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SOME INVESTIGATIONS REGARDING "BRACK" (ALKALI) IN CAPE COLONY SOILS.

By C. F. JURITZ, M.A., D.Sc., F.I.C.

(Read at a Meeting of the Royal Society of South Africa, held on
June 17, 1908.)

Plates XIII-XX.

Descending rain constantly carries clay particles from the surface down to the subsoil, and so enriches the latter with a supply of the *available* plant food which is generally contained in the finer soil grades, *i.e.*, the silt and clay. On the other hand, surface evaporation, causing an upward movement of the soil water, brings to the upper soil layers a constant supply of *readily* available plant food. Bearing in mind, then, the references made in a former paper* to the different grades of plant food, it may be deduced that the subsoil is constantly being supplied from the surface with plant-food constituents of Grade II., while the surface soil receives an equally continuous increment from below of the plant-food constituents of Grade I. The former of these two processes takes place more especially during the wet season, while the latter becomes more marked during the dry, but in arid regions this increase of salts in the surface soil may proceed so far, and result in an accumulation of salts of such a nature as to cause distinct injury to plant growth.

The extent to which these salts have accumulated in the surface soil can be definitely estimated only by chemical analysis,† but such analysis is of totally different nature from that which investigates the proportions of plant food or of plant-food constituents present, for we are now dealing not with beneficial but with harmful substances in the soil.

Thus the agricultural chemical analysis of soils, although as a rule confined to ascertaining whether they contain a sufficiency of plant *food*, may at times have to proceed beyond this limit and determine whether there be not an excess of plant *poison*. This generally resolves itself into an investigation of the brackness or alkalinity of the soil.

What is generally called "brack," or alkali, in soil consists in the presence of excessive quantities of certain sodium salts. These, under favour-

* S. A. Phil. Soc. Trans., vol. xviii., p. 9.

† For the present purpose this term may be considered to include the electrolytic process of the United States soil chemists.

able conditions, dissolve in the rain-water and drain out of the soil, but they accumulate and act injuriously where circumstances are unfavourable to their removal by natural drainage. During a rainy season the salts are carried to varying depths according to the penetrating capacity of the rain-water. The surface soil is thus left free from injurious salts. When dry weather sets in, however, the soil water rises to the surface as oil rises in a wick by capillary attraction, carrying the noxious salts with it from below. The water evaporates from the surface soil, leaving behind the salts as a white incrustation. There is, hence, a constant downward passage of these injurious alkaline salts during rain, and an equally constant upward movement during dry weather.

It will be easily understood that irrigation will tend to increase the accumulation of alkaline salts in a soil, seeing that the irrigation water will probably penetrate to greater depths than the rain, and carry to the surface larger quantities of salts. The danger is naturally augmented when the water used for irrigating is itself alkaline.

Hence, when adaptability of any tract of country for irrigation has to be pronounced upon, two chemical problems have to be decided: firstly, does the soil contain any constituent which may render it brack or otherwise unproductive? and secondly, assuming a satisfactory answer to the first point, is the land sufficiently provided with the necessary components of the food of plants to make farming profitable?

When the amount of plant food in a soil is the only point at issue, one needs not to probe to a greater depth than the first foot or 18 inches, but it is obvious, from what has been stated above, that in order to ascertain not only whether a soil is at present unproductive through brackness, but also whether it is liable to become so when irrigated, it is not enough to take merely a sample of soil from the surface and analyse that. It is essential to take samples at regular intervals below the surface to a depth at least equal to that which the irrigation water may possibly reach. There should be no omission that may leave a loophole for mistake. For this reason the method employed is to take samples representing successive sections vertically downwards from the surface to a depth of from 4 to 6 feet. Generally 1-foot sections are taken, but in certain cases 10-inch, 8-inch, or even 3-inch sections have been collected as occasion seemed to demand. Sometimes it has been advisable to sample solid blocks of soil, for instance, in the Thebus investigation, where the following method was used:—

A hole, several feet in diameter, was excavated to a depth of 6 feet, a solid pillar of earth being left untouched in the centre. From this central pillar six samples were taken in each case, every sample representing the average of 1-foot depth of soil. It will be readily seen that such a method of sampling involves more labour than scraping a couple of handfuls of

soil from the surface—a method which has sometimes been employed with somewhat misleading results.

It is to the presence of alkaline salts, comprising the chloride, sulphate, and carbonate of sodium, that the brackness of a soil is due. Of these salts, sodium sulphate is the least and sodium carbonate the most injurious on account of the corrosive effect of the latter on the bark, and its puddling of the soil and so interfering with tillage; the last-named salt is the cause of what is commonly termed black brack, the dark colour being due to the organic matter dissolved by the alkaline carbonate, while the chloride and sulphate, which do not dissolve organic matter, form what is called white brack. In small quantities these alkaline salts are contained in nearly all soils, being derived from the insoluble sodium silicates, which slowly decompose under the influence of air, water, and the solar heat into the soluble salts above mentioned. Hence there is ever going on a constant addition to the soil of soluble sodium salts, and, unless means exist for a constant, and as rapid a removal of these salts, they would in time so accumulate in the soil as to render it incapable of cultivation.

As a rule natural drainage is sufficient to remove the noxious salts from the soil, and they are continually carried down to the sea by the rain-water in which they are dissolved. Exceptions to this rule, however, exist: thus, when the surface soil is porous but has an impermeable layer underneath, the alkaline salts accumulate, as it were, in a basin from which there is no outlet; or the soil may itself be so compact or otherwise constituted as to prevent proper drainage; * lastly, a high-water line in the subsoil may prevent the exit of the injurious compounds; † in all these cases, unless a remedy be provided, there can be but one result, an accumulation in the soil of the salts which render it brack.

When, therefore, drainage of a soil becomes impossible, the question to be considered is whether the alkaline salts may collect at any particular level, or whether, on the other hand, they will be more or less evenly distributed throughout a mass of soil several feet in thickness. In such localities where rain is frequent and the temperature not excessive the probability is that the salts will be fairly evenly distributed throughout the soil, so that comparatively little, if indeed any, injurious effect on the vegetation ensues. If, however, the rainfall is scanty and the climate warm, or if there even be a brief period of heavy rainfall succeeded by a dry season, time and opportunity are afforded for the harmful salts

* Such a possibility demonstrates the importance of properly ascertaining, by mechanical analysis or otherwise, the physical condition of the soil all the way from the surface, down to a depth of from 4 to 6 feet, wherever an irrigation project is under consideration.

† This again shows that if a soil is likely to prove brack under irrigation, no investigation can be considered complete unless a series of determinations of the height of the water table in the subsoil has been made.

to rise to the surface by capillary attraction, in the way already outlined, and accordingly the surface soil is given such an accumulation of salts that cultivation is greatly hindered, if not rendered absolutely impracticable.

Under these circumstances it becomes an important matter to consider what proportion of sodium salts a soil may contain and still be capable of successful cultivation. Professor Hilgard has devoted considerable time and attention to investigating this point in connection with the alkali soils of California, and he states (Bulletin No. 128): "Barley failed to grow where the total salts were .203 per cent., but gave a full crop where they were .159 per cent. (half of which was carbonate). Wheat is rather more sensitive; maize fails on slightly alkaline land; but certain sorghums do well on mild white alkali (*i.e.*, not containing much carbonate)."

In India Dr. Leather's experiments have led him to conclude that germination was possible where the percentage of carbonate did not exceed .4, nor the sulphate and chloride 1 per cent. In after-growth .2 per cent. of carbonate was harmful, and .4 generally fatal. Maize was least affected of the cereals. Wheat grew well in the presence of .137 per cent. of carbonate, but was destroyed by .2 per cent. Legumes are more affected than cereals, but even the latter were fatally affected if the soil around their roots contained a proportion of .2 per cent. of sodium carbonate.

METHODS OF ANALYSIS.

The chemical analysis of an alkaline soil is far from being as arbitrary in its nature and in the method by which its results have to be interpreted as is the case with the investigations into the proportions of plant food in soils. There is therefore not always the same necessity when tabulating results of analyses of alkaline soils to specify particularly the methods adopted by the analyst. And yet it is for many reasons not only convenient, but also advisable that the methods employed in the Government laboratories should be stated here. These methods, as now carried out, are usually as follows:—

1. *Preparation of Solution.*—100 grammes of true soil (*i.e.*, the field sample sifted through a 3 mm. sieve) are placed in a flask marked to contain 1,000 c.c., and the flask is filled up to the mark with distilled water and placed in a revolving continuous shaking apparatus for twenty to twenty-four hours. At the expiration of that time the solution is either filtered under pressure through a dry filter placed in a porcelain perforated plate funnel, or by means of a Berkefeld candle filter.

2. *Determination of Total Soluble Salts.*—50 c.c. of the above soil solution are evaporated to dryness in a tared platinum dish, ignited at a temperature just below redness, so as to destroy any organic matter present, and weighed.

3. *Determination of Total Carbon Dioxide as Carbonates.*—An aliquot portion of the above soil solution is very cautiously titrated with $\frac{N}{50}$ sulphuric acid, a few drops of methyl orange, or preferably of phenacetolin, being used as indicator; from the quantity of acid used the total quantity of carbon dioxide present as carbonates is calculated.

4. *Determination of Sodium Chloride.*—To the aliquot portion used in the last determination a few more drops of $\frac{N}{50}$ sulphuric acid are added, then four drops of a chlorine-free potassium chromate solution, and titration is carried on by means of $\frac{N}{100}$ silver nitrate, all the chlorine thus determined being calculated as sodium chloride.

5. *Determination of Sulphuric Oxide.*—Another aliquot portion of the original soil solution is slightly acidulated by means of hydrochloric acid. If this causes the flocculation of clay, the mixture is filtered and the residue on the filter thoroughly washed. The clear acidulated solution is heated to boiling, and a large excess of boiling barium chloride solution is then slowly added, the mixture being allowed to continue boiling for five minutes. After the precipitate has completely settled the supernatant liquid is poured on to a filter; to the precipitate remaining in the beaker is added about 20 c.c. of boiling water, with which it is after thus washing transferred to the filter. On the filter the precipitate is again washed, at first with distilled water slightly acidulated by hydrochloric acid, and ultimately with pure water. The filter is then dried, ignited, and weighed.

6. *Determination of Sodium Sulphate and Carbonate.*—To an aliquot part of the soil solution a measured volume of $\frac{N}{50}$ sodium carbonate is added in excess of that required for complete decomposition of all calcium and magnesium sulphates, chlorides, and nitrates that may be present. The mixture is evaporated to dryness on a water bath, the residue being taken up with water and filtered, and the filter thoroughly washed. The sodium carbonate in the filtrate is then determined by titration with $\frac{N}{50}$ sulphuric acid. The quantity of $\frac{N}{50}$ sulphuric acid used in the titration, deducted from the total quantity of sodium carbonate originally added, gives the equivalents of calcium and magnesium sulphates present. The difference between the amount of sulphuric acid thus combined with calcium and magnesium and the total amount already found gives the proportion combined as sodium sulphate. Should more $\frac{N}{50}$ sulphuric acid required than the quantity of sodium carbonate originally added, the

excess over such amount is calculated as sodium carbonate. By "total alkaline salts" is understood the sum of the sodium chloride, carbonate, and sulphate.

7. *Determination of Total Lime.*—To an aliquot part of the soil solution two or three drops of rosolic acid are added; then dilute ammonia by means of a dropping tube and a sufficiency of ammonium chloride to redissolve any precipitated magnesia, after which the liquid is warmed, 20 c.c. of 4 per cent. ammonium oxalate solution are added, and the determination is further conducted exactly as in the extraction of the soil by hydrochloric acid. It may, however, be found preferable, especially when the quantity of lime is small, to dissolve the oxalate precipitate in dilute sulphuric acid and determine its amount by titration with $\frac{N}{100}$ potassium permanganate.

8. *Calcium and Magnesium Carbonates and Sulphates.*—Any carbon dioxide which may be present in excess of that combined with soda, as sodium carbonate, is calculated in the first instance as calcium carbonate. Should this not yet account for all the carbon dioxide, the rest of the latter is calculated as magnesium carbonate; on the other hand, if there still remains an excess of lime unaccounted for, it is calculated as calcium sulphate. Any excess of sulphuric oxide which may still remain is assigned to magnesia.*

HERBERT.

According to the methods outlined above, determinations of alkaline salts were made in three samples of surface soil from Douglas in the Division of Herbert. These determinations resulted as follows † :—

DOUGLAS (HERBERT DIVISION) SOILS.

Number.	Sodium Chloride.	Sodium Sulphate.	Sodium Carbonate.	Total Alkaline Salts.	Calcium Sulphate.	Calcium Carbonate.	Magnesium Sulphate.	Magnesium Carbonate.	Total Soluble Salts.	
									Calculated.	Found.
1	·006	—	—	·006	·021	·028	—	—	·055	·048
2	·005	·002	—	·007	·001	·038	—	—	·046	·060
3	·006	·003	—	·009	—	·035	—	·003	·048	·056

* Should there be more lime or magnesia, or both, than required for the sulphuric oxide present, these are in such cases calculated as chlorides, a corresponding deduction from the sodium chloride being made.

† The results are stated in percentages, and, except where the contrary is indicated, blanks in the tables denote absence of the particular substance specified.

These results are favourable towards the suitability of the soil for irrigation, but, at the same time, had opportunity offered, it would have been desirable to extend the investigation to 3 or 4 feet lower down, for reasons already detailed, in the manner illustrated above.

DIVISION OF COLESBERG.

Six soils from the farm Oorlogspoort, in the Colesberg Division, were also examined with a view to ascertaining the proportions of soluble salts present. These were found to range between .038 and .090 per cent., and to average .058 per cent. Such amounts are not sufficient to be harmful to plant life, even if the salts consisted entirely of sodium carbonate or "black alkali," the most injurious form in which alkaline salts are found in the soil.

DIVISION OF BRITSTOWN.

One of the first investigations into the possible alkalinity of lands proposed to be irrigated was carried out in connection with the farm Houw Water, in the Division of Britstown. Five sets of samples were taken in almost a straight line, nearly a mile and a half from end to end, from the lands intended to be irrigated, below the site of the proposed dam. In each case samples were taken in the manner already described to a depth of 6 feet. The physical nature of the soil may be gathered from the following table:—

HOUW WATER (BRITSTOWN DIVISION) SOILS.

Surface.	A.	B.	C.	D.	E.
1st foot	Fine loose loam	Fine loose loam	Loose loam	Loose loam	Loose loam
2nd foot					"
3rd foot	Stiff compact clay	Stiff hard clay	Stiff hard clay	Rather stiffer loam	"
4th foot	"	"	"	"	Rather stiffer loam
5th foot	"	"	"	Stiff hard clay	Looser loam
6th foot	Very loose loam	Very loose loam	"	Loose loam	Moist loose loam

The approximate distances apart of the points whence these samples were taken were as follows:—

Between A and B.....	430 yards
" B „ C.....	250 „
" C „ D.....	850 „
" D „ E.....	900 „

Time and circumstances did not permit of any thorough investigations into the depth of the water table below the surface, but as the average annual rainfall is very low—only about 5 inches—and as E was the only one of the five probings which showed a suspicion of moisture within

6 feet of the surface, there did not appear much probability of a high water level in the subsoil.

The results of the chemical investigations into the alkalinity of these soils are given below; A 1, it should be explained, denotes an average sample of the soil at the point A from the surface to a depth of 1 foot, A 2 signifies the same soil between 1 foot and 2 feet depth, and so on.

Number.	Total Soluble Salts, per cent.	Sodium Chloride, per cent.	Sodium Sulphate, per cent.
A 1	—	·0094	—
A 2	—	·0069	—
A 3	—	·0117	—
A 4	—	·0279	—
A 5	·244	·0980	·0488
A 6	·280	·1587	—
B 1	—	—	—
B 2	·172	·0069	—
B 3	—	·0076	—
B 4	—	·0163	—
B 5	—	·0350	—
B 6	·376	·1447	—
C 1	·264	·0058	—
C 2	·176	·0069	—
C 3	·136	·0076	—
C 4	·168	·0117	—
C 5	·200	·0117	—
C 6	—	·0163	—
D 1	—	—	—
D 2	·400	·0094	—
D 3	·392	·0398	—
D 4	·496	·1261	—
D 5	·600	·2357	—
D 6	·760	·2754	—
E 1	—	·0117	—
E 2	·348	·1028	—
E 3	·640	·3080	—
E 4	·920	·4155	·4189
E 5	1·284	·5438	—
E 6	1·636	·6272	—

These analyses were somewhat tentative, and, owing to lack of time and also of the necessary filtering and other appliances, the tables are

studded with gaps. These drawbacks, however, do not prevent certain definite deductions. It is noticeable that, as a rule, the amounts of sodium chloride, and of soluble salts generally, steadily increase as we proceed downward from the surface to the 6-foot limit, and that this downward limit increase becomes more rapid as we pass from A towards E.

Taking the entire 6-feet depth of soil, in each case the average percentages of salts, as far as they may be based on the foregoing determinations, are as follows:—

	Total Soluble Salts.	Sodium Chloride.
A.....	—	·0521
B.....	—	·0421
C.....	·189	·0100
D	·530	·1373
E	·966	·3348

The question now to be pronounced on is: What would be the effect of irrigation upon such soils? Broadly speaking, and having no regard to modifying causes, there can be only one answer. The result of irrigation would assuredly be to raise the bulk of the alkali salts, within the first 4 feet of soil, to the surface.

It appears most probable that the low rainfall in the district around Houw Water, accompanied by other causes, prevents the water from ever penetrating the soil to any great extent, and, therefore, from bringing up the salts during subsequent evaporation. Irrigation would very probably alter all this. The large quantity of water led on to the soil is bound to penetrate, and, when evaporation follows, as it undoubtedly must, large quantities of salt will be carried up to the surface, and accordingly render the surface soil more saline.

In connection with some alkaline soils it has been found at Tulare, in California, that, although the salts in the soil have been drawn upwards, they have not been drawn right to the surface, and, in spite of the fact that a considerable amount of alkaline salts was present in the soil, there was not sufficient at the surface to cause any interference with the growth of shallow-rooted crops like barley, which flourished, to all appearances, satisfactorily. The reason for this is to be found in the fact that the surface soil was kept under constant cultivation, whereby evaporation from the soil itself was checked, and proceeded instead from the verdure of the cultivated crops. If the land can be kept under continuous cultivation, there would be simultaneously two causes at work to retard evaporation, and consequently prevent the rise of alkaline salts to the surface. Evaporation from foliage instead of from soil would not be the only saving factor, but the shading of the ground by the crops reducing its temperature, still further diminishes the tendency to evaporation from the soil surface.

It would appear that the most noxious of the sodium salts, the carbonate, is practically absent from the Houw Water soils, the two compounds of sodium which form the bulk of the alkaline soil constituents being the sulphate and the chloride. Professor Hilgard estimates that, for barley, sandy soils should not contain within the first 12 inches over .10 per cent. of sodium carbonate, .25 per cent. of sodium chloride, or .45 to .50 per cent. of sodium sulphate; in clayey soils even smaller percentages may prove injurious. It has been calculated that the average proportion of total alkaline salts in the 4 feet nearest the surface should not exceed .2 per cent. if barley is to be grown. According to Professor Hilgard's experiments, as already stated, barley thrived on a soil which contained on an average .159 per cent. of alkaline salts in the first 4 feet; on the other hand, the cereal refused to grow where the average amount in the first 4 feet reached .203 per cent. Now, of the Houw Water soils it seems likely that A would satisfy this condition, and possibly B may also; the average percentage in C is .186, but both D and E are considerably on the worse side of the danger limit.*

DIVISION OF STEYNSBURG.

A similar investigation to that outlined above was made at Thebus, in the Steynsburg Division, a distance of about 160 miles E S.E. of Houw Water. In this case, too, there was a proposal afoot to construct a dam whereby the farm Zout Kuil and part of Van Vuurens Kraal with adjacent lands could be irrigated. As Parliament had voted £150,000 for the purpose, much depended on the suitability of the area. The last-named farm had been under cultivation for close on to half a century, and the occupant prided himself on the returns which he has obtained by means of irrigation. At a point within this cultivated area a set of samples was taken in order to ascertain, if possible, the effect of continuous irrigation on the soil, by comparing the analytical results yielded by the irrigated soil at this spot, which will be called K, with those of samples from the adjacent tracts which had never yet been irrigated. This point, K, was on the opposite side of the railway to that where the dam construction works were situated, and is rather more than 3 miles below the dam, and $1\frac{1}{2}$ mile from Thebus railway station; it constituted, in fact, the head of the area which it was intended to irrigate. Four samples, L, M, N, and P, were taken at other points in this area, on the farm Zout Kuil, extending altogether over a space about 2 miles in extent.

The alkaline salts in these five samples were determined in similar manner to that employed with regard to those from Houw Water, only much more completely.

In this way the following percentage results were obtained:—

- It is of course obvious that efficient drainage may prove a complete safeguard.

THEBUS (STEYNSBURG DIVISION) SOILS.

Number.	Sodium Chloride.	Sodium Sulphate.	Sodium Carbonate.	Total Alkaline Salts.	Calcium Sulphate.	Calcium Carbonate.	Magnesium Sulphate.	Magnesium Carbonate.	Total Soluble Salts.	
									Calculated.	Found.
K 1	% ·034	% —	% —	% ·034	% —	% ·006	% ·007	% ·024	% ·071	% ·204
K 2	·033	·012	—	·045	—	·015	·004	·060	·124	·232
K 3	·055	—	—	·055	—	·013	·049	·053	·170	·258
K 4	·083	·210	—	·293	·283	·028	·212	—	·816	·872
K 5	·073	·237	—	·310	·030	·029	·121	—	·490	·496
K 6	·103	·181	—	·284	·067	·031	·274	—	·656	·700
L 1	·191	·048	—	·239	—	·019	·017	·023	·298	·372
L 2	·161	·181	—	·342	·144	·035	·224	—	·745	·660
L 3	·118	·120	—	·238	—	·026	·035	·015	·314	·230
L 4	·173	·082	·002	·257	—	·019	—	·035	·311	·340
L 5	·205	·108	·005	·318	—	·016	—	·043	·377	·380
L 6	·102	·088	·039	·229	—	·011	—	·057	·297	·328
M 1	·086	—	—	·086	—	·021	·013	·001	·121	·252
M 2	·211	—	—	·211	—	·033	·025	·022	·291	·416
M 3	·277	·101	—	·378	—	·026	·020	·028	·452	·582
M 4	·224	·293	—	·517	·051	·035	·080	—	·683	·800
M 5	·242	·037	—	·279	—	·021	·159	·031	·490	·508
M 6	·291	·304	—	·595	—	·024	·030	·034	·683	·880
N 1	·213	·071	—	·284	—	·013	·004	·034	·335	·348
N 2	·234	·208	—	·442	—	·034	·071	·012	·559	·594
N 3	·181	·131	·063	·375	—	·010	—	·079	·464	·568
N 4	·221	·127	·056	·404	—	·010	—	·072	·486	·480
N 5	·251	·096	·058	·405	—	·008	—	·088	·501	·452
N 6	·193	·070	·048	·311	—	·013	—	·072	·396	·394
P 1	·225	·115	·012	·352	—	·008	—	·040	·400	·664
P 2	·271	·762	—	1·033	·572	·023	·279	—	1·907	2·160
P 3	·193	·146	·111	·450	—	·010	—	·101	·561	·608
P 4	·159	·104	·111	·374	—	·008	—	·116	·498	·604
P 5	·205	·055	·129	·389	—	·009	—	·125	·523	·672
P 6	·216	·023	·156	·395	—	·019	—	·142	·556	·570

It will be seen that the soil at K is the only one which falls within the limits of safety as laid down by Professor Hilgard; in fact K is the only soil which one would expect to yield a profitable return, and the fact that farming has been carried on there with fair success does not therefore settle the matter for the entire valley. The lower layers of the soil at K contain a fair proportion of gypsum which has converted the noxious sodium carbonate into the less harmful sulphate. There is a general prevalence of carbonate of lime throughout these soils, and in nearly every case a stratum of gypsum (calcium sulphate) runs through the soil at various levels; this stratum appears in the fourth foot at K and M, and in the second at L and P. It is invariably accompanied by an increase in the proportion of other soluble salts, including those which produce

brack, and although the gypsum in these layers may minimise to some extent the evil effects of the black brack by converting it into sodium sulphate, it is not probable that it will do away with these effects entirely.

There is a general resemblance between the soils K and M, the former being an improvement on the latter. The worst kind of brack, sodium carbonate or black brack, occurs in the soils L, N, and P. At L it makes its appearance at the fourth foot, at N it rises to the third, and in larger proportions, while at P it appears at the surface, and is distributed through the soil profile in amounts averaging from two to three times those in the corresponding soil layers at N.

It will be noticed that the magnesium salts exceed, on the whole, the lime salts in quantity, and I may here say—what does not appear from the figures already given—that the soils K and M show a small proportion of the rather undesirable magnesium chloride in the first couple of feet.

The amounts of alkaline carbonates in the Thebus samples are lower than in the soils of the Tulare Experiment Station, California, as reported by Professor Hilgard, and the alkaline salt present in largest proportion is sodium sulphate at K, and sodium chloride at the other points where samples were taken; but then the Californian Station may be taken as representing an extreme case, and there is no saying whether much worse instances than the present may not be found at Thebus if a more complete investigation be undertaken.

It will be noticed how irregularly the soluble salts are distributed through the soil; this irregularity is caused by the varying permeability of the soil layers, and by the bands of gypsum which traverse the valley. This variability also showed itself in the peculiar nature of results obtained by ordinary agricultural chemical analysis from other samples collected at Thebus. These samples were evidently not typical, and may even, in some cases, have been taken out of the very bands of gypsum just mentioned, hence they showed abnormal percentages of lime. Irregularities of this type are of common occurrence in alkali soils; King ("Irrigation and Drainage," p. 283) states that "in examining soil for alkalies it is a matter of the utmost importance to recognise that the distribution of them is extremely liable to be capricious, and that it is easy to overlook their presence by stopping the sampling of the soil just short of the level at which all the alkalies had chanced to be concentrated; or, again, by taking a sample of the first, second, and fourth feet, or of the first, third, and fourth feet, when, owing to the capricious distribution, all of the salts had been collected in the second and third foot, and thus were overlooked because it may have been thought not worth while to make a complete section of the soil in question."

An analysis was made of a sample of efflorescence from the soil in the

neighbourhood of the works, obtained by enclosing a quantity of the soil, to a depth of several feet, with a metal cylinder, drenching the soil with water and allowing it to dry by exposure. As was to be expected, evaporation of the water led to the appearance of a layer of salts on the surface, and this layer, on being scraped off, was found to have the following composition :—

Sodium chloride	40·16 per cent.
Sodium sulphate	11·64 „
Magnesium sulphate	37·21 „
Calcium sulphate	10·86 „
Calcium carbonate	Trace

Of the alkaline salts that present in largest amount is sodium chloride, and the magnesium compounds exceed those of calcium in quantity. In the absence of sufficient lime this magnesia may prove harmful.*

Two similar samples of efflorescence mixed with earth, collected by Dr. Nobbs near the same spot, were analysed with the following results :—

Total soluble salts	1·209 per cent.	1·495 per cent.
Sodium chloride	·058 „	·491 „
Sodium sulphate	1·122 „	·895 „
Magnesium sulphate ...	— „	·048 „
Magnesium carbonate...	·008 „	—
Calcium carbonate	·010 „	·020 „

Here, too, it will be seen sodium sulphate prevailed.†

In a sample of water, taken from a pit on the site of the proposed dam, the total dissolved salts amounted to 50·40 grains per gallon; of these salts the following are the principal ingredients :—

* See Storer, "Agriculture in some of its Relations with Chemistry," vol. ii., pp. 518 and 519.

† From the farm Culmstock, in the Division of Middelburg, and lying about 20 miles south of Thebus, a sample of efflorescence, such as frequently occurs on the surface of brack soils, was collected. Analysis showed it to contain, *inter alia* :—

Chlorine	7·8 per cent.
Carbon dioxide	6·2 „
Sulphur trioxide.....	33·8 „

The salts present therefore consisted mainly of sulphates. In both these Divisions (Steynsburg and Middelburg) there are extensive plains of Karroo veld, which, but for the liability to brack, would answer excellently for irrigation and cultivation purposes.

	In grains per gallon.	In parts per thousand.
Sodium chloride	6·35	·091
Sodium sulphate.....	6·76	·097
Sodium carbonate	6·68	·095
Magnesium carbonate	16·54	·236
Calcium carbonate	8·87	·127

Here again, as in the soils and also in the efflorescence taken from the surface of the soil, magnesium compounds form the chief ingredient. Sodium carbonate is present in small quantity, the amount being apparently less than in the water from Thebus dam.

The latter yielded the following results in grains per gallon :—

Total salts	45·2
Sodium chloride	6·3
Carbon dioxide in combination	12·8

The water from the dam contains but small quantities of lime and magnesia, so that in all probability the carbon dioxide in it was combined with soda, forming sodium carbonate, and the use of it, unless accompanied by effective drainage, would therefore tend to increase in the soil that most injurious form of alkali, “black brack.” The water from the pit, on the other hand, had most of its carbon dioxide combined with lime and magnesia.

On p. 266 of King’s “Irrigation and Drainage” will be found a table, compiled from Bulletin 29 of the Oklahoma Experiment Station, p. 4, showing the composition of alkaline waters that may be regarded as safe and those which are considered unsafe to use for irrigation.

Bearing in mind that sodium carbonate represents what is called “black alkali” in King’s tables, and that sodium chloride and sulphate together constitute “white alkali,” it will be seen that the amounts in the pit water are as follows :—

Black alkali	·095 part per thousand.
White alkali	·188 “ “ “

Now, it is to be noticed from the tables in King’s book that a water may be considered safe if the black alkali—which is the most harmful constituent—does not exceed, say, ·100 part per thousand, provided the white alkali be not too high, but that if the former exceed the figure just mentioned the water cannot be regarded as safe. White alkali is less injurious, and up to about ·500 part per thousand may be passed, but beyond this limit, even though the black alkali may be low (as in the case of sample 741 of the tables alluded to, where the black alkali is ·026 and the white ·818 per thousand) it would be risky to make constant use of the water.

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In the sample of water from the pit at Thebus the white alkali was well within the limits of safety, but the black alkali was on the border-line, and in the sample of water from the dam the limit was apparently exceeded, although the smallness of the sample sent prevented this being definitely ascertained.

It must, of course, be kept in view that the figures with which the analytical results of the Thebus water are compared are derived from experimental data obtained in Europe and America. If the facilities for making such very necessary experiments existed here, figures obtained under local conditions might be found to differ from those obtained in Europe and in the United States, but this very fact makes it all the more necessary to exercise great caution in proceeding with extensive irrigation schemes.

DIVISION OF ROBERTSON.

A series of determinations, similar to those conducted in regard to the Thebus soils, have also been made in connection with the soil of the Government Experiment Station at Robertson. Two soils were collected for this purpose on the station. The soil at one part of the farm was a red sandy loam with a clayey subsoil and tending towards brackness in parts. From one of these brack patches the samples marked S were taken. A calcareous loam, in another part of the farm, showed brack

ROBERTSON SOILS.

Number.	Sodium Chloride.	Sodium Sulphate.	Sodium Carbonate.	Total Alkaline Salts.	Calcium Sulphate.	Calcium Carbonate.	Magnesium Sulphate.	Magnesium Carbonate.	Total Soluble Salts.	
									Calculated.	Found.
R 1	·024	—	—	—	—	—	—	—	—	·060
R 2	·018	—	—	—	—	—	—	—	—	·044
R 3	·010	—	—	—	—	—	—	—	—	·070
R 4	·011	—	—	—	—	—	—	—	—	·062
R 5	·011	—	—	—	—	—	—	—	—	·056
R 6	·019	—	—	—	—	—	—	—	—	·080
S 1	1·029	·162	—	1·191	·112	·020	·043	—	1·366	1·400
S 2	·942	·114	—	1·056	·088	·020	·071	—	1·235	1·272
S 3	·662	·037	—	·699	—	·037	·067	·003	·806	·858
S 4	·516	·071	—	·587	—	·029	·041	·018	·675	·700
S 5	·487	·082	—	·569	—	·024	·014	·027	·634	·674
S 6	·409	·082	—	·491	—	·018	·014	·030	·553	·572
S 7	·342	·062	—	·404	—	·016	·014	·005	·439	·504
S 8	·301	·067	—	·368	—	·014	·007	·005	·394	·450
S 9	·291	·066	—	·357	—	·009	·012	·011	·389	·428
S 10	·307	·073	—	·380	—	·012	·012	—	·404	·476
S 11	·321	·076	—	·397	—	·007	·012	·004	·420	·496

(The blanks in the upper part of this table signify "undetermined.")

water a short distance from the surface. Under these circumstances fuller investigations into the alkaline character of the soil were made. At two spots, R and S, the samples mentioned below were collected representing successive sections of the soil to a total depth of 4 feet; at R, six samples, each extending vertically through 8 inches, were taken; at S, an alkaline patch with a superficial area of about 2,000 square yards, eleven samples were taken, of which the first eight represented 3-inch, and the remaining three 8-inch vertical sections.

The analyses made resulted as shown in Table on previous page.

In the case of the soil R there was no necessity to push the investigation further, the total soluble salts being considerably below the danger limit. At S a very different condition of things exists, and a diagram is attached, showing the curves of the various soluble salts in the soil as we descend from the surface to a depth of 4 feet.

DIVISION OF CARNARVON.

An investigation of the alkaline tracts near the large dam called Van Wyks Vlei, 45 miles north-west of Carnarvon village, was conducted, on lines somewhat similar to those already indicated. By means of this dam, which holds many thousand million gallons of water, fairly extensive irrigation has been practised for several years. Under this treatment the barren area has gradually spread, and at present the nearest land that is being cultivated below the dam is no less than 7 miles distant therefrom. It is, nevertheless, estimated that about 20,000 acres of irrigable land of good quality are still free from any signs of alkalinity, and available for cultivation.

Two samples of water from artesian borings in the vicinity of the dam were analysed, with the following results, stated in grains per gallon :—

	No. 1.	No. 2.
Sodium chloride	48·94	358·98
Magnesium sulphate	49·20	177·57
Calcium sulphate	53·26	76·86
Calcium carbonate.....	10·16	147·95

A specimen of water from the dam itself was found to contain chlorine—in combination as chlorides—to the amount of 1154·6 grains per gallon, and, on another occasion, a sample similarly taken yielded the following figures :—

Sodium chloride	862·9 grains per gallon
Sodium sulphate.....	226·3 " " "

At some places in the neighbourhood beds of limestone, containing gypsum occur: specimens of these were analysed, but did not prove of good quality.

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The land most affected by alkaline salts is that in the immediate proximity of the dam, and from there the saline area is working its way downwards by degrees, the lands being drenched with water during the season, and then left to the action of evaporation, which does not fail to draw the salts to the surface, with the consequence that, in the long run, one area after another has been discarded as too salt for cultivation. Under such circumstances, the practice has been to transfer to a plot of virgin soil until that, in turn, becomes too alkaline for use.

To test chemically the results that this mode of cultivation brings about, samples of soil, T and V, were taken, respectively, from Lot 111, which had been under cultivation for seventeen years, and had, during that period, grown fourteen crops of wheat, and from Lot 94, which had never been cultivated, at a spot 315 yards from that where T was collected. The crops at T were originally as good as could be desired, but have been gradually deteriorating. The sample taken at V is typical of the Van Wyks Vlei soil in its natural state.

The way in which these samples were collected was as follows: In each case an excavation was made to a depth of 7 feet, and, down one side of the excavation, a vertical groove, of 6 inches square section, was cut by removing for analysis blocks of soil of 6 inches cube at 6-inch intervals. The first sample of each series was taken from the surface to a depth of 6 inches, and then samples of each alternate 6 inches below that. In both cases, at a depth of 6 feet, a stratum consisting for the most part of large-sized stones was encountered; of this it was not considered necessary to make analyses, but the soils taken from the higher levels were examined for alkaline salts, with the results tabulated below:—

VAN WYKS VLEI (CARNARVON DIVISION) SOILS.

Number.	Sodium Chloride.	Sodium Sulphate.	Total Alkaline Salts.	Calcium Chloride.	Calcium Sulphate.	Calcium Carbonate.	Manganese Chloride.	Magnesium Sulphate.	Magnesium Carbonate.	Total Soluble Salts.	
										Calculated.	Found.
T 1	·849	—	·849	1·542	·106	·014	·046	—	—	2·557	2·672
T 2	·432	—	·432	·114	·040	·022	·029	—	—	·637	·708
T 3	·355	—	·355	·039	·081	·024	·017	—	—	·516	·548
T 4	·359	·105	·464	—	·003	·038	—	·036	—	·541	·594
T 5	·304	·363	·667	—	·049	·034	—	·065	—	·816	·840
T 6	·214	·397	·611	—	—	·037	—	·007	·011	·666	·664
V 1	·051	—	·051	·068	·019	·024	·012	—	—	·174	·222
V 2	·355	—	·355	·500	·032	·026	·090	—	—	1·003	1·056
V 3	·590	—	·590	·404	·071	·020	·066	—	—	1·151	1·210
V 4	·736	—	·736	·082	·198	·026	·055	—	—	1·097	1·102
V 5	·759	·318	1·077	—	·042	·048	·007	·053	—	1·227	1·238
V 6	·502	·419	·921	—	·105	·017	·006	·049	—	1·098	1·116

The effect of irrigation, as practised at Van Wyks Vlei, on this type of soil, is seen, in the case of soil T, by the accumulation of salts at the surface. In its natural condition the vertical distribution of the saline material is such as to leave the surface soil comparatively free, so that shallow-rooted crops may be cultivated without difficulty. In the irrigated soil the present failure to grow crops is easily explained by the existence of the chlorides of calcium and magnesium in the upper soil layers. The occurrence of these very soluble salts in "brack" is somewhat unusual, and can only take place in arid regions like Carnarvon. At Thebus, too, where the rainfall is not abundant—although less scanty than in the Carnarvon Division—the presence of magnesium chloride in the soil was noticed. In the Robertson Division, on the other hand, where rain is frequent and the atmosphere more humid, a surface efflorescence containing these salts is an impossibility.

It will be noticed, especially from the appended diagram, that, in the irrigated soil, the chlorides are, for the most part, accumulated within the upper 30 inches, while the sulphates have remained at the lower levels.

Calculating from the figures in the last table, the percentage composition of the salt at the soil surface at T is as follows :—

Sodium chloride	33·20
Magnesium chloride	1·80
Calcium chloride	60·30
Calcium sulphate	4·15
Calcium carbonate.....	·55

With this may be compared the following results, quoted by Hilgard ("Soils: their Formation, Properties, &c.," p. 442), of an analysis of alkali occurring in California (Imperial) :—

Potassium chloride	1·15
Sodium nitrate	8·21
Sodium chloride	31·82
Sodium carbonate	·58
Magnesium chloride.....	2·81
Calcium chloride	58·42

There is considerable resemblance in the respective percentages of sodium, calcium, and magnesium chlorides.

Diagram illustrating soil alkalinity at Houw Water, Britstown Division.

Diagram illustrating soil alkalinity at Houw Water, Britstown Division.

Diagram illustrating soil alkalinity at Houw Water, Britstown Division.

Diagram illustrating soil alkalinity at Van Wyks Vlei, Carnarvon Division.

Diagram illustrating soil alkalinity at Thebus Steynsburg Division.