic lead acetate when added to a faintly acid solution. Since the colourable substance of the latex is not so precipitated, the presence of red *dura* in no way interferes with the test, as several trials on red *dura* extracts to which small quantities of latex had been added, have proved.

Examination of foodstuffs to exclude possibility of confusion

Of the other foodstuffs examined, none was found to give the deep Prussian blue colour produced by the latex. The majority gave pale yellow or greenish-yellow rings, and pale yellow colorations on shaking. Two, the cucumber and sweet potato (Arabic, *bambé*) give pale blue rings, and pale blue colorations. The pumpkin (Arabic, *gara*) gives a purplish-blue colour, and the vegetable marrow a yellowish-green. This latter colour was found to mask the colour given by the latex when the reagent was added to a mixture of a very small quantity of latex and a large quantity of vegetable marrow, a green tint being imparted to the blue. With the latex in larger proportion, the green tint was not seen.

The foodstuff extracts were also treated with lead acetate, etc., as previously described (*vide page* 88), and the reagent applied to the decomposed ammoniacal basic lead acetate precipitates. Some differences in the colour reactions given were observed. The cucumber gave a pale blue colour, which changed slowly to pale pink, and the pale blue colour given by the sweet potato was rapidly discharged. The vegetable marrow gave no ring or immediate coloration, but a strawberry-pink colour developed on standing. The pumpkin gave a pale heliotrope colour, becoming more pronounced, and then fading. In all cases the colour faded comparatively quickly; a solution of latex similarly treated gives a Prussian blue colour, which does not fade until after some considerable time. In carrying out these tests the liquids were not cooled after shaking, and the fading of the colours in the case of the vegetables may be due to the heat developed. It is worthy of note, however, that the blue colour of the latex does not readily fade under these conditions.

It is to be borne in mind that the degree of dilution of the latex, when no interfering body is present, determines whether the blue coloration can be correctly described as Prussian blue. Dilutions of 1 in 5 to 1 in 25 give an unmistakable Prussian blue, 1 in 50 gives a pale Prussian blue, while 1 in 250 gives what could be described as a pale blue, although of exactly the same tint as a much diluted solution of Prussian blue.

Effects of dilution on the Prussian blue coloration

The depth, purity and permanence of the blue colour given by the latex are quite distinctive, but a confirmatory reaction has been discovered which eliminates any risk of mistaking these foodstuff colours for the colour of the latex, and also enables the latex to be detected with certainty when mixed with these foodstuffs.

A very striking colour-reaction, which, so far as is at present known, is characteristic of the latex, is given by sulphuric acid containing a trace of formaldehyde. The reagent found to give the best results consists of a mixture of 75 c.c. concentrated sulphuric acid and 25 c.c. water, to which is added a drop of 40 per cent. formaldehyde solution. When this reagent is added (not too carefully, so as to allow slight mixing) to the coagulated latex, or to the decomposed ammoniacal basic lead acetate precipitate [(d) Table A], a grass-green ring or band is developed. Almost immediately a strawberry-pink band begins to form below the green, gradually deepening, and, after allowing to stand for a short time, super-imposed bands of colour are seen in the following order, from below upwards: pale strawberry-pink, deep strawberry-pink, purple (narrow ring), grass-green, chrome-yellow. On now cooling in ice, and carefully shaking, a bright olive-green solution, of decided depth and permanence of colour, is obtained.

A confirmatory test

This reagent has been applied to the four foodstuffs, which give colorations with the sulphuric acid reagent simulating in some degree the blue colour given by the latex. Both strong water extracts, and similar extracts treated with lead acetate, etc. (*vide* Table A seq.) were tested, and in no single case was any coloration produced. The formalin-sulphuric acid reagent thus furnishes a certain means of distinguishing the latex from these foodstuffs, and of detecting it in their presence.

The application of this reagent as a test is being extended to other foodstuffs.

The solution of the colour-yielding substance of the latex obtained by decomposing the ammoniacal basic lead acetate precipitate with sulphuric acid (*vide* footnote, *page* 88) has also been submitted to the action of reagents in the following manner. After making faintly alkaline with ammonia, small portions were evaporated on crucible lids to dryness. To the dried residues were added a number of the customary colour reagents; the most striking colour reactions obtained are given below.

(*a*) Sulphuric acid :—yellow, changing to orange and finally to rose-pink.

(*b*) Fröhde's reagent :—bright greenish-blue, changing at once to grass-green, then slowly to mahogany-brown and finally olive-green.

(*c*) Sulphuric acid and ferric chloride :—electric blue, changing at once to green then brown and finally dark olive-green.

(*d*) Sulphuric acid and trace of formalin :—purplish, then rose-pink.

Speaking generally, sulphuric acid with oxidising agents gives blue and green colours, while, with reducing agents, sulphuric acid develops yellow and pink colorations.

Analysis of the latex

The latex of *C. procera* is distinctly acid in reaction; the acidity to phenol-phthalein of eight samples, expressed in terms of acetic acid, was found to vary from 0·13 gramme to 0·23 gramme per 100 c.c. One sample, collected from several plants, showed an acidity of 0·46 per cent. These differences are probably due to the age of the plants. Steam distillation of the latex showed this acidity to be fixed.

A sample of latex, collected from several plants, gave the following figures on analysis :—

Acidity, as acetic acid	0·15 gramme per 100 c.c.
Total solid matter	13·0 per cent.
Ash	2·4 per cent.

The ash consisted chiefly of magnesium, calcium, sulphates, and phosphates, and was distinctly alkaline. The magnesium was present in far larger quantity than the calcium.

Exhaustion of the latex, by Adam's fat-extraction method, with alcohol, petroleum-ether, and acetone in succession, yielded a considerable extract to the alcohol, and comparatively little to petroleum-ether and acetone. The petroleum-ether extract was varnish-like, almost colourless, and acrid in taste. The alcoholic extract was only partly soluble in cold water, but soluble in hot. This solution gives a deep blue colour with the diluted sulphuric acid reagent. If water be added to the alcoholic solution previous to evaporation of the alcohol, a bright yellow, acrid resin is obtained.

On reducing the coagulated latex with zinc dust and acetic acid, a liquid is obtained, which, after removal of the zinc by sulphuretted hydrogen, gives no coloration with sulphuric acid, unless previously reoxidised. Concentration of this liquid leaves an amorphous brownish residue, and a considerable crop of silky needle-like crystals of calcium sulphate. Extraction of the liquid with solvents revealed no organic substance of a crystalline nature.

Summary of results

The following tables give in summary form the results of the experiments carried out to gain some information as to the character of the substance in the latex to which the blue coloration, produced by sulphuric acid and an oxidising agent, is due. From 100 c.c. to 200 c.c. of the latex were taken for each experiment, so that concentrated solutions were obtained.

TABLE A

LATEX

Added 4 volumes of water and a few drops of acetic acid, and heated on the water-bath to coagulation. Strained and filtered.

<table>
<tr><td rowspan="4">GUTTA-PERCHA, and associated resinous bodies, etc.</td><td colspan="4">FILTRATE.† Added slight excess of neutral lead acetate, and filtered.</td></tr>
<tr><td rowspan="3">HEAVY WHITE PRECIPITATE. Washed well with water and decomposed with dilute sulphuric acid. Solution °</td><td colspan="3">FILTRATE (a).† Added slight excess of basic lead acetate, and filtered</td></tr>
<tr><td rowspan="2">PRECIPITATE. Washed well with water and decomposed with dilute sulphuric acid. Solution °</td><td colspan="2">FILTRATE (b).† Added excess of ammonia = bulky yellowish-white precipitate. Filtered</td></tr>
<tr><td>PRECIPITATE (d). Washed, and decomposed with dilute sulphuric acid. Solution †</td><td>FILTRATE (c) °</td></tr>
</table>

† indicates positive reaction with reagent
° ,, negative ,, ,,

TABLE B

LATEX

Added 4 volumes of water, and a few drops of acetic acid, and coagulated. Strained and filtered.

<table>
<tr><td rowspan="2">GUTTA-PERCHA, and associated resinous bodies, etc.</td><td colspan="2">FILTRATE.† Digested on the water-bath for several hours with animal charcoal, and filtered</td></tr>
<tr><td>CHARCOAL RESIDUE (a)

Washed with cold water, dried over sulphuric acid, and extracted thoroughly with absolute alcohol. Alcoholic solution.†</td><td>FILTRATE ° (b)</td></tr>
</table>

† indicates positive reaction with reagent
° ,, negative ,, ,,

The time at disposal has not permitted of any thorough investigation, but the following observations have been made. The acid liquid [(a) in Table A] left after the removal of the lead salt was treated with ammonia until no further precipitation took place. After filtration, the alkaline liquid was boiled until free from ammonia, and the lead removed by sulphuretted hydrogen. The liquid was freed from sulphuretted hydrogen by a current of air, filtered, and concentrated. This concentrated liquid gave amorphous precipitates with tannic and picric acids, mercuric chloride, iodine, Meyer's reagent, and phosphomolybdic acid, and with basic lead acetate, the latter being soluble in excess. The tannic acid precipitate was soluble on boiling, reappearing when the solution was cooled, a reaction characteristic of the proteids. The examination of this liquid is proceeding.

Further examination

The lead compound [(d) Table A] produced by the addition of ammonia and basic lead acetate to the filtrate from neutral lead acetate was washed, suspended in water, and decomposed by sulphuretted hydrogen. After filtration, and removal of excess sulphuretted hydrogen by a current of air, the solution was concentrated on the water-bath. This concentrated solution gave a deep blue coloration with the sulphuric acid reagent. Attempts to obtain from it anything of a crystalline nature were unsuccessful; on evaporation to dryness a brown amorphous residue was obtained.

The charcoal residue [(a) Table B], previously washed with water, and dried over sulphuric acid, was extracted with absolute alcohol, and the alcoholic solution evaporated to dryness. A small quantity of a brown, gummy, and somewhat resinous residue, acrid to the taste, and only partially soluble in cold water, was left. This was dissolved in hot water, cooled and extracted with ether. The aqueous liquid, which was distinctly acid to litmus, did not reduce Fehling's solution, even after hydrolysis, but gave voluminous precipitates with tannic acid, picric acid, mercuric chloride, iodine, potassium-bismuthic-iodide, and phosphomolybdic acid, and a deep blue colour with the sulphuric acid reagent. The precipitates were amorphous, and the picric acid precipitate was soluble on boiling, re-forming on cooling. The ethereal liquid left a small quantity of a resin-like substance on evaporation.

On making the aqueous liquid alkaline with ammonia and extracting with ether, a white amorphous residue, sparingly soluble in ether, insoluble in cold water, but readily soluble in alcohol and chloroform, was obtained. This substance has not yet been further examined.

The filtrate from the animal charcoal [(b) Table B] was evaporated on the water-bath to a syrupy consistency, and allowed to evaporate slowly over sulphuric acid. A large quantity of crystalline salts was deposited, extremely soluble in water, but insoluble in alcohol. On evaporating the syrupy liquid to dryness, a yellow, crumbly, sugar-like mass remained, which charred on heating in a dry tube, with the formation of an amorphous sublimate, soluble in cold water, and strongly acid to litmus. The charred residue was alkaline, and consisted chiefly of magnesium oxide.

Toxicity of the Latex

Toxicity

Animal experiments

Experiments have been carried out to determine the toxicity of the latex by subcutaneous injection and by feeding. Rabbits were the only animals used in these experiments. With regard to subcutaneous inoculation, one rabbit was inoculated with a quantity of the decomposed ammonium hydrate precipitate [(d) Table A] corresponding to 0·2 c.c. latex. Another rabbit was inoculated with the filtrate from the basic lead acetate precipitate [(c) Table A] corresponding also to 0·2 c.c. latex. A third rabbit received an inoculation corresponding to 0·5 c.c. latex of the filtrate [(b) Table B] from animal charcoal, while a fourth was inoculated with 0·5 c.c. of the water solution of the alcoholic extract [Table B]. In all cases the animals remained quite well, and showed no symptoms of illness.

Feeding experiments

With regard to the feeding experiments, the fresh latex was slowly dropped from a pipette into the mouth of the animal. In the first experiments, doses of 0·05 c.c. and 0·3 c.c. were given, but these produced no effect. Larger doses were then tried, 1 c.c. (2) 1·5 c.c. (1) and 2 c.c. (2) being given. The rabbits receiving the 1 c.c. doses showed no symptoms. One of the rabbits receiving the 2 c.c. quantity showed, almost immediately, paresis of the hind legs and died in 20 minutes. Post mortem examination showed slight congestion of the mucous membrane of the stomach, but no other pathological change. The stomach contents were tested for the presence of the latex, and gave a positive result.

The other rabbit receiving 2 c.c., and the one receiving 1·5 c.c., showed no symptoms during the time they were under observation—viz., six hours—but died during the night. A rabbit receiving 2 c.c. of latex which had been digested in boiling water for half-an-hour also died. Post mortem examination showed no pathological change in the organs; the contents of the intestines were, however, semi-liquid. The stomach contents were tested for the presence of the latex, with a positive result where the 2 c.c. fresh latex had been given, and negative results in the case of the 1·5 c.c. fresh latex and 2 c.c. boiled latex.

A rabbit fed with 2 c.c. of fresh latex, from which the gutta-percha had been removed by coagulation, remained well.

So far as can be judged from the experiments yet carried out, the fresh latex of *C. procera* is toxic to rabbits when given by the mouth in doses greater than 1 c.c. per kilo body-weight. In smaller doses it produces no toxic symptoms whatever.

Conclusions

The fact that 2 c.c. of boiled latex proved toxic, while 2 c.c. of latex from which the gutta-percha had been removed, was non-toxic, indicates that the toxic bodies are in all probability the resins or other bodies associated with the gutta-percha, but further experiments are necessary before any definite conclusions can be arrived at.

I desire to acknowledge my indebtedness to Captain R. G. Archibald, R.A.M.C., and Lieutenant W. E. Marshall, R.A.M.C., for their assistance in the toxicological experiments.

[*Editor's note.*—The continuation of the above research by Dr. Thompson was unfortunately prevented by his illness and retirement from these laboratories. The extent to which the colour tests mentioned may be relied upon in cases of suspected poisoning remains, therefore, to be determined. Attention should especially be called to the fact that the production of a violet colour on the addition of sulphuric acid containing a small amount of iron constitutes Hehner's test for formaldehyde in milk and that the colour described above as "strawberry" is yielded by sulphuric acid, formalin and peptone. The last named is a common constituent of stomach contents so that the possibility of error from this source must be borne in mind. In the presence of proteids and of vegetable matters it may be found that a reaction simulating that of the above confirmatory test might be produced, or again that the colour due to these might mask that of the latex. These points are now under investigation. In any case, the reactions described are useful presumptive indications of the presence of *ushar* latex.]

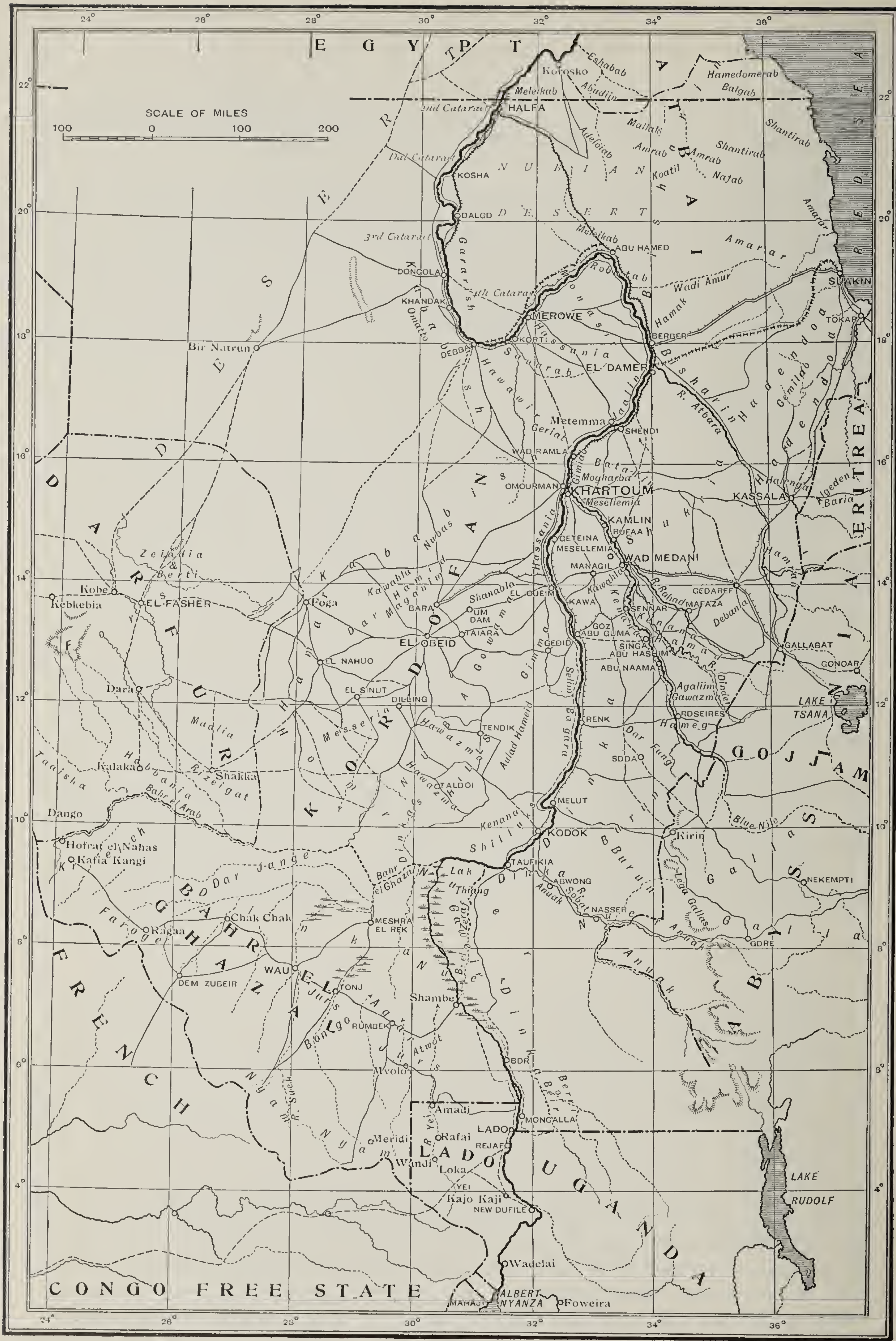

FIG. 11.—MAP OF ANGLO-EGYPTIAN SUDAN

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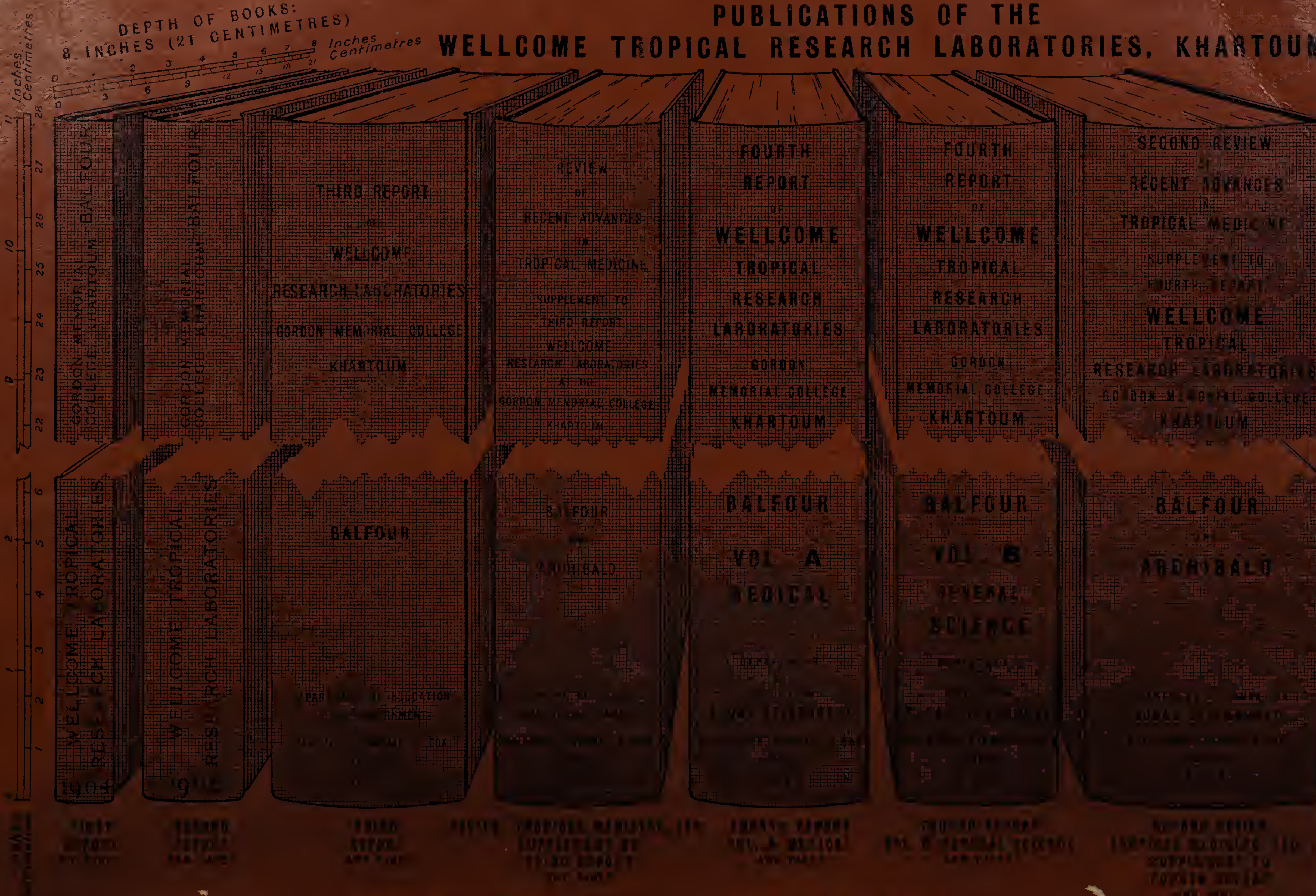

LARGE QUARTO SIZE CLOTH BINDING

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