

SELECTED NOTES ON THE MANURING OF TEA*

T. EDEN, DSc (Manc.) AIC

INTRODUCTION

From time to time addresses on the subject of manuring have been given to the various District Planters' Associations. The addresses in question have sought to relate the general principles of agricultural chemistry to practical problems and to illustrate the arguments used by data from the Institute's experiments.

Although these addresses have been published regularly in the pages of *The Tea Quarterly* a request has been made that their essential parts should be gathered under one cover. This Bulletin is the result. The notes that follow do not claim to be any more complete or definitive than the original lectures and are, in the main, only edited reproductions of their salient parts.

This publication should, therefore, be regarded as an interim account of a subject which will receive further attention when, in the course of the naturally slow development of agricultural experiments, more complete information is available.

*Reprinted from the TRI Bulletin No. 16, 1-20, 1936.

HISTORICAL ASPECTS

Any attempt to describe manurial practice must take some account of past history; Ceylon will be chiefly used as the example, but India and Java have passed through parallel stages, and divergences will be noted in their place.

The cultivation of tea was marked in the first place by a thorough-going exploitation of natural resources. Land under virgin forest was cleared and planted, and for a considerable time no thought was given to manuring. In Ceylon this period was shorter than elsewhere because tea was a comparatively late arrival, and superseded coffee when disease destroyed the earlier industry. A questionnaire circulated in 1896 and answered by sixty representative correspondents, showed that at this date manuring was a novelty, but that the practice was spreading on old coffee estates; it was sometime before occupants of virgin land learned their lesson from the older cultivators. At this time it was admitted that crop increases were assured by manuring, and there was no preponderating fear that harm would result either to the permanent health of the bush or to quality of the made tea. The sources from which manure was drawn were inevitably local, and oilseed cakes and bones from India were chiefly used in the proportions of four parts of cake (castor seed) to one of bones. Applications were irregular and not more frequent than every other year.

During the ensuing ten years there was a marked expansion in manuring. Nitrogen, as always, was the chief manurial constituent, and organic forms were predominant. Mann reports that in 1907 no sulphate of ammonia was used by the tea industry of North India and that only 40 tons of superphosphate (made locally) could be traced. In Ceylon both these manures had obtained a footing but the quantities did not exceed 500 tons. Fashions in nitrogenous manures changed according to supply, demand, and price, and import data list varying quantities of castor, groundnut, rape, and mustard cakes.

The manner of this introduction of artificial manures is of considerable interest, because later the belief

arose that nitrogen in these (organic) forms was more steadily available than that supplied by "soluble artificials" and was better for preserving quality. In the absence of large industrial centres that could produce the more highly manufactured inorganic products, it seems probably that there was a considerable *post hoc, ergo propter hoc* element in the birth of this hypothesis.

The next decade, which closed at a time when war influences were being felt in the fertilizer industry, saw the introduction of a large variety of fertilizers, though local material remained predominant. In particular, inorganic manures were being imported at competitive prices and, in consequence of trials and demonstrations by the research stations of India and Java, they became an important factor in manurial schemes. In India and Ceylon, superphosphate, basic-slag, and sulphate of ammonia were enjoying considerable popularity at this time as shown by Hope's qualitative review of the manurial situation and Bruce's compilation of import figures for Ceylon. The latter figures refer to all the visible supplies, no matter on what crop they were used, but they reflect the position as regards tea to this extent, that the only serious competitor for manures at this time was rubber, with an acreage, in 1917, of only half that devoted to tea.

The first point that emerges from a study of import figures is the variable fashions in the use of particular manures. In the early part of the period, castor cake was the favourite fertilizer, but it soon found rivals in the groundnut cake and fish manure. From 1916 castor cake has been in decline, and amongst organic artificials groundnut cake has the predominance. It is evident also that fish manure has given place to fish guano; rape cake has been virtually abandoned, whilst bloodmeal provides a substantial though only moderately popular source of manurial nitrogen. These fluctuations are doubtless largely determined by corresponding changes in price per unit of nitrogen and by the ease with which supplies can be maintained.

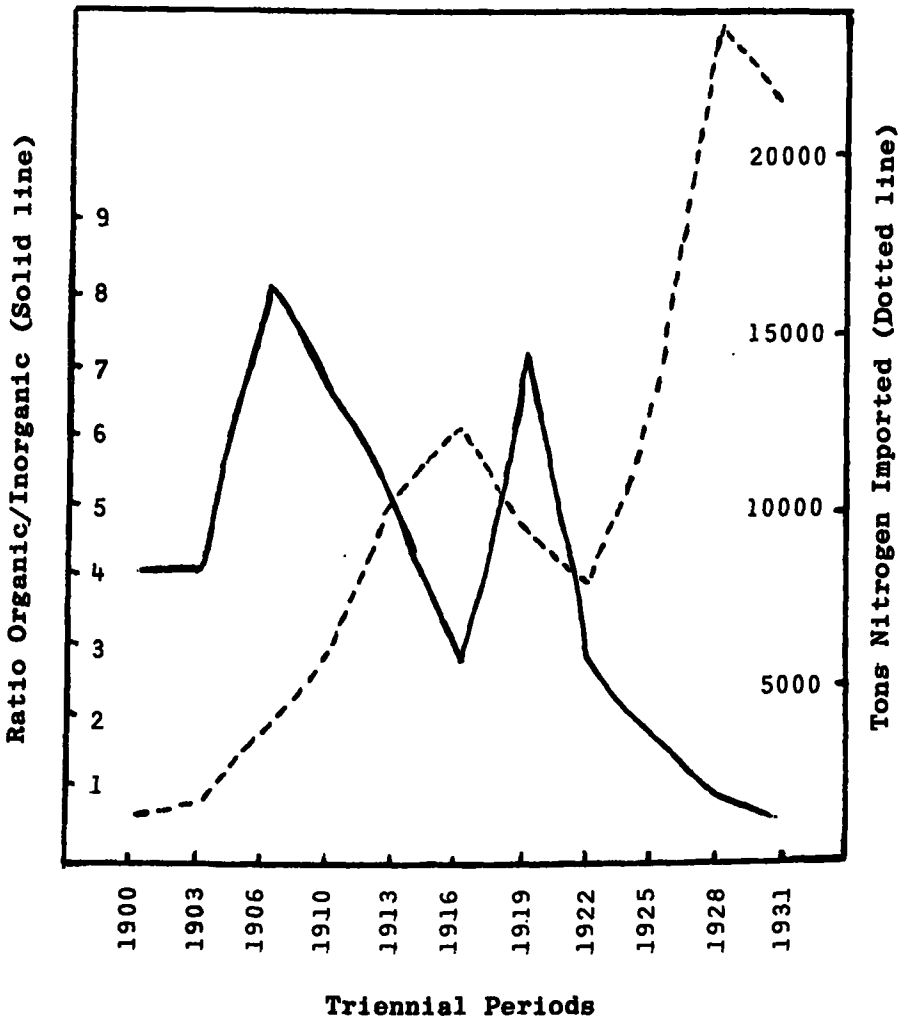
Of the inorganic fertilizers, sulphate of ammonia stands in a class by itself. The cheapest of all sources of nitrogen, its use has progressed by leaps and bounds till now it is not only the largest individual source,

but has suffered less decline than other important fertilizers, and is supplying more nitrogen than all the organic sources put together. Nitrate of soda comes second, but both this fertilizer and cyanamide have entered a very chequered stage in their history.

Equally interesting are the figures for total nitrogen employed. In general they show a steady increase checked by circumstances of a non-agricultural nature. The war years and the 1920-1921 slump had an appreciable effect on imports, but recovery was rapid and mounted to quite astounding figures for the period 1925-1931, notwithstanding the uncertainty of the rubber situation towards the end of this period. At the time of maximum prosperity, the consumption of nitrogenous fertilizers was almost double that reached in the undisturbed period immediately prior to the war.

No account of nitrogenous fertilizers would be complete without some more particular reference to the organic *versus* inorganic manure situation. In the early days, inorganic nitrogen was negligible in quantity. This was naturally so because supplies were far distant. Till after the war sulphate of ammonia was obtainable solely as a byproduct of the gas works industry, whilst nitrate of soda is a South American product. Oil cakes on the other hand lay near at hand in India. The sudden increase in ratio in the period ending 1906 is perhaps at first surprising. It coincides with an important increase in total consumption for which probably the late Mr Joseph Fraser's advocacy was largely responsible. Under conditions of sudden expansion, and supplies of inorganics being less mobile, the brunt of the demand would naturally fall on readily obtainable organic manures. The graph shows that from this period the decrease in use of organic nitrogen has been steady, except for the exceptional circumstances of the war years. This is an even more positive and striking instance of the effect of supply and demand. Lack of tonnage cut out inorganic fertilizers imported from a distance and the highest ratio but one was attained. By the time the next triennium was complete the normal figure had been regained.

In assessing to what extent the tea industry has participated in these remarkable changes some reference



to the growth and practice of other agricultural enterprises is necessary. Taking the figures up to 1917 it is fair to represent them as largely reflecting conditions of tea manuring. At that time, for every acre of rubber in bearing there were two acres of tea; moreover, a young industry exploiting fresh natural resources seldom if ever manures as intensively as its older counterparts. During the last two periods rubber manuring has been diminished for other recognisable reasons, so that over a large portion of the total period the conditions obtaining on tea estates have been the predominant factor.

Hand in hand with the increased use of artificial manures there has been an increase in green manuring. Starting in the form of loppings from shade trees, progress has been steadily maintained till at the present time leguminous bush crops and some ground cover are in addition commonly interplanted with the tea. The advocacy of Bamber and Wright in Ceylon and of the research stations in North India and Java has played a large part in establishing green manuring as a general policy. There is no doubt of the gain to soil conservation that has resulted from the use of green manures, though there has been a tendency to exaggerate their potentiality as a conserver of nutrients, because it has commonly been assumed that the whole of the nitrogen returned to the soil is bacterially-fixed nitrogen.

A subsidiary method of manurial conservation is that of burying tea prunings. Formerly, much woody tissue was buried, which not only complicated the soil nitrogen cycle, but was instrumental in spreading root diseases. For a time a lively controversy was maintained between the advocates of burying and of burning, respectively. It is now usual either to fork in the soft green shoots or to mulch the prunings and beat off the dried leaves for subsequent burial. Except in areas of severe root disease no epidemic from this cause seems to occur.

CHEMICAL ANALYSIS AND MANURING

The problem of obtaining the maximum value from artificial manures is one which has become particularly urgent since the decline of the tea market set in. The most satisfactory basis for manurial practice is that afforded by accurate experimentation on tea, but at present there are relatively few data relevant to present needs though efforts are being made by the Institute to acquire them. Nevertheless, there are certain principles of general application that are not so widely understood as they might be.

The first general consideration of importance is that of the relationship of soil analysis to manurial practice. There is no difficulty in determining accurately the amounts of the various nutrients that are to be found in the soil. Anyone who is interested in such data can obtain it from half-a-dozen sources without go-

ing out of Ceylon. Moreover, the analyses of different analysts would agree. Where unanimity of opinion might probably be lacking is in the interpretation of the results so obtained. What does a given chemical analysis of the soil mean in terms of plant behaviour? Methods for determining chemically that portion of the plant nutrient that is available are admittedly tentative. They frequently fail for two reasons. They may err considerably in their estimate of what portion is useful to the plant, and they frequently give no information at all as to how rapidly the unavailable portion is transformed into available supplies. It is obviously important to know, so to speak, not only how much palatable food there is in the storeroom, but also how rapidly it can be transferred to the table. As an illustration of the kind of difficulty met with in actual practice, examples are known of data showing that a series of soils, known to differ widely in phosphate content, showed negligible differences in the phosphate content of their soil solution. In actual yield response the plants grown on these soils differed widely, but not in proportion to the total phosphatic supply of the soils.

The foregoing does not invalidate the use of the soil analyses in special cases. Much sound advisory work has been done by combining a wide knowledge of soil analysis with agricultural observation and acumen, or better still with actual field experiments of proved accuracy. In general, however, such analytical work has proved valuable only in special circumstances on well-defined soil types, with a few specific crops. It has been more successful for nitrogen requirements than for potash, and the case of phosphate has been least satisfactory of all.

A way out of this *impasse*, which one hopes may be temporary, has been sought in the analysis of the plant itself, but here again soil analyses and analyses of plants grown on the respective soils do not tally. There is no equivalence nor even a fixed ratio between the amounts of nutrients in the crop and the amount needed or supplied as fertilizer. By way of illustration, at Rothamsted, winter rain causes a loss of 1.4 bushels of wheat per acre which represents a loss of two pounds of nitrogen in the crop. It requires eight pounds

of nitrogen applied to the soil, however, to make good that damage. Again, the average phosphatic content of the tea crop is lower than the average content of nitrogen or potash: the quantity of phosphate normally applied to the soil is on the other hand greater than the quantities of nitrogen or potash used per acre. In view of the crop analyses it may at first appear a wrong practice to apply such large quantities of phosphate, but experience shows that the utilisation of added "soluble" phosphate is low and never exceeds a 15 per cent recovery of what has been added. In the face of these inquiries it must be conceded that field experiments offer the best method of judging manurial requirements and that the soil and plant analyses should be regarded as ancillary weapons only.

There should be little need at the present time to emphasise the necessity for supplying all the major nutrients in manure mixtures. As far as our knowledge of manurial balance goes, in Ceylon, definitely ill-balanced rations seem to be the exception, but the point may well be stressed that economy in manuring should never be made at the expense of a single ingredient. One nutrient will not work efficiently in the absence of the others. To illustrate this point an experiment may be mentioned in which nitrogen was supplied in the presence and absence of mineral nutrients. Since the plants were grown in pot culture, leaching losses did not occur, but results showed that the nitrogen recovery by the plant in the plots supplied with mineral manures exceeded that attained in their absence by 50 per cent.

TYPES OF MANURES

In surveying the field of organic and inorganic manuring, manures can be divided into four classes:

1. Inorganic artificials
2. Organic artificials
3. Green manures
4. Bulk manures, including composts

These four classes have all special characteristics of their own.

There should be no ambiguity as to what is meant by an inorganic artificial. It is a material made either synthetically or derived from mined deposits which are not derived directly from animal or vegetable material. Nitrate of soda, sulphate of ammonia, cyanamide, potash salts, and rock phosphate derivatives fall naturally into this class. Organic artificials are taken to include the residues from plants or animals, such as oil-cakes or animal offals and are familiar in terms of groundnut cake, whale and fish guano and bloodmeal. Green manures need no definition. Bulk manures and composts are essentially vegetable material, with or without animal excreta, that have undergone a process of fermentation.

These types can be separated into various classes. First they can be divided roughly into soluble and insoluble manures, putting the nitrogenous members of class (1) by themselves as soluble, with the exception of cyanamide. But even amongst inorganic artificials a distinction must be made. Suppose nitrate of soda, sulphate of ammonia and muriate of potash are considered. Ordinarily speaking, these are all highly soluble materials, but in the soil they behave differently. In nitrate of soda it is the nitrate portion that is of interest, and it is correct to regard this nitrate as readily soluble and easily leached away. With sulphate of ammonia the ammonia portion is wanted, and with muriate of potash, the potash is the important part. Now, soil has the power of removing from solution these important parts of the manure and of fixing them. An experiment to show that this is the case is very easily contrived, and has been frequently demonstrated to visitors at St Coombs. Sufficient to say at the moment, that a so-called soluble manure does not necessarily behave as such in the soil immediately.

These groups can also be separated according to a further criterion, particularly with respect to the behaviour of their nitrogen. Which are readily available and which less so?

It is admitted on all sides that the compounds of nitrogen which a growing plant can directly use are fairly simple. The old text-book notion that every

form of nitrogen must ultimately be changed to nitrate before it can be absorbed by the plant, is now known to be fallible, but the classes we have been considering do vary most markedly in the complexity of their nitrogenous compounds. The main step in arriving at this complexity is when the nitrogen is chemically combined with carbon as is the case with organic artificials, green manures and bulk manures. At first sight therefore it looks as if organic nitrogenous manures should be classified as markedly less readily available than inorganic nitrogenous manures.

Actually it is not quite as simple as that. To a large extent the rate at which a complex compound will break down to a readily available one is determined by the proportion of carbon to nitrogen in it, i.e., the much-quoted carbon-nitrogen ratio. This aspect will receive further attention later. Usually an organic substance containing more than two per cent of nitrogen will easily furnish available nitrogen, and the higher the percentage of nitrogen the more readily available it will become. From this it follows that inorganic artificials and organic artificials with percentages varying from four to twelve-and-a-half, readily supply nitrogen usable by the plant, and may be classed together. Dr Joachim's experiments confirm this classification in work he has carried out at Peradeniya. On the other hand, green manures, bulk manures and composts may have quite a lot of nitrogen in them that is only slowly available.

Another point is that relating to the difference between green manures and bulk manures and composts. The availability of green manures will depend largely on their having a suitable carbon-nitrogen ratio when dug in. The other two materials are usually made from products where the carbon-nitrogen ratio is too high for immediate use, but the fermentation processes in manufacture modify the ratio in the direction of increased availability.

A further point of view is that of the effect of these manures on tilth or the physical state of the soil. In so far as the addition of organic matter is the cause, then bulk manures stand in a class apart. The few hundreds of pounds of organic material contributed

by an organic artificial to the 2½ million pounds which represents the weight of soil to a depth of nine inches over an acre, is a mere drop in a bucket. It may be of interest here to say that so far as tea is concerned, sulphate of ammonia preserves tilth, but continuous use of nitrate of soda in large quantities destroys it.

Reviewing the classification of manures, it is evident that on all counts organic artificials resemble inorganic artificials more than they do the bulk manures, composts and green manures. Without further examination, therefore, all the virtues which are known to accompany the use of bulk organic manures cannot be claimed for organic artificials.

The question has arisen recently whether organic manures contain any accessory foodstuff analogous to vitamins, or some growth regulating substance which will impart to them special properties. This may possibly be the case. At present one of the most exciting lines of chemical and plant physiological research, in relation to agriculture, is the search for growth regulating substances. Such substances have been found, but their properties are not yet well understood. A substance which promotes growth in the above-ground portions may act as a growth restricting agent as regards the roots. These substances appear to occur both in animal and vegetable tissues, and we are not in a position yet to say whether they are generally necessary as additions to ordinary plant nutrients, or whether the plant ordinarily contains sufficient for all normal growth. But current opinion is disposed to think that green manuring offers a means of supplying or preserving these little known substances. This information is given for what it is worth, because it seems that it is on these lines that any attempt to distinguish "inorganic" from "organic" manures must proceed.

RELATIVE COST OF MANURES

Manurial enquiries cannot go very far without considering cost of manure. If there is one thing that is inexcusable and meaningless it is the common practice of talking about manurial doses as so many hundred pounds, without consideration of what those

poundages represent in useful food material. Nitrogen, potash or phosphoric acid are never added alone; they are always in combination with other materials and so 400 pounds of this, or 500 pounds of that, means nothing in terms of utility or price. There are about a dozen different forms of nitrogen to choose from, and somewhere about the same number of possible sources of phosphoric acid, and there are four or five types of potash compounds. They differ in price per ton, and, what is of real importance, in price per unit of useful foodstuff. It is usual to calculate the unit price of, say, nitrogen for these various kinds, by dividing the cost per ton by the percentage composition. This figure is actually the price of 22.4 pounds of the nutrient (not the manure) and hence a comparison of unit prices tells one immediately which is the cheapest manure. By way of illustration consider a manure mixture supplying per acre nitrogen 40 pounds, phosphoric acid 30 pounds and potash 20 pounds; and that using the cheapest forms of the last two we are considering what kind of nitrogenous manure to use. It will be found that of those in extensive use, sulphate of ammonia is cheapest. We can then calculate the cost of the other mixtures and find how much dearer they are.

The following figures are the increases in cost per acre, based on recent quotations, which these other kinds of nitrogen would entail for exactly the same amount of nutrient:

		Increase cost per acre for standard mixture
		Rs
Nitrate of soda	...	6.00
Groundnut cake	...	10.00
Bloodmeal	...	17.00
Castor cake	...	21.00
$\frac{1}{2}$ Sterilized animal meal		21.00

In the last figure the composition of the mixture is such that only half the nitrogen could be supplied in this form and the rest is assumed as being sulphate of ammonia. Without discriminating in detail between these sources of nitrogen it is obvious that some are vastly more expensive than others. Ultimately it is for the user to decide whether, taking every aspect of the case into consideration, the benefits that accrue from the use of the higher-priced materials balance the increased crop or value of crop. We have not tried them all at St Coombs but we have groundnut cake, blood meal and sterilized animal meal under examination. The figures relating to blood meal over the past five years show that the crop harvested is the same as with sulphate of ammonia (for these actual doses considered), that the distribution of crop throughout the cycle is identical, *i.e.*, that no rush of crop follows the use of sulphate of ammonia, and that no consistent differences have emerged in the characteristics of the finished teas.

This point about the distribution of the crop is important. It casts grave doubts on the availability-by-slow-stages view which has already been shaken by Dr Joachim's work previously referred to, and, whilst it does not settle the inorganic *versus* organic question, it leaves little room for the specification of mixtures with four or five different types of nitrogen compounds in them.

METHODS OF APPLICATION

Having decided on the composition of the manure mixture on these general grounds, it is advisable to have a last look at it from one other point of view, its distribution. The benefit of the best manures can be very much discounted if bad distribution is taking place. Ease of distribution will be affected by the consistency of the mixture. Great improvements in the consistency of purely inorganic manures have recently been made, but substances, such as muriate of potash will always remain potentially hygroscopic, and phosphates will always be liable to cake in this climate. For this reason it is advisable to include a "conditioner" to the amount of 10 per cent of the whole, in order to prevent caking. An inert substance like coir dust could be

added, but that would increase freight without providing any appreciable nutrient, and by far the best way is to use the organic nitrogen compounds. Castor cake and blood meal are most suitable, and it is surprising how well a little of these answers the purpose. When speaking of a conditioner it must be understood that what is meant is something that keeps the manure mixture in condition, and not something which has any effect upon the soil. The addition of these conditioners also increases gross bulk and, against heavier freight charges there must be set off the improvement in distribution obtained in the field when larger quantities are employed.

Next comes the problem of putting manure on. There are one or two fundamental principles in the matter of application which can be deduced from technical considerations, but apart from these, application is chiefly a matter of practical expediency. All methods have disadvantages and it is simply a question of weighing up the *pros* and *cons*.

Dealing first with the technical considerations, deep cultivation is the prime necessity for two reasons: shallow cultivation encourages soil erosion, and however well and instantaneously soil fixes manurial principles, if the shallow top soil containing the manure is lost, the manure also is lost. In addition, since a high degree of immobilization takes place, especially with phosphate, it is essential to get the manure well into the root range of the plant.

Another important thing to remember is that the motion of soil water in the ground is mainly vertical, and that unless a hard pan interferes and deflects the downward motion, lateral movement is pretty well ruled out. The most striking demonstration of this is on the Rothamsted grass plots where the use of various manures has changed completely the flora of the various plots during eighty odd years of continuous treatment. There are no paths to separate the plots, but a dead straight line can be drawn down the dividing line, with one species of grass on one side and a totally different one on the other, so infinitesimal has lateral motion been.

Looking at present and past practice in the light of these details, the scraping in of manures by means of

small hand forks or such like implements can be ruled out. With deep-forking three possibilities remain: (a) general broadcasting, (b) distribution over limited areas such as a half circle above the bush, (c) placing a stated quantity of manure behind every fold of envelope-forking at the time of forking.

The first method has the advantage of getting the manure widely distributed and encouraging wide development of the root system. It also enables the Superintendent to see where his manure has gone. Misapplication of the standard rate is reasonably well visible. Its disadvantage is that with present systems of forking some appreciable proportion remains on the top. There is little danger of this being washed away, because the corrugated surface is a good hindrance, and with deep cultivation the movement of soil in heavy rain storms soon after application should not normally occur; but it must be admitted that a certain proportion of the manure is not deep seated. Whenever possible it is well to combine artificial manuring with forking in of prunings, mulch or actual lop-pings; lop first, and then distribute the manure on top, so that when the vegetable matter is pushed home into the fold, the adherent manure is carried with it. Apart from this, it is excellent practice to use green stuff or mulch in conjunction with artificial manuring.

The half-moon system concentrates the manure on a smaller area, and in forking it is doubtful whether a larger proportion becomes deep seated; because of what has been said about lateral movement of soil moisture, apart from actual soil wash one cannot expect manure to diffuse very satisfactorily over the rest of the area. The method makes easier the rationing of the manure over the prescribed area, but not its even distribution. The manure-behind-the fork method would be ideal in a world of perfect workmanship, but more than either of the other methods it lends itself to abuse. As things are it is too easy to dump large quantities in the folds near the manure base and, effectively covered up as it is, detection is not so ready.

SUMMARY OF RESULTS FROM MANURING EXPERIMENTS

The Institute's manurial trials are now in their sixth year. The results so far can be summarised as follows:

INFLUENCE ON YIELD

Nitrogen is the chief yield promoter in tea; up to 40 pounds per acre per annum (the upper limit for which results are at present available) the response is directly proportional to the quantity applied. On an average 1 pound of nitrogen may be expected to produce 4 to 5 pounds of tea.

The nitrogen of artificial manures of the various types is not used very efficiently. The data of the Institute's experiments provide the only estimate made of the efficiency of manuring in the sense of a comparison between the amount supplied and amount recovered in the growing plant. The percentage recovery in new growth is under 20 per cent.

These two facts show that normally the largest part of the crop secured is the result of nutrients derived from the soil rather than from the practice of artificial manuring.

So far no difference between the yield capacity of inorganic and organic nitrogenous artificials has emerged, nor any evidence that the former produces rush crops shortly after application.

During the five completed years potash has produced no increase in crop.

Varying quantities of phosphoric acid were not studied in the first pruning cycle; in the second cycle in progress 30 and 60 pounds per acre were included. The results show that the beneficial effects of phosphoric acid are limited to the smaller dose, there being no further yield increase when an extra 30 pounds is included in the manurial mixture.

There is no evidence that at different times in the pruning cycle, manures of different ratios with re-

spect to nitrogen, phosphoric acid and potash are necessary.

The returns from mixtures applied at pruning time are small and cannot be relied upon. Recovery from pruning appears to be governed by the reserves present in the bush and not by manures applied at a time when the bush is devoid of foliage.

Manures applied late in the pruning cycle do not benefit the crops in the succeeding cycle in comparison with manures applied early in that cycle, *i.e.*, any superiority in growth shown at the end of the cycle as a result of this pre-pruning mixture is subsequently lost owing to the intervention of the pruning operation.

INFLUENCE ON QUALITY

Nitrogen in the moderate quantities used (40 pounds per acre) has no harmful effect on the quality of the manufactured tea. No distinction can be drawn between inorganic and organic artificials in this respect.

Up to the present, phosphate has shown no significant effect.

At the end of the fourth year of these experiments potash began to show an effect which has so far been consistently maintained in the favour of potash manuring.

GREEN MANURES AND COMPOSTS

Green manuring has been practised in Ceylon for many years and few would gainsay the benefits that have been derived from it. But because the term green manuring is so wide, and the methods of carrying it out so varied, this agricultural operation does not admit of so wide a generalisation as the ordinary practice of artificial manuring. Artificial manures are relatively few in number and their production is standardised. Green manures are many and varied and the product that is turned into the soil is by no means standardised; consequently at times disappointing results have been obtained.

The fundamental principle of green manuring is relatively simple and will be described in some detail later, but as carried out in Ceylon, a distinction must be drawn between green manuring and artificial manuring. Artificial manures provide entirely new nutrient for crop development. They have distinct disadvantages such as the relatively transient existence in the soil of the nitrogenous manures, organic as well as inorganic, but the manure applied is a definite outside contribution to soil fertility and properly used this is a valuable contribution. Green manures on the other hand only make a new contribution if they are leguminous. Even in this latter case the whole of the nutrient supplied to the soil when green manures are forked in is not new, *i.e.*, is not the product of bacterial fixation. Some of it has been derived from normal soil resources and has merely been temporarily removed from the possibility of absolute loss by leaching. This in itself is important, but green manures can never rightly be regarded as suppliers of nutrient as artificials and farm-yard manure can. They are really conservers of nutrient more than suppliers. It has become a habit in some quarters to ask for analytical details about green manures and to calculate, from these and estimated yields, the amount of nitrogen, potash and phosphoric acid put into the soil at each lopping. Imposing figures are thus produced which have no relation to actual gains. Most of the nutrient elements concerned are circulated again and again in a cycle of changes that alternates between the soil and the plant, so that the figures sometimes quoted are in the nature of turn over, not of profit.

The right use of green manures necessitates some knowledge of the processes taking place when vegetable material is returned to the soil. The following is a sketch of what occurs put as briefly as possible.

THE PART PLAYED BY MICRO-ORGANISMS

Vegetable material is decomposed by the activities of micro-organisms, both fungi and bacteria. They are not consciously altruistic, and their main concern is food. As in higher organisms, the food they require is of two types, that which supplies energy for

their activities, and that which supplies body-building material. The energy-supplying foods are mainly sugars

Table 1

Composition of various materials with respect to Carbon and Nitrogen

Material	Carbon per cent	Nitrogen per cent	Ratio C/N
1. Leaf of tea prunings ...	43.65	2.52	17.3
2. Maana grass ...	45.29	1.68	26.9
3. Dadaps ...	45.39	4.06	11.2
4. Tephrosia vogelii	45.08	3.92	11.5
5. Tares ...	40.1	3.01	13.3
6. Mustard ...	39.9	1.51	26.4
7. Straw ...	40.9	0.32	127.8
8. Blood meal ...	41.5	11.1	3.7
9. Ground-nut cake	44.9	7.92	5.7
10. Farm-yard manure	30.9	2.15	14.4
11. Compost (Single sample) ...	18.72	1.77	10.6
12. Indore Compost (Howard) ...	-	-	10.8-16.5

Table 2

Nitrogen in various portions of the Tea Plant

	Per cent.		
Bud and first leaf	4.84
Second leaf	4.47
Third leaf	4.07
Foliage leaves	3.48
Flush	4.09
Pruning wood	0.85

and starches and other allied compounds that the chemist classifies as carbohydrates. For body-building the organisms depend, as we do, largely on proteins. Having consumed these foods, their tissues exhibit a very nice balance of the two main constituents of these foods, carbon and nitrogen, and so, on their death, they tend to cause an accumulation in the soil of material of fairly standardised composition with respect to these two elements. That is the reason why the ratio of carbon to nitrogen in soils is, within reasonable limits, so constant, with a value roughly of ten. Now the logical outcome of this manner of decomposition is that if the organisms find a very abundant supply of carbon, they will grow and reproduce themselves up to the limit prescribed by the amount of nitrogen available to them. On the other hand, if nitrogen is plentiful and carbonaceous material is short, activity will stop when the latter is exhausted. The ideal is attained for them when the vegetation they are attacking supplies balanced rations of both foods. In nature this seldom happens. There is sometimes a surplus of nitrogen and this from a cropping point of view is generally advantageous, for this surplus nitrogen, broken down into similar compounds, becomes readily available to the crop. Sometimes there is a surplus of carbon and the organism demolishes what nitrogen is in the vegetation to start with, and subsequently sets out to commandeer further supplies in the form of nitrates and other simple forms present in the soil. This is obviously unsatisfactory agriculturally because it means that there will for some time be an acute shortage of simple nitrogenous compounds upon which the crop can live. In point of fact, if the material used as microbial food has a carbon-nitrogen ratio much greater than 10, nitrogen starvation for the crop can be expected for some time. If the ratio is less than 10, a readily available excess of nitrogen can be expected for the crop. Provided the excess is not so great that it can be leached away before the crop has time to use it, this is all to the good. One other point remains. Carbon, as has been said, is an energy provider. It is partly used up in the process of breathing to produce carbon-dioxide gas which is liberated. The complete picture in brief therefore is that materials of high carbon-nitrogen ratio will lose

carbon and retain nitrogen till the equilibrium figure of 10 is reached, whilst materials of low carbon-nitrogen ratio will lose nitrogen and to a large extent retain carbon till they also arrive at the same equilibrium point. That is the basic conception.

PRACTICAL APPLICATION OF THE CARBON-NITROGEN RATIO

Admitting then that a certain amount of care is necessary in choosing materials for putting into the soil, what criteria should be adopted in making the choice? For the type of material that would naturally suggest itself for use as green manure, it happens that the carbon content is tolerably constant, so that a fair idea of changes in the carbon-nitrogen ratio can be had merely by considering changes in the nitrogen composition. Table 1 gives a selection of carbon and nitrogen contents and their ratios for a series of substances. It thus follows that a material poor in nitrogen is unsuitable for direct incorporation in the soil. The older the plant, or portion of the plant, the less its nitrogen content, as can be seen from Table 2 which gives a selection of figures for tea leaves, and the woody portions of prunings. Normally, in a shade tree, the leaves and flexible green branches will have a suitable nitrogen content. In bush crops the period just before flowering will give the optimum average figure for nitrogen. It will be noticed how low in nitrogen pruning wood is, and hence how unsuitable for forking in. Wood is unsuitable for another reason. Its tissues are highly lignified and this lignin is very resistant to microbial attack. Being so intimately associated structurally with the other tissues, it acts as a preventative factor in the course of decomposition.

In agricultural terms then we may say that green leafy material is suitable for direct green manuring, that woody and pithy tissues are definitely out of the question, and that straws or the standing foliage of plants producing seed, which have accumulated in that seed nitrogen withdrawn at the expense of the vegetative tissue, are generally unsuitable for direct green manuring. If used, they are likely to produce the nit-

rogen starvation effect.

THE ALTERNATIVES: GREEN MANURES VERSUS COMPOST

There is a school of thought led by Howard and Anstead, that will not admit that any green manures are suitable for direct incorporation in the soil. In this connection the last column of Table 1 is of interest. It is admitted generally, and by the adverse critics of green manuring in particular, that a ratio of 10 to 1 for carbon-nitrogen is ideal for the purposes of plant nutrition. Of the first four materials listed in that Table, all of which are in common uses as producers of organic matter in Ceylon, two, namely dadap and *Tephrosia*, representing our main types of green manure, are as near to the optimum value as one is likely to get in an imperfect world, whilst tea pruning leaf is not far removed, relatively speaking. For comparison the range of ratios given in Howard's "Waste Products of Agriculture" for finished compost are shown in the last line. Maana grass stands in a different class. It thus appears that the contention that green manures and pruning leaf in Ceylon have a carbon-nitrogen ratio which renders them quite unsuitable for direct incorporation as green manures in the soil, is not valid. The cost and trouble involved in composting our loppings is therefore unwarrantable, since the object of composting is to produce a suitable carbon-nitrogen ratio. Used as one constituent amongst others of higher ratio they serve a useful purpose, provided they are not taken from amongst the tea but are grown on waste land.

The foregoing discussion leads naturally to the case where composting has a contribution to make. Where materials such as manna grass are available, the carbon-nitrogen ratio must be adjusted before application is made. It will be adjusted in the properly made compost heap by fermentation which dissipates the surplus carbon as carbon-dioxide whilst preserving the nitrogen. Item Number II in Table 1 shows how much lower in carbon content an average compost is than the raw material from which it is made.

Attention has already been drawn to the fact that the carbon-nitrogen ratio of finished compost represe-

nts an equilibrium point which can be approached from both sides, *i.e.*, by loss of carbon or by loss of nitrogen. The practical application of this is that to attempt to manufacture a specially rich compost is to defeat the ends for which compost is conceived. Composts are sometimes made solely or almost solely from refuse teas. Apart from the fact that refuse teas can be used direct, in the compost heap they are liable to lose their excess nitrogen in the attainment of the equilibrium, and so the process is unsatisfactory on two counts.

THE USE OF MULCHES

Passing now to a different though a related topic, various people, especially in dry zones, have made a practice of using maana grass as a direct mulch over the surface of the soil. Results on coffee have shown enhanced yields from this practice. Mere observation shows that it maintains soil moisture better than any attempt to produce a so-called dust mulch by cultivation, and that in times of heavy rain it checks erosion. From the point of view of moisture conservation it is extensively used in Assam on nursery beds. In Assam, where seed is sown in the dry season, frequent watering is not practised, and the nurseries have to subsist on scattered rains helped out by this protective device. The mulch must therefore not be so thick that light rains cannot penetrate. The point of contact with the present subject is that, bearing in mind the carbon-nitrogen ratio of 27 for maana grass, it is advisable, when such a mulch is eventually forked in, to plan that the mulch is incorporated with a normal dose of artificial manure.

CONSERVATION OF NITROGEN

One of the reasons for green manuring is to form a cycle of changes whereby readily available nitrogen, which cannot be immediately used for nutrition of the major crop, is locked up in green manure vegetation, returned to the soil, and then gradually released. Throughout the whole of this discussion it should have been evident that the only method for conserving nitrogen in the soil is by linking it with carbon. In past years this fact was tacitly assumed as the basis

for the advocacy of organic artificials. In these materials carbon was linked with nitrogen, and the availability was thereby thought to be greatly decreased in comparison with inorganic fertilizers. To a large extent the availability of the nitrogen in these manures depends on their carbon-nitrogen ratio. It is interesting therefore to see where they stand. Table I contains two examples, blood meal and groundnut cake, and for comparison farmyard manure. Both the organic artificials are well on the low side of the ratio; they cannot, as is frequently done, be classed with farmyard manure. Their nitrogen is really quite readily available, which explains why the cropping curves, following the use of organic artificial manures, are so similar to those for inorganic manures. Without entering further into the respective merits of organic and inorganic manures these facts must be borne in mind before too much importance is attached to the slow but steady supply of nitrogen in organic artificial fertilizers. On the evidence available, green manuring or composting, under the special circumstances where it is an economic proposition, offers the best means of conserving nitrogen in the soil.