CHEMICAL AND BIOCHEMICAL INVESTIGATIONS ON CEYLON TEA SOILS

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Before explaining some particular aspects of our soils which I think urgently need investigation if we are to maintain high yields from areas replanted with vigorous clones, I will remind you of some of the more important general properties of soil.

The easiest way of explaining one of the most important properties of soil is to compare it with a domestic water softener. The domestic water softener is a cylinder connected with the water main on one side and the taps on the other. It is filled with nodules of a base exchange compound. The hard lime and magnesium bearing water passes through the nodules and the lime and magnesium are largely replaced by sodium which does not give water the property of hardness. When the nodules are exhausted or saturated, the cylinder is flooded with a strong solution of sodium chloride, best known as common salt, and the calcium and magnesium are again replaced by sodium. The softener is thus regenerated and ready for use again.

If a solution, roughly equivalent to that which will result from the solution of sulphate of ammonia in rainwater after manuring, is passed through a cylinder of sand, unchanged ammonium sulphate solution will drain away. When the same solution passes through a cylinder of good soil, the greater part (not all) of the ammonia is held by the soil and the drainage water contains mostly sulphates of other bases such as calcium, magnesium and potassium.

ammonium sulphate + calcium magnesium potassium [clay] $\rightleftarrows$ ammonium calcium magnesium potassium [clay] + calcium magnesium potassium } sulphate

This capacity which soil possesses for holding nutrients is known as base exchange capacity and may be measured with some accuracy.

Both clay and organic matter possess this property. The type of clay found in our soils has, however, only about a twentieth of the capacity which other clays in some good arable soils have for holding nutrients and the organic matter is possibly therefore relatively more important. More detailed work is required and I hope that a survey of base exchange capacities of our tea soils will be possible in the near future.

Since tea soils are acid, the total capacity of the clay and organic matter for holding bases, such as calcium and magnesium, is only partly saturated. The parent rocks are relatively poor in these elements and whenever we add sulphate of ammonia we cause some loss of calcium, magnesium and potassium. In good arable soils the loss of exchangeable calcium is made good from reserves contained in minerals in the soil. In tea soils there is very little calcium, either in the exchangeable form or as reserve, and we have recently found that ammonium sulphate causes mostly potash to be displaced which is then lost as potassium sulphate. We are, of course, adding potash in the manure but it is a much more expensive mineral than calcium or lime and we are beginning to think in terms of limestone as a possible potash economiser. Apart from the aspect of economising the use of potash I am frankly alarmed by the very low reserves of calcium and magnesium and Mr. Tolhurst will later give additional information which does nothing but substantiate my fears.

In a recent article in the *Tea Quarterly* Mr. Tolhurst and I pointed out that the calcium phosphate in saphos phosphate is a source of lime and magnesium as well as phosphate. 50 per cent. muriate of potash is also another source of magnesium but the more highly purified salts contain less magnesium. Even with a certain amount of calcium and magnesium in T.R.I. 500 mixture we appear to be dangerously near 'scraping the bottom of the barrel' so far as these two elements are concerned. Acid soils in high rainfall tropical areas, especially those derived from acidic rocks, are at the best of times low in calcium and magnesium and cultivation will do nothing to improve their status.

We have recently carried out some analyses of the total content of calcium and magnesium in a typical profile (Table 1). This total content includes exchangeable or easily available fractions, which are in fact scarcely detectable, as well as the content in clay, organic matter and unweathered minerals. It was obtained by dissolving soil completely in a powerful acid known as hydrofluoric acid and the method is difficult and expensive to apply to extensive analysis. Curiously enough the content of the upper layers of soil, certainly in the case of calcium, is higher than the content of the sub-soil. It is not what we expected to find and we cannot explain it.

Table 1—*Content of calcium and magnesium in parts per million of dry matter.*

Depth inches	Calcium (Ca)	Magnesium (Mg)
0-6"	677	2180
6-12"	555	1911
12-24"	460	852
24-36"	310	764
36-60"	380	895
60-84"	250	1114

Note 677 p.p.m.=0.0677%

At the present rate of carry off of calcium, in crop and prunings alone, the top soil contains only sufficient of the minerals to last for 40 years. Some loss of calcium in the drainage water is inevitable and is increased every time we use sulphate of ammonia as a manure. The reserves locked up in the mineral particles will not of course become completely available in anything but geological time, and it does appear that calcium supplies need very close investigation. The soil reserves of nitrogen are far higher than those of calcium and it is just as essential to ensure calcium supplies as it is to ensure nitrogen supplies. For all we know at present, limitation of available calcium and magnesium may be restricting growth. The magnesium status is somewhat better than the calcium status but is nevertheless low enough also to require close investigation. An industry of the size of the tea industry should have a central research organisation staffed and equipped to ensure against future troubles. The aim of research should be primarily prevention and not cure.

It has been known for some time that potash has not only been held as exchangeable potash but that in certain clays some of it is held much more firmly; to the extent of becoming fixed and unavailable to plants. The fixation of potash is aggravated by wetting and drying of soils and is one reason why manure should always be applied when rain is, as far as one can see, likely to follow application and why manure should be dibbled or forked into the soil.

More recently it has been established in Trinidad that, at least in a number of tropical soils, a proportion of ammonia also becomes fixed. This work was published just as we were coming to the same conclusion with regard to Ceylon tea soils (Table 2) and partly explains some of the very high nitrogen contents of our soils described in my previous paper.

Table 2—*Percentage fixed ammonia in St. Coombs profile.*

Depth of soil	Percentage of fixed nitrogen (mainly ammonia)
0-6"	5.3
6-12"	6.7
12-24"	18.2
24-36"	10.7
36-60"	14.3
60-84"	11.1

Whether or not nitrifying organisms have any access to this fixed ammonia is very doubtful. Just how long soils can go on absorbing ammonia in this way remains to be discovered. Presumably there is a saturation point.

It is probable that alternate wetting and drying increases fixation of ammonia as it does potash and makes it even more important to keep the soil moist and to avoid frequent drying of the top layers. There is, as you will now realise, a tremendous amount of research to be done on the chemistry of our soils.

Next I will give you some account of the investigations into the chemistry of biological processes which take place in our soils, *i.e.* soil biochemistry.

As many of you are aware most plants have a limited ability to take up ammonia directly and that ammonia has to be 'nitrified' in the soil, that is to say, changed to nitrate. We are now attempting to find just how the tea bush takes up its nitrogen requirements.

In the first place the ammonia content of our soils, as revealed by the soil survey, is naturally high, yet tea undoubtedly responds to manuring with sulphate of ammonia. I may as well confess that we are no nearer to an explanation of this curious fact than we were when we started investigation, but we have discovered a number of quite interesting things and no doubt patient research will eventually sort the complicated tangle of factors out into some sort of shape.

Closely to study the nitrogen requirements of the tea bush we constructed some lysimeters about eighteen months ago. For some time the lysimeters containing the tea bushes were manured with everything the bush could require except nitrogen. The drainage from the lysimeters containing bushes contained much less nitrate than those containing soil only. The ammonia in the drainage water was the same in both cases. This suggested that the bushes took up nitrate.

Eventually the bushes became very yellow and showed every sign of nitrogen starvation. The soil at this stage contained 14 parts per million of ammonia in an exchangeable and apparently freely available form. The total nitrogen content of the soil was 0.269 per cent.

When nitrate was added the yellowness disappeared in a few days at quite remarkable speed, and even old leaves made a gallant attempt to recover. This appeared to be fairly conclusive evidence that tea takes up its nitrogen as nitrate but it is never safe in research work to jump to conclusions. All I can say at the moment is that we have failed to keep the bushes vigorous and healthy with a complete manure containing nitrogen as nitrate only.

Now although ammonia is firmly held by the soil, nitrates are not, like sulphates, chlorides, etc. held by base exchange (they are acidic and not basic). Nitrates normally wash out of soil quite rapidly, and we expected to collect the balance in the drainage water from the lysimeters. After we had added considerable quantities of nitrate, recovery in the drainage water and response in the form of new growth was poor. We decided to wash the lysimeter through and attempt recovery of the nitrate. To cut a long story short, most of it had disappeared but we do not think it has been lost as nitrogen gas; it is probably in the lysimeter still, as protein in some fat bacteria and fungi, and as ammonia.

This illustrates the particular need for basic research under tropical conditions. According to the text books, based largely on work on temperate soils, the reaction is a slow change of ammonia to nitrite, followed by a very rapid change of nitrite to nitrate. This reaction does occur to some extent and we find small quantities of nitrite, but the text books tell us little about the reverse process of nitrate to ammonia. We have to work this out ourselves.

It would take me a very long time to explain the work we have already done in any detail. It is quite obvious that a number of reactions involving chemical, bacterial and fungal changes are constantly taking place in our soil and I can only give you a brief summary of what we have found.

(1) Aeration in collecting top soil for experimental purposes stimulates the production of ammonia from the organic matter in the soil within two weeks but the effect soon disappears. Some of this ammonia may be converted to nitrate but certainly not all. As would be expected, additions of green manure and ammonium sulphate also increase ammonia production but the ammonia level returns to practically normal in four months. Lime appears to reduce ammonia production. (*Note.*—Even the disturbance of soil in sampling upsets its biochemistry).

(2) Disturbance and aeration in collecting top soil has little effect on nitrate production. There is no rise in nitrate content within two weeks of aeration as in the case of ammonia content. The addition of ammonium sulphate, green manure or lime has no effect within two weeks. All three, however, stimulate nitrate production within four months. Green manure plus ammonium sulphate and lime plus ammonium sulphate both have a very marked and practically equal effect. Lime alone has slightly more effect than sulphate of ammonia alone. Sulphate of ammonia alone nitrifies more quickly than green manure alone. The amount of lime added in these experiments was not enough to effect the pH of the soil and it is obvious that small quantities of lime have a beneficial effect upon nitrification. Please however remember the effects of excess lime described in my previous lecture.

(3) Compared with published results for other soils, the nitrification rate in Ceylon tea soils is very low. Lack of aeration not only arrests nitrification in top soil but may cause loss of nitrate. There appears to be very little nitrification in soils collected at a depth of more than 12 inches and the production of nitrate is not markedly stimulated by aeration or addition of lime. This is something more fundamental than lack of nitrifying organisms because inoculation of sub-soil with top soil has very little effect upon the rate of nitrification even when the inoculated soils are incubated at the temperature most favourable to nitrification.

(4) Nitrate added to top soils under conditions of low aeration, especially high moisture content, rapidly disappears. There is a corresponding rise in the ammonium content of the soil but not sufficient to account for all the nitrate. If nitrate is likewise added to soils collected from below 12 inches depth it remains unchanged and does not disappear in the same way as it does in top soil.

Mr. Webster has examined some top soils. He found the samples contained a rich flora of soil fungi, especially those of the Penicillium group. The most probable explanation of the disappearance of nitrate is therefore that it has been used by soil organisms. We must not conclude too much from this, but if the fish for lunch has disappeared, and the cat is washing herself and purring, we naturally have suspicions. When these soil organisms die and decompose some ammonia is no doubt liberated. Part of the nitrogen will almost certainly be locked up in some form of humus produced from the decomposition of the fungi and this may explain the build-up of organic matter in our soils.

Referring again to the lysimeters we find that in very wet weather the drainage water shows increased ammonia parallel to the loss of nitrate added as manure. Under conditions of light rainfall the ammonia content of the drainage water falls to a very low level. This strongly supports the laboratory findings.

General Conclusions

The only practical conclusion which can so far be drawn from this work is that the top foot of soil must be managed with all possible care and skill. First it must be protected from drying out, especially alternate wetting and drying. A good cover of tea is the first essential. Shade trees and green manures must be skilfully used to supplement the cover and contribute to surface mulch. Thatch, carried in from waste areas and ravines adapted to the production of grass and other green stuff, can be most usefully employed in thin areas.

The pruning mulch is a most important protection in the bare period after pruning. I venture the suggestion that manure stirred into a moist mulch before rain will be more usefully employed than manure put in by envelope forking. At the present moment I cannot see how any sulphate of ammonia forked in deeply—if it is actually ever achieved in the field, can be utilised by the tea bush.

Secondly, this active top layer must be kept open, well aerated and freely drained. Personally I have little faith in the fork for any sustained effect. One good tea bush and one good shade tree with vigorous root systems are in my opinion worth fifty forkers. The fork must be used with skill and discretion as a means to an end, the end being that root action will eventually take over the job of the forkers—what may be called 'rootisation' of forking. Feeding roots will aerate and deep roots will drain. Channels formed by rotting roots of shade trees cut out in rotation will materially assist drainage.

Once this soil attains a good structure, and organic matter is vital to structure, it will stay open, aerated and drained. Our soils have a naturally good structure which is destroyed by excessive cultivation. If you do not believe me, go and look in the jungle, where you will find that surface mulch and good cover go hand in hand with good structure and free drainage. Alternatively, come and look at St. Coombs estate, where persistent efforts to practice these ideas is undoubtedly having the most beneficial effects.

The more theoretical conclusions or perhaps I had better say indications, for the work is in its early stages, are that fungi play an important role in Ceylon tea soils. There is little doubt that decomposition of organic matter is intended by nature to take place on the surface of our soils, for there is a remarkable scarcity of small animals, worms and insects, which on other types of soils are doubtless intended to incorporate organic matter in the soil. The downward movement of organic matter must I think be largely achieved by the passage of decomposition products from surface fungi to other organisms at lower levels, which, in turn, flourish, die and humify.

Nitrifying bacteria, which are difficult organisms to isolate and identify, appear to take some part in nitrifying processes, but they are generally supposed to be intolerant of acid conditions. It is not improbable that fungi stimulate them to some extent by production of ammonia which, being alkaline, will afford temporary protection from the inhibitory effects of acidity. Much tedious research is essential to find how nitrogen does become available to the tea bush, but there is obviously an elaborate natural mechanism to prevent its loss by leaching out of the soil.

Finally I urge the necessity for a vigorous programme of basic research work. Field experiments and practical trials both at St. Coombs and in other districts are undoubtedly of the first importance and the ultimate goal of the Tea Research Institute is acknowledged to be the provision of sound practical advice. The ultimate goal cannot however be achieved without a primary objective and this must be basic research into the fundamentals of the various branches of science which lead up to the practical findings. As this is my final lecture as Director of the Tea Research Institute of Ceylon, I do, most sincerely, urge the industry to ensure that basic research is never stinted, that generous facilities and experienced workers trained in research methods are always maintained at a strong and active central station, where the various research specialists work as a team.

Do not at any cost allow the Institute to disintegrate into a series of small units trying to give advice on localised problems without an adequate backing of sound fundamental knowledge.