SECTION I

THE PRINCIPLES OF GREEN MANURING AND THEIR APPLICATION IN CEYLON

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INTRODUCTION

GREEN manuring is an agricultural practice which dates back to ancient times, but it is only comparatively recently that a scientific study of the subject was begun. Simultaneously with the development of our knowledge of green manuring, the adoption of the practice extended. At the present time it is widely practised in both temperate and tropical agricultural countries, and particularly so in the latter. The reason for this is not far to seek. Green manuring offers so many advantages to both soil and crop and its effect on the latter are so markedly evident, that it was bound to become popular wherever these advantages were demonstrated. In Ceylon, green manuring, in the widest sense of the use of plants for conserving or increasing soil fertility directly or indirectly, has come to be recognised as an essential agricultural operation on tea and, to a lesser extent, on rubber plantations. Within the last few years progressive coconut estates in Ceylon have started systematic green manuring. As for paddy, the value of turning in green leafy material while puddling the fields is universally recognised, but the practice is not followed as extensively as it should be. The scientific study of green manuring has received, in recent years, a considerable amount of attention from the staff of the Department of Agriculture, Ceylon, and much useful information has been secured. The results of investigations on the subject have been published from time to time in the various publications of the Department, but as they have been of a desultory nature, it has been considered advantageous to collect and classify all the available information. In this section, the general principles of green manuring with special reference to the various investigations carried out to determine how these apply to Ceylon agricultural conditions will be dealt with, and suggestions will be made as to how the Ceylon practices may be modified in order to secure the best results. The chemical data obtained on the composition of specific green manures is also included in this chapter. Reference will further be made to the results of work carried out by investigators in other countries when they have a direct bearing on Ceylon agricultural problems. The specific green manures suitable for the different Ceylon crops and their treatment will not be considered in this section but in those that follow. Where a practice more particularly adopted in one crop is considered suitable for other crops as well, its advantages and applicability to the latter will be discussed.

Before progressing further, it would be best to explain the sense in which the terms *green manure*, *green manuring*, and *cover crop* will be used in this paper.

DEFINITIONS

By *green manuring* is meant the practice of incorporating into the soil undecomposed plant material with the object of increasing soil fertility. The green material may be grown *in situ* or brought from outside. It is commonly believed that only leguminous plants are beneficial as green manures, but this is not the case. Non-leguminous leafy material can be used for green manuring provided it is brought from outside and not grown on the area which is to be green manured. Leguminous plants are of value as green manures because of the large amounts of gaseous nitrogen they fix in the soil through the nodules on their roots. Most of the nitrogen contained in leguminous plants comes from the atmosphere[31]. The presence of nodules on leguminous roots is always an indication of nitrogen-fixation. All leguminous plants are not however nitrogen fixers. Further, varieties which normally produce nodules on their roots may not do so under certain conditions. Either the soil may not contain the specific bacteria necessary for nodule development, or, it may be so acid that the organisms are destroyed, or, it may supply such large quantities of available nitrogen to the legumes at all stages of their growth, that the latter will assimilate the nitrogen supplied and not fix any of, or all, the nitrogen they require, which they would do if the soil were not so fertile. The nodules contain bacteria which carry on the work of nitrogen-fixation, the energy for the process being derived from the carbohydrate material supplied by the plant. The greater part of the available nitrogen formed in the nodules is transferred to the stems and leaves where it is converted into organic nitrogen, but some of it is assimilated by the bacteria in the nodules or goes into the roots. When, therefore, leguminous plants that produce nodules on their roots are grown in a soil, they can be expected generally to increase the nitrogen content of the latter to a small extent. If they are turned into the soil large quantities of nitrogen and organic matter may be added to it. On the other hand, though non-leguminous plants may contain large amounts of nitrogen, they take all of it from the soil. When these crops are turned into the soil on which they are grown, no extra nitrogen is added, but the available nitrogen assimilated from the soil is merely returned to it in organic form. As the plant material decays in the soil, the organic nitrogen it contains is transformed into inorganic nitrogen and the cycle is thus completed.

The term *green manure* will be employed for any crop material whether leguminous or non-leguminous, which is used for green manuring, and this will include *cover crops*, leguminous or otherwise, which are planted for the purpose of protecting and covering the soil. A cover crop can be used as a green manure crop.

ADVANTAGES OF GREEN MANURES AND GREEN MANURING

The chief advantages to be gained from the growing of green manures and the practice of green manuring are:

(1) Increase in the organic matter, especially the humus contents, of soils.

(2) Increase in the nitrogen content of soils.

(3) Conservation of the soil and its fertility and the improvement of its physical condition.

(4) Economy in the cost of weeding.

(5) A source of fodder.

(6) Conservation of the soil moisture.

These may now be considered more fully.

(1). *Increase in the organic matter and humus contents of soils.*—By ploughing in green manures, valuable organic matter is added to the soil; on decomposition this forms humus. Tropical soils in general, and Ceylon soils in particular, are for the most part deficient in organic matter. This is, as Mohr [1] points out because "the moisture and temperature conditions of the tropics are more favourable for the organic matter decomposing micro-organisms of the soil than for the higher plants which furnish the materials for these organisms to act upon, the organic matter being destroyed as rapidly as it is supplied by plants". In temperate regions where green manuring has been practised large gains in soil organic matter and nitrogen have been recorded [6]. Recent work [2] carried out at Peradeniya has shown that, under the conditions of these experiments, the carbon and nitrogen contents of soils may be maintained, or even increased, by the use of green manures. Eden[3] has shown that soil from an estate which had liberal green manuring had a higher organic matter content than one which was not so liberally green manured. More recently still, the results of organic matter and nitrogen determinations on soils from the tea plots under *Indigofera endecaphylla* at the Experiment Station, Peradeniya, taken after a four years' growth of this cover, showed that there was a marked increase in the organic matter and nitrogen contents of the soils as a result of growing the cover. The average organic matter content of these plots was 3·73 per cent. in 1925, 4·56 per cent. in 1927 and 5·29 per cent. in 1929. Green manure crops give from 2 to 10 tons of green material per acre and the increase in humus will therefore be appreciable after a few years. Humus has many properties. Among others (1) it absorbs water and the mineral constituents of the soil and regulates the supply of these and of nitrogenous substances to plant roots. Reference will be made again to the soil moisture relationship of green manures; (2) it improves the texture or tilth of soils, breaking up heavy soils and binding together light soils, and rendering them better able to withstand drought. Its presence in the soil serves to diminish the resistance of the soil to tillage implements. This has been clearly demonstrated at Rothamsted[4] from trials with the dynamometer—an instrument for recording the draw-bar pull on tractors, etc; (3) it is directly and indirectly the main source of nitrogen in the soil; and (4) on it depends the activity and number of the micro-organisms which are responsible for all the organic changes taking place in the soil. Amongst these organisms are bacteria, whose chief function is to fix the free nitrogen of the soil, the energy required for so doing being derived from the organic matter of the soil. The carbon dioxide formed as a result of the various biological processes which organic matter undergoes in the soil makes available to the crop some portion of the mineral constituents of the soil.

(2). *Increase in the nitrogen content of soils.*—The amounts of nitrogen supplied to the soil by green manuring with leguminous crops grown *in situ* or with non-leguminous crops brought from outside can be considerable. In the case of the former reckoning on an average crop of 4 tons of green material per acre per annum, containing on an average ·6 per cent of nitrogen, the amount of the latter added to the soil will be at least 50 lb. per acre. This is a conservative estimate as it does not take into account the amount of nitrogen contributed by the roots and nodules of a leguminous crop. An experiment at Rothamsted[5] showed that on a plot on which clover had been grown previously, in addition to the 150 lb. of nitrogen taken up by the succeeding crop of barley, the soil nitrogen was enriched to the extent of about 450 lb. per acre to a depth of nine inches. Pieters[6] cites numerous other instances of the value of leguminous crops for increasing the nitrogen content of soils. Recent work carried out at Peradeniya has indicated that by the growth of green manures the nitrogen contents of soils are maintained while those of the controls have shown an appreciable fall. Thus the average nitrogen contents of the green manure plots were ·107, ·102, and ·110 per cent in 1928, 1929, and 1930 respectively and those of the controls ·098, ·087, and ·084 per cent respectively. The composition of the different green manure crops commonly grown in Ceylon will be dealt with separately later. Not all the nitrogen present in green manures is directly available for crops. Experiments in temperate countries have shown that if the availability of nitrate of soda is reckoned as 100, that of green manures is about 65. Some of the remaining nitrogen is incorporated in the soil humus, some of it is lost as free nitrogen or ammonia, and the rest leached from the soil in the drainage water in the form of nitrates.

(3). *Conservation of the soil and its fertility and the improvement of its physical condition.*—If a green manure crop is a cover crop, it prevents the loss of valuable surface soil from hilly and undulating land caused by the heavy rainfall of the tropics. This is entirely borne out by the soil erosion experiment carried out at the Experiment Station, Peradeniya, the results of which are shown in table I below [14]. The experiment was designed to compare the erosion on a hill slope from unprotected land (the control), with land growing a cover crop of *Indigofera endecaphylla* and with land where *Clitoria cajanifolia* was used as a contour hedge for preventing erosion. The plots were each one-thirtieth of an acre in extent. The table shows the average losses of soil in pounds per acre from differently treated plots. The figures in brackets show the percentage loss as compared with that of the control.

Table I

	Control lb.	Growing *Indigofera* lb.	Growing *Clitoria* lb.
1926-1927	863·8	738·1	1055·7
	(100)	(85·4)	(122)
1927-1928	1810·9	1538·4	2069·6
	(100)	(84·9)	(114·3)
1928-1929	1733·1	732·35	1416·6
	(100)	(41·7)	(81·7)
1929-1930	1039·7	321·8	577·9
	(100)	(30·9)	(55·6)

It will be noted that the plots in which *Indigofera endecaphylla* is grown as a cover crop show the lowest losses of soil. *Clitoria cajanifolia* as a contour hedge for preventing erosion, it will be observed, is not nearly so effective as *Indigofera* as a cover crop in the prevention of erosion.

Cover crops also take up the plant-fertilising constituents contained in the surface layers of soil which would otherwise be leached out. By green manuring the surface soil is supplied in a quickly available form with plant-food constituents obtained by the green manure crop from the lower layers of soil and the sub-soil. A cover crop also protects the soil against the beating action of the rain and the excessive heat of the sun. This in the tropics is a matter of great importance. Tropical rains are so heavy that the soil surface is often "capped" and made impervious to water. As a result, excessive losses of moisture from the soil surface take place through capillary action when dry weather sets in. When rain subsequently falls on the capped surface, the greater part of it flows over, and is not absorbed by, the soil. Green manures keep the soil open by their root action and hence rainwater is absorbed much more readily on green manured soils, and the natural drainage too is much improved. The growth of green manures thus improves the aeration and drainage of the soil and the roots of the main crop are enabled to penetrate deeper into the sub-soil. This is particularly the case with tree green manures as "dadap" (*Erythrina lithosperma*) and *Gliricidia* in tea.

The results of investigation at Peradeniya during the last three years have indicated that in the case of tree green manures the shade afforded by them, where good, is an important factor in counterbalancing losses of soil moisture by transpiration from the leaves and from the soil surface by evaporation, provided the drought is not too prolonged [7].

(4). *Economy in weeding costs.*—Green manures reduce weeding costs, especially on new clearings. Cover crops when firmly established smother out weeds and as weeding is a heavy item on many tropical estates, greater economy can thus be effected in the cost of production.

(5). *A source of fodder.*—The leafy material of many green manure plants, especially of the cover varieties, affords a very useful fodder for cattle. This is a point of great importance in certain planting districts where pasture land is generally not available and cattle essential for the welfare of the plantation. Part of the green manures grown under the crop can be reserved for feeding cattle. A few of these cover crops are, however, poisonous to cattle, e.g., *Phaseolus lunatus*. Care must be taken to prevent the cattle from getting at such a crop.

(6). *The conservation of soil moisture.*—It has already been mentioned that by turning in green manures the humus formed will help in increasing the moisture content of the soil. Work at Peradeniya carried out since 1925 has indicated that, in the case of cover crops, more moisture is lost to a depth of 24 inches during periods of drought from soils under cover crops during the first two years of the growth of the covers than from bare soil, but that after this period the reverse is the case. This is due to the fact that in the early stages of the growth of the covers more moisture is lost from the soil through transpiration than is retained by the surface layer of decomposed organic matter or by the shade afforded. The reverse is the case once the cover is well established and a layer of organic matter has formed as a mulch on the surface [7, 8]. The shade effect of tree green manures in relation to soil moisture conservation has already been referred to. Directly connected with the question of moisture conservation is that of the time of lopping and burying in green manures. This will be dealt with later. In the case of bush green manures, it has been found that the lopping and forking into the soil of these crops will ensure an increased soil moisture retention; by allowing them to grow during periods of drought considerable losses through transpiration will result, the shade effect of these crops not being sufficiently effective to counteract the transpiration losses. With reference to the soil moisture problem of green manures, it has to be pointed out that work carried out in America has shown that where the rainfall is less than 20 inches, green manuring is impracticable and not to be recommended [6, 9]. The green manure crops take the moisture reserved for the main crop and, when turned under, do not have sufficient moisture for decomposition. The air spaces thus created cause further losses of moisture by evaporation.

THE COMPOSITION OF GREEN MANURES

In view of the frequent enquiries made as to the chemical composition of the more extensively cultivated green manure crops, and in order to ascertain to what extent leguminous green manure crops are richer in nitrogenous constituents than non-leguminous crops used for green manuring, analyses of the more important species of these plants were made. These were published at various times in *The Tropical Agriculturist* [10, 11, 12, 13]. A few typical analyses of leguminous and non-leguminous plants are quoted in table II below. Analyses were carried out in most cases on the leafy green material and tender stems. The analytical figures cannot however be regarded as absolute for all samples of the same species of green manure, for it is obvious that they will vary with the age of the plant at the time of sampling, the soil and climatic conditions under which it was grown, the season at which it was cut, the proportion of leaf to stem, etc. They however give a sufficiently accurate idea of the manurial values of these plants, and as such may be of use and interest to agriculturists.

With regard to the leguminous green manures an examination of table II shows that there is a fairly wide range of variation in the nitrogen and ash contents of the different green manures. The nitrogen per cent of the leafy material on dry matter at 100°C varies from 2·95 to 4·84 except in the case of *Mimosa pudica*, the common sensitive plant, which has only ·97 per cent of nitrogen. The ash contents vary from about 6 to 11 per cent. Of the individual ash constituents, the figures for lime are highest on the average; the potash contents are fair, while the phosphoric acid percentages are low for all green manures. The percentages of dry matter remain fairly constant in the case of all these leguminous plants. The table also illustrates the variation in composition of *Gliricidia* and dadap leaves and twigs, and tender stems and branches. As expected, the nitrogen and ash contents of the older branches are lower than those of the leaves and tender stems [(12)].

In the analyses of the leafy material of non-leguminous green manure plants, the nitrogen contents on dry matter vary from about 1 to 2·95 per cent. These figures are much lower, on the average, than those of the leguminous green manures. It will be observed that in all cases where the leafy material is from large trees and hence in greater quantity than from shrubby or creeping green manure plants, low nitrogen percentages are obtained. The shrubby or creeping varieties, e.g. *Tethonia diversifolia* and *Micania scandens*, have nitrogen contents comparing favourably with those of leguminous green manures. The ash contents of the non-leguminous green manures are generally higher than those of the leguminous varieties. The figures for potash and lime are higher, but the phosphoric acid contents are about the same.

A point of importance about leguminous green manure crops is the amount of green matter they yield. The absolute amounts of fertilising constituents contributed by them will depend on their analytical compositions as well as on their total yields. The yields of green material vary considerably for the different

Table II

Analyses of Green Manures

	Of green material							Of material after drying at 100°C					
	Mois-ture	Organic matter	Ash	Nitro-gen	Lime	Potash	Phos-phoric acid	Organic matter	Ash	Nitro-gen	Lime	Potash	Phos-phoric acid
	per cent.							per cent.					
Leguminous Green Manures													
Dolichos hosei (Vigna)	79·9	17·8	2·3	·71	·43	·39	·18	88·8	11·2	3·53	2·13	1·94	·93
Indigofera endecaphylla	74·7	22·1	3·2	·78	·90	·41	·12	87·3	12·7	3·09	3 55	1·61	·48
Clitoria cajanifolia	74·2	23·6	2·2	·79	·39	·30	·15	91·4	8·6	3·05	1·50	1·16	·59
Crotalaria striata	75·2	22·8	2·0	1·00	·40	·33	·09	94·0	6·0	4·07	1·60	1·33	·38
do anagyroides	72·8	25·4	1·8	1·32	·53	·38	·10	93·5	6·5	4·84	1·96	1·38	·37
Tephrosia candida (boga)	64·4	33·8	1·8	1·72	·66	·49	·18	95·0	5·0	4·84	1·84	1·37	·50
Desmodium triflorum	50·9	44·8	4·3	1·40	·53	·67	·16	91·3	8·7	2·84	1·08	1·36	·32
Centrosema pubescens	65·5	32·3	2·2	1·39	·60	·34	·08	93·6	6·4	3·96	1·74	·99	·24
Calapagonium mucunoides	74·7	22·5	2·8	1·10	·79	·46	·14	88·8	11·2	4·34	3·11	1·83	·55
Mimosa pudica	69·4	29·2	1·4	·30	·29	·42	·10	95·5	4·5	·97	·95	1·37	·32
Dadap (leaves and tender stems)	69·8	28·4	1·8	1·09	·58	·34	·14	93·9	6·1	3·62	1·91	1·13	·46
do (older stems and branches)	70·3	28·6	1·1	·32	·25	·24	·07	96·4	3·6	1·08	·83	·92	·24
Gliricidia maculata (leaves and tender stems)	73·1	24·3	2·6	·79	·77	·37	·19	90·4	9·6	2·95	2·88	1·37	·71
do (older stems and branches)	71·8	27·3	·9	·39	·20	·19	·07	96·9	3·1	1·40	·72	·66	·25
Non-Leguminous Green Manures													
Oxalis latifolia (leaves and bulbs)	85·0	13·4	1·6	·36	·26	·34	·06	89·1	10·9	2·38	1·73	2·26	·40
Tethonia diversifolia (wild sunflower)	77·1	19·5	3·4	·67	·73	1·21	·16	85·4	14 6	2·93	3·34	5·27	·68
Adathoda vasica	70·7	24·6	4·7	·81	·14	·93	·19	83·8	16·2	2 77	4·90	3·19	·65
Thespepsia populnea (Suriya, S.)	85·8	12·5	1·7	·32	·39	·39	·11	88·7	11·3	2·26	2·74	2·75	·77
Croton lacciferus (Keppitiya, S.)	57·6	38·8	3·6	·80	·12	·38	·27	91·4	8·6	1·88	2 93	·91	·64
Micania scandens	85·7	13·1	1·2	·38	·10	·52	·05	91·5	8·5	2·64	·70	3·63	·39
Grevillea robusta (leaves)	50·9	45·9	3·2	·53	1·30	·42	·06	93·4	6·6	1·08	2·65	·85	12
Strychnos nux-vomica (Goda kaduru, S.)	—	—	—	—	—	—	—	92·3	7·7	2·38	2·61	1·26	·32

varieties of green manures. The weights of loppings of tree green manures vary from 8 to 14 tons of green material per acre per annum [13], of bush varieties like *Tephrosia candida* from about 10 to 12 tons per acre, and of the creeping varieties from 3 to 6 tons per acre. The quantities of fertilising material added to the soil in the form of green manures can therefore be very considerable.

In order to determine the variation in composition and decomposability of green manures with age and hence the optimum time for lopping green manure crops in order to obtain the largest yield of quickly decomposing material containing large quantities of fertilising constituents, an investigation was started at Peradeniya with tree and bush green manure crops. The results obtained are interesting. They indicate that as the green manure crop advances in age the total amount of green material it gives increases but the proportion of leaf to stem decreases. In the case of bush green manures, the proportion falls from 2 to 1 when the plant is about four months old to 1 to 2 when the crop flowers. In the case of tree green manures the proportion falls from 3 to 2 when the branches are four moths old, to 1 to 3 when they are nine months old. As the crop matures there is a steady fall in the percentages of nitrogen and ash of the leafy material. Of the constituents of the ash, phosphoric acid shows the maximum decrease, and lime the minimum. The nitrogen percentage of the stem is about one-fourth to one-fifth that of the leafy material and the ash percentage about half that of the latter. The largest amounts of nitrogen and ash constituents in the leafy material are found about the time of flowering and this would therefore appear to be the best time for cutting green materials in the case of bush and creeper plants. This finding is confirmed by the work of other investigators with creeping leguminous crops [6]. The "decomposability" of the green material from these types of green manures, which Rege [15] has demonstrated is dependent on its pentosan/lignin ratio, falls as the crop advances in age from about 1:1 at four months to 1:2 at the time of flowering in the case of the stems only. The pentosan/lignin ratio falls much more rapidly in the case of the branches of tree green manures. The "decomposability" of green manures therefore decreases with age. Work at Peradeniya has shown that, under the climatic conditions obtaining at this place, the optimum times for lopping *Gliricidia* and dadap branches are when they are about three and five months old respectively.

THE DECOMPOSITION OF GREEN MANURES IN THE SOIL

Green Manuring Under Dry-land Conditions.—The important factors connected with the decomposition of green manures in the soil are the physical state of the latter, climatic conditions, the soil micro-organic population, and the composition of the plant. Provided there is sufficient moisture in the soil, the decomposition of green manures will take place almost immediately they are turned in. Work carried out both in Ceylon and India indicated that the optimum soil moisture content for decomposition was three-eighths to one-half of the saturation moisture content of the soil. The actual amount will vary with the type of soil, but for a medium loam it was found to be some 15 to 20 per cent of moisture on dry soil [17, 18]. If there is insufficient soil moisture the material will remain undecomposed. This is what happens in arid districts and even in districts with a good rainfall if green manuring is carried out during periods of drought. The best time for turning in green manures so as to effect speedy decomposition is towards the end of the rains, when dry weather alternates with showers. This was clearly indicated from an investigation carried out to determine the losses of nitrogen from green manures through drying on the field [23]. The decomposition will be the more speedily effected the better aerated the soil is. This is directly due to the beneficial effect of aeration on the soil micro-organisms.

Green manures offer an available source of energy for the activities of a great many micro-organisms in the soil responsible for the decomposition. Among the latter are fungi and bacteria. The presence of different micro-organisms will also influence the speed and nature of the decomposition. Fungi are believed to play an important part in the decomposition of the cellulose of plant material, the final decomposition products formed being humus, organic acids, and carbon dioxide. Bacteria are chiefly responsible for the decomposition of the organic nitrogenous material of the tissue, nitrate nitrogen being the final product formed. Several species of bacteria help in the decomposition, some functioning at one and some at another stage of the process. So far as is known amino-acids are first formed. These undergo reduction to ammonia which in turn is converted by the soil carbon dioxide into ammonium carbonate. A bacterial species *Nitrosomonas* converts the ammonium carbonate into nitrite, and this is rapidly changed by *Nitrobacter*, another species of bacteria, into nitrate.

The composition of the plant material plays an important part in the decomposition. Young plants decompose quicker than mature plants and plant residues since the first contain the more readily-decomposing constituents, namely, sugar, pentosans and proteins in large amounts, while older plants contain more of the decomposition-resisting lignins and celluloses. If the plant material is too mature as in the case of the thick branches of dadap, *Gliricidia* and even boga, its decomposition in the soil will be very slow indeed. Further, not only will there not be any liberation of ammonia or nitrates in the soil as a result, such as occurs in the decomposition of leafy green manure material, but there may be an actual consumption by the soil micro-organisms of the inorganic nitrogen of the soil. It has been found that for the liberation of ammonia and nitrate from green material buried in the soil, its nitrogen content should not be less than two per cent. [22] Most green manure materials have nitrogen contents considerably higher than this minimum; hence their incorporation in the soil should result in the liberation of large amounts of available nitrogen. The whole subject of the chemical and biological principles underlying the decomposition of green manures in soil has been ably dealt with by Waksman [22, 31], to whose papers reference may be made for further details.

The results of both laboratory and field experiments carried out in Ceylon on the decomposition of the more widely-used green manures have been detailed in several papers in *The Tropical Agriculturist* [18, 19, 20], but it may be well to review briefly the general conclusions obtained. It has been shown that, (1) maximum nitrate accumulation or nitrification in the soil resulting from green manuring takes place between the sixth and eighth week after the burial of the green material. The field experiments further demonstrate that nitrification takes place subsequent to this, but to a lesser extent, and that after the fifth or sixth month the direct effects of green manuring from the nitrogen standpoint are hardly appreciable. Figures I and II will illustrate the above observations. Figure I shows the progress of the decomposition for some of the green manures in the laboratory experiments and Figure II the stages of the decomposition in the field. The curve for the nitrate content in the green-manured plots represents the averages for all the plots at the different times of sampling. The green manures used in these experiments were *Erythrina lithosperma* (dadap), *Gliricidia maculata*, *Tephrosia purpurea* (boga), *Albizzia*, *Crotalaria anagyroides* of the leguminous varieties and *Tethonia diversifolia* (wild sunflower) of the non-leguminous species. Cattle

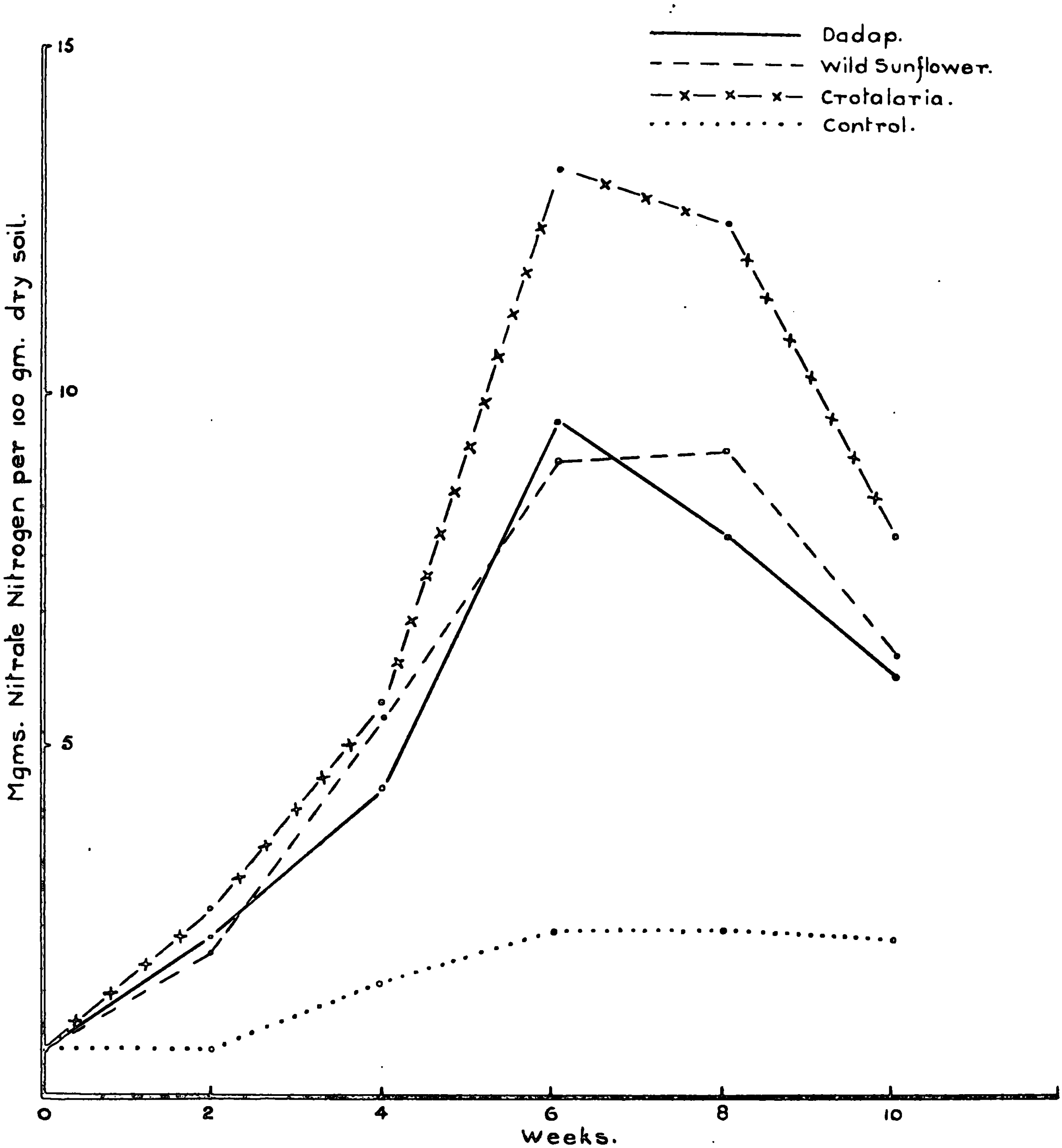

Figure I. Showing the decomposition of green manures under arable conditions in the laboratory.

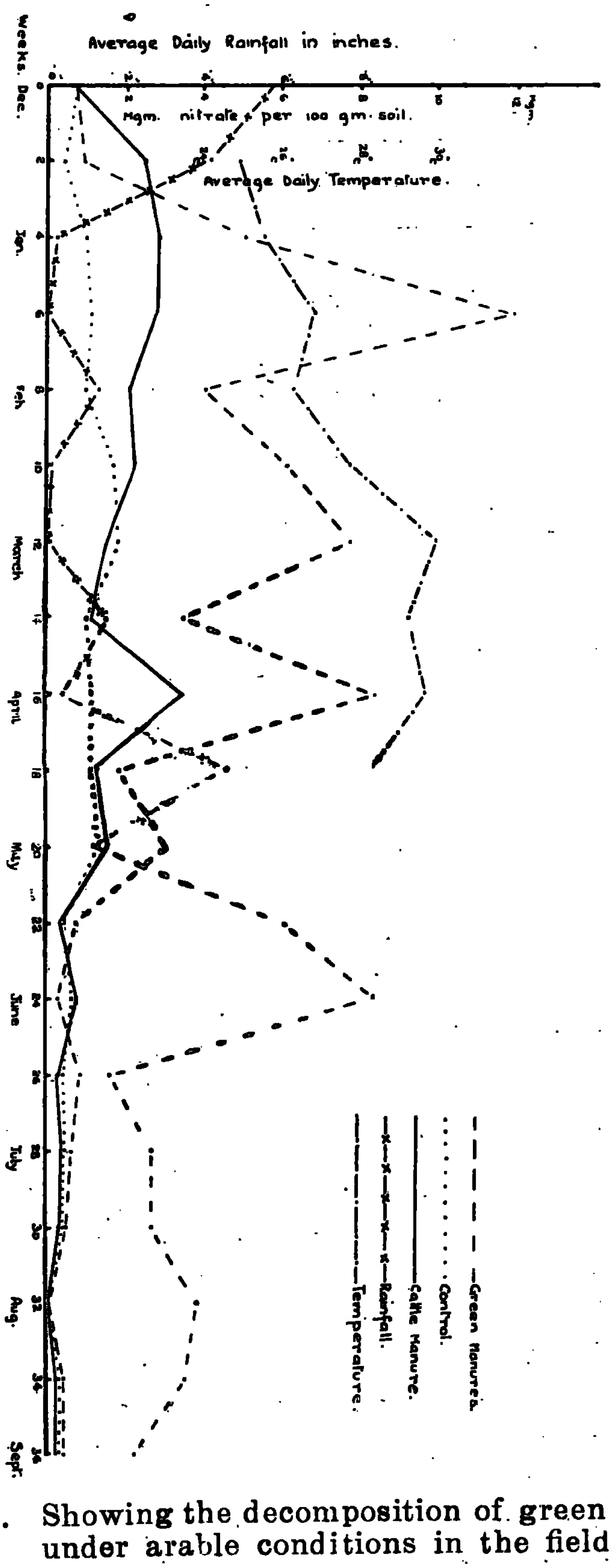

Figure II. Showing the decomposition of green manures under arable conditions in the field.

manure and control plots were included in the series. The full data of the laboratory and field experiments are shown in tables III and IV respectively.

Table III

Green Manure Laboratory Experiment Results

Treatment	Mgm. nitrate nitrogen per 100 gm dry soil						Maximum per cent. nitrified
	4/12/25	18/12/25	4/1/26	18/1	1/2	15/2	
Gliricidia	·61	1·11	3·48	7·82	8·96	2·20	43·7
Albizzia	,,	·48	3·98	5·66	4·06	5·28	23·3
Dadap	,,	2·28	4·36	9·60	7·93	5·99	68·6
Wild sunflower	,,	2·07	5·44	9·06	9·12	6·31	67·2
Crotalaria	,,	2·60	5·54	13·20	12·40	8·20	77·7
Tephrosia	,,	3·23	5·09	14·40	14·20	8·19	60·0
Cattle manure	,,	1·54	1·76	2·48	3·17	2·22	27·5
Control	,,	·60	1·58	2·42	2·40	2.28	—

From what has been stated above it is apparent that under estate conditions it will be preferable to green manure at shorter intervals, e.g. at least twice a year and in smaller quantities than at longer intervals and with larger amounts of green material; (2) the amounts of nitrate present in the soil at any particular time in the green manure plots are dependent on the rainfall during the previous fortnight. As the rainfall increases the nitrate contents falls and vice versa. This is clearly seen in Figure II. The low nitrate content is probably due to (1) the washing away of the nitrate to the lower layers of soil, (2) excessive moisture which is detrimental to bacterial action. The temperature curve is noted to follow the nitrate curve; (3) the maximum nitrification percentages vary from 27·5 for cattle manure to 77·7 for *Crotalaria* in the laboratory experiment and from 40·2 for *Tephrosia* to 126·4 for dadap in the field experiment. The nitrification percentages are higher in all cases in the latter than in the former. This is probably due to the mineralisation of part of the organic matter of the soil, and the latter is certainly the cause of the high results obtained for dadap and wild sunflower in the field experiment. The great variation in the results is to be attributed to the variation in the composition and nature of the green materials used in the experiments; (4) the use of non-leguminous leafy material, e.g. wild sunflower, resulted in as great an accumulation of nitrate in the soil as when leguminous crops were used. The advantage of using such material for green manuring provided it is not grown on the field which is to be manured and provided it is cut before the flowering stage, is thus apparent; (5) the cattle manure plots show hardly any increase of nitrate over the controls. This is due to the low nitrogen content of the sample.

Table IV

Green Manure Field Experiment Results

Treatment	Moisture on green material per cent.	Nitrogen on material at 100°C per cent.	Mgm. nitrate and nitrite nitrogen per 100 gm dry soil															Maximum per cent. nitrified
			4/12/25	18/12/25	4/1/26	18/1	1/2	15/2	3/3	16/3	30/3	12/4	26/4	10/5	25/5	4/6	22/6	
Gliricidia	58·7	3·63	·63	·47	4·72	14·14	4·76	7·58	8·10	3·55	8·82	1·82	2·91	·95	—	·86	·67	86·3
Albizzia	56·4	3·19	,,	·56	4·96	10·40	4·10	4·43	4·67	1·93	8·65	1·55	3·18	·52	·48	1·37	·57	66·3
Dadap	76·2	4·39	,,	1·01	5·62	14·46	5·26	7·88	10·26	3·02	7·68	2·55	2·88	·53	—	·62	15	126·4
Wild sunflower	77·1	4·36	,,	2·06	4·55	11·69	4·87	4·77	7·43	1·94	7·62	1·47	2·22	·57	·46	·80	·78	105·0
Crotalaria	61·2	4·32	,,	·96	6·26	10·99	4·28	5·33	7·61	4·78	9·07	1·88	3·44	·95	—	·35	·80	70·5
Tephrosia	54·5	4·53	,,	·56	4·26	9·46	4·93	6·91	7·91	4·94	8·63	1·63	4·00	·43	—	·87	·66	40·2
Cattle manure	65·0	·81	,,	2·50	2·81	2·78	1·98	2·27	1·71	1·13	3·50	1·10	1·50	·30	·68	·29	·25	57·9
Control	—	—	,,	·41	1·00	1·19	1·00	1·74	1·81	·91	1·03	1·04	1·10	·37	·63	·19	·23	—
Green manures (Average)	*64·0*	*4·07*	*·63*	*·94*	*5·06*	*11·90*	*4·03*	*6·08*	*7·66*	*3·36*	*8·40*	*1·82*	*3·10*	*·66*	*·16*	*·81*	*·60*	—
Average daily rainfall during previous fortnight (inches)	—	—	·57	·41	·02	nil	·13	·03	nil	·16	·04	·45	·12	·60	·83	·16	·25	
Average daily soil temperature during previous fortnight (°C)	—	—	—	—	24·8	25·4	26·8	26·2	27·7	29·9	29·1	29·6	28·3	—	—	—	—	

The addition of lime hastens the decomposition of green manures, as in the case of organic manures [20, 21, 22].

Experiments carried out at Peradeniya on the effect of desiccation on the nitrification of the leaves and tender stems of leguminous plants indicate that drying delays as well as hinders nitrification. A later investigation showed that dry weather alone does not encourage decomposition of green manure materials [23]. Other investigators too arrived at the above conclusions [24, 25]. The delay in decomposition is attributed to the conversion of soluble hemi-celluloses into less soluble forms as a result of the drying. From the above it will be realised how important it is that leafy material should be buried green and not dry in order to secure speedy decomposition.

In connection with the decomposition of green manures under arable conditions, it may be stated that experiments at Peradeniya have indicated that the effect of green manures here is to make the soil somewhat less acid than what it originally was[2]. Work in other countries has shown that green manures do not materially, if at all, increase soil acidity in the field [6]

Green Manuring Under Anaerobic (Paddy-land) Conditions. In a paper such as this which deals with the general principles of green manuring in relation to all crops, reference should be made to investigational work carried out in Ceylon on green manuring under anaerobic (paddy-land) conditions. The practical aspect of this will be dealt with separately in the chapter on paddy and hence only the scientific aspect of green manuring under these conditions will be discussed in this chapter. The decomposition of green manures under anaerobic conditions such as obtain in swampy paddy land is brought about by soil micro-organisms. Harrison and Aiyer [28] showed that the gaseous products formed as a result of the decomposition of green manures under anaerobic conditions are carbon dioxide, hydrogen, marsh gas, and a small proportion of nitrogen. The main constituents of paddy soil gases are marsh gas and nitrogen. The former is oxidised to carbon dioxide by bacteria contained in the organized algal film on the soil surface. The carbon dioxide is in its turn decomposed with the evolution of oxygen, which becomes available for the aeration of the roots. The absence of carbon dioxide and hydrogen from paddy soil gases is attributed by Harrison to the reduction of the carbon dioxide by hydrogen as a result of a subsidiary bacterial action. Harrison and Aiyer attribute the efficiency of green manures upon paddy mainly to their indirect action on the soil by increasing root aeration, and not to the nitrogen contained in them, which they consider is liberated to a great extent as free nitrogen. The chief point of difference between the decomposition of green manures under dry land and wet land conditions, is that in the latter case ammonia and not nitrate is the nitrogenous end-product. Most previous workers [26] had shown that the rice plant took its nitrogen in the form of ammonia and hence the value of green manuring became apparent. A detailed investigation of the decomposition of green manures under these conditions in order to determine how green manuring of paddy could most effectively be carried out [26], has shown that as a result of incorporating green manures in paddy soils at the time of puddling, i.e., *late*, large quantities of ammonia are made available to the soil at all stages of the decomposition process and which coincide with the period of crop growth. Maximum

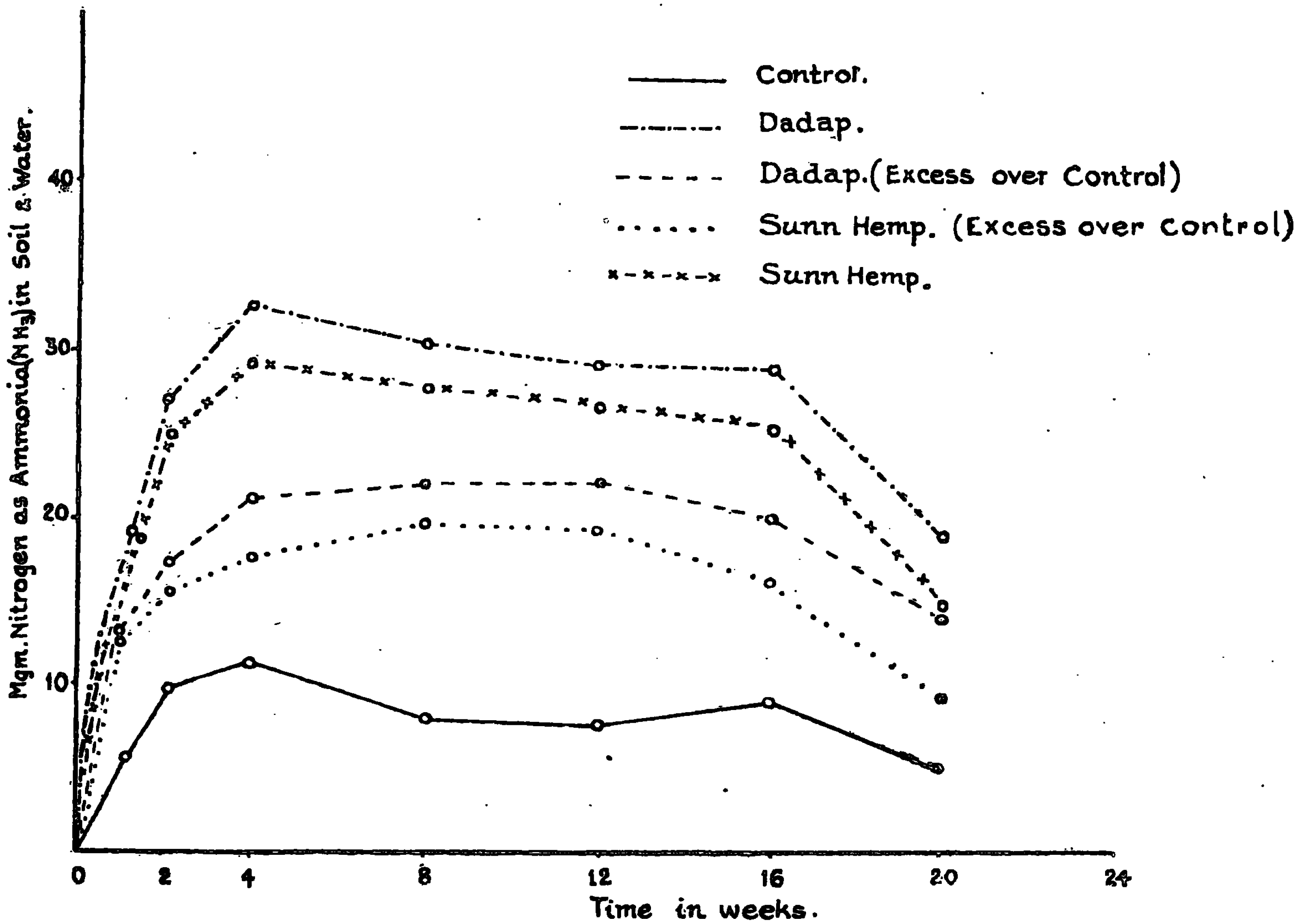

Figure III. Showing the decomposition of green manures applied *late* under anaerobic conditions in the laboratory.

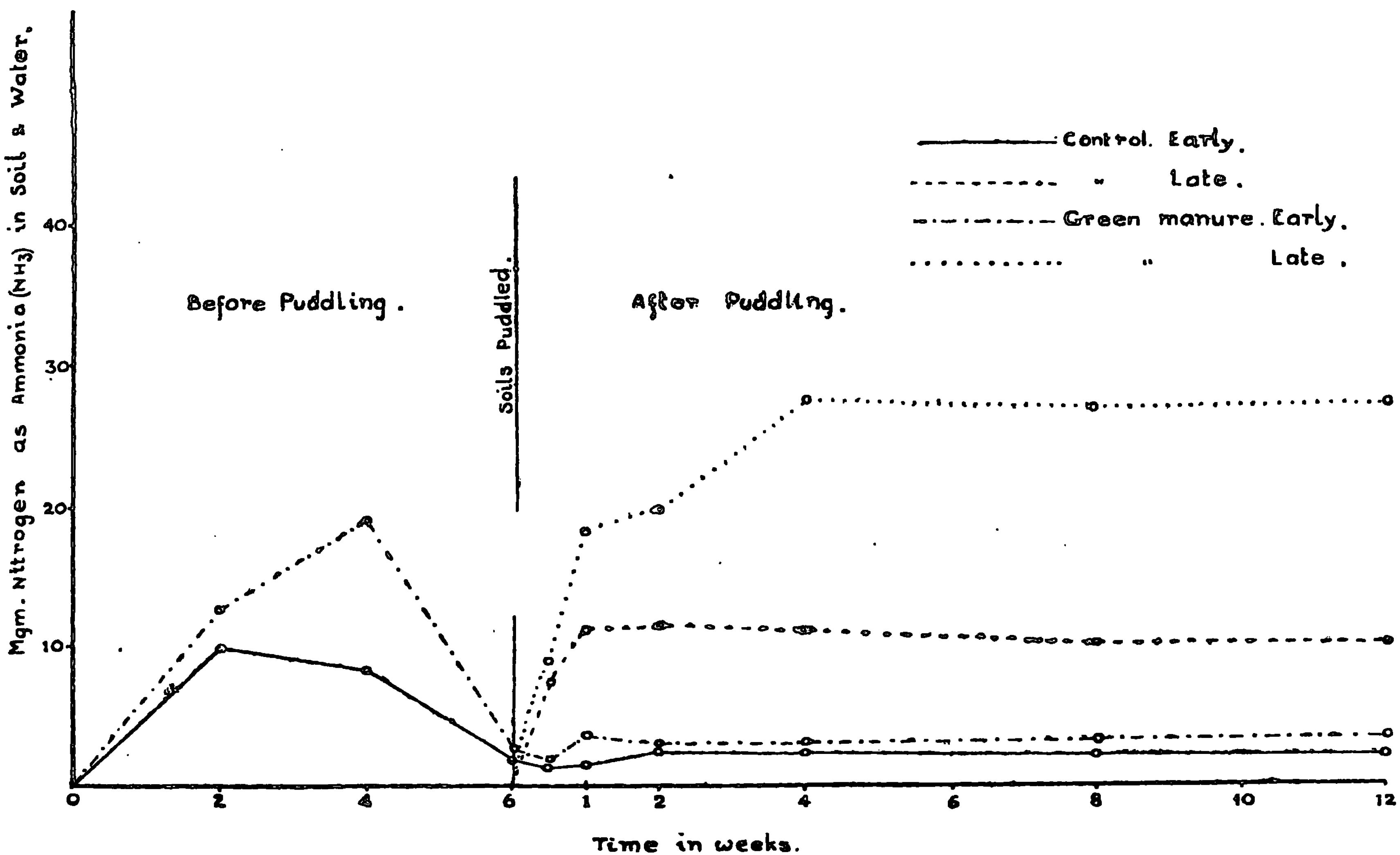

Figure IV. Showing the decomposition of green manures applied *early* under anaerobic conditions in the laboratory.

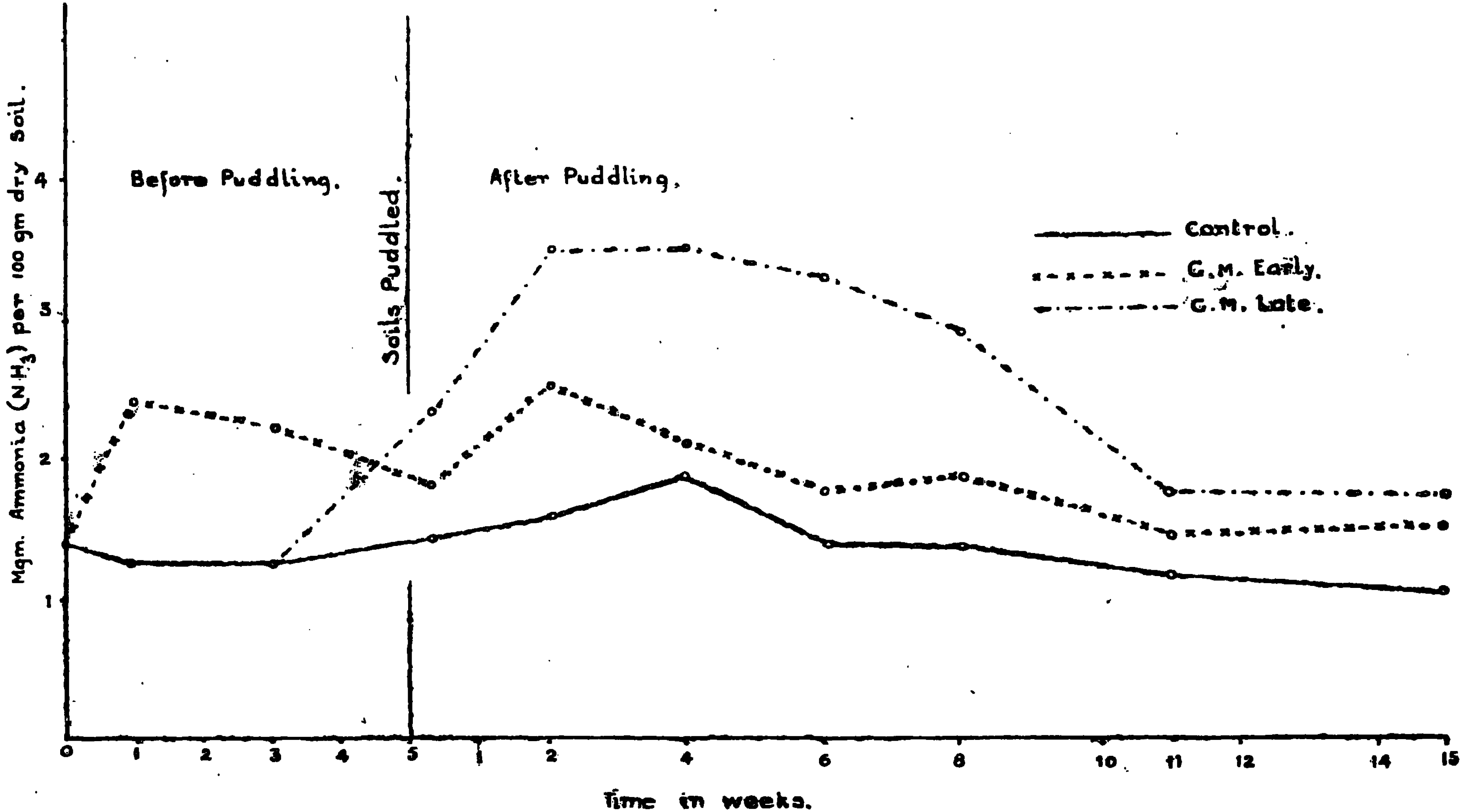

Figure V. Showing the decomposition of green manures under anaerobic conditions in the field.

ammonification is obtained in about four weeks from the time of puddling. By *early* green manuring, i.e., ploughing in the green manures when the soil is semi-dry, large quantities of nitrates are formed. On the subsequent flooding and puddling of the soil these are lost as free nitrogen, leached in the drainage water, or reduced to nitrites which are injurious to paddy seedlings if present in excess. The amounts of ammonia found in *early* green-manured soils are very much less than those found in *late* green-manured soils. By the *late* green manuring of paddy soils their nitrogen contents can be maintained or even increased. *Early* green manuring results in large losses of soil nitrogen. No nitrates are found in paddy soils after they have been puddled, any nitrates present or added before puddling being denitrified or converted into nitrites. Large increases in crop yields of both grain and straw have been obtained through the *late* green manuring of paddy under anaerobic conditions [29]. Green manures can therefore be of direct manurial value to a crop like paddy if they are incorporated into the soil at the proper time.

Figures III, IV, and V will illustrate graphically the conclusions referred to in the above paragraphs.

CONSIDERATIONS ON GREEN MANURING PROBLEMS

(1). *On what soils should green manures be grown and under what climatic conditions ?*—Provided there is sufficient rainfall, green manures can be grown on any type of soil. Poor sandy soils in particular will benefit most by green manuring, as their humus and nitrogen contents and water-holding capacities will eventually be increased by the practice.

It has already been stated that where the annual precipitation is less than twenty inches, green manuring is not practicable; but very few parts of Ceylon are as dry as this, and most districts get the benefit of at least one monsoon. It is only in certain parts of the Northern and North-Central Provinces that green manuring would appear to be impracticable. In the Puttalam and Chilaw districts the soils are of a light sandy type, the rainfall on the whole is low, and long periods of drought occur. The question then arises whether green manuring can successfully be practised under these conditions. It is possible to do so, but under such conditions a quick-growing annual leguminous crop should be grown. It should be cut and left as a mulch during the drought and ploughed in during the next rainy season, a second crop being planted at the same time; or, where possible, the green manure should be forked in early enough for decomposition to set in before the rains cease. In districts with adequate rainfall green manuring will offer all the advantages already referred to.

(2). *The optimum time for cutting and the best method of treatment of green manures.*—Green manures should be cut at a stage when (1) they produce the maximum quantity of easily-decomposable green material, (2) climatic considerations demand that they should not compete with the main crop for the moisture in the soil. On the first point it has already been stated that in general the optimum time for cutting green manures for forking into the soil is just about the time of flowering. This applies to the bush and cover types in particular. The tree types are best lopped when the branches are from three to four months old.

The loppings or cuttings of all green manures, particularly in drier districts, should be ploughed in towards the end of the rains when showers alternate with dry weather. If ploughing is not possible the green material should be left as a mulch on the surface. In this case a certain amount of the carbon and nitrogen of the green material will be lost, as was found at Peradeniya[23] but as in these dry districts moisture is the limiting factor of crop growth, the mulch will serve as a useful means of conserving soil moisture. It is preferable, however, to turn in the cuttings about three to four weeks before the drought sets in, as by that time a certain amount of decomposition will have taken place and the decomposed material will have been able to retain some moisture for the subsequent use of the crop. In wet districts or in districts with an evenly distributed rainfall it is preferable that green manures should be turned into the soil immediately. The reason for this is that the drying of green manures delays as well as hinders nitrification, and loppings left on the surface are completely dried in a short time if dry weather prevails. If dry weather should alternate with wet weather then large losses of nitrogen and organic matter may result [23]. Thus losses of over 43 per cent of the nitrogen of *Gliricidia* and 37 per cent of dadap leaves were found at Peradeniya, when alternate dry and wet weather occurred. When dry weather alone prevailed, decomposition of the leafy materials did not take place and no losses of nitrogen consequently occurred. The loss of nitrogen is also effected by the nature of the plant material and this is greater in the case of more easily-decomposed leaves such as *Gliricidia* than tea and *Grevillea* leaves. The forking in of green manures in the fresh state is therefore advocated whenever possible. On no condition should green manures be cut and forked into the soil during a drought, even at the beginning of it. This applies particularly to light sandy soils in dry districts where green manures are ploughed in. It may be necessary in some instances to compact the soil after green manuring in order to minimise losses of soil moisture and to establish capillarity in the soil. The loppings of tree and bush green manures should not be allowed to become too woody. If in this conditoin, they should not be ploughed into the soil.

(3). *How can a good growth of green manures be obtained on poor soils ?*—It may be found difficult to establish green manures for the first time both on medium and on poor soils. In this case the following methods may be tried:

(i) *Manuring the crop.*—The green manure should be given a start by applying cattle manure to the seed bed. If this is not available, some nitrogenous manure, e.g., a mixture of nitrate of soda and blood meal incorporated with twice its weight of soil should be supplied at the rate of a handful or two per hole. Leguminous crops will be benefited by the presence of nitrogen in the early stages of their growth till the formation of nodules has taken place. Potash and phosphoric acid should also be applied as the green manures have to compete with the main crops for these fertilising constituents. As a result of manuring, the nodule bacteria are reported to become more active and able to enter the plants readily, and nodule formation is increased[6]. The root growth of leguminous plants in general is stimulated by manuring with phosphatic acid.

(ii) *Inoculation.*—Leguminous crops at times do not come up well in new areas. This is because the soil does not contain the specific type of bacteria needed by the particular legume for the formation of the root nodules. In this case inoculation of the soil or of the seed becomes necessary. There are three methods of soil inoculation, of which the soil method is alone suitable under Ceylon conditions at the present time. It consists of broadcasting over the area to be planted 300-400 lb. of soil per acre which has been taken from an area on which the green manure, it is desired to establish, has been grown with success.

(4). *Other practical points on green manuring.*—As regards the period of retention of green manures it may be stated that, in general, perennial cover crops should not be allowed to grow for more than two or three years without being ploughed in. The reasons for this are that the soils on which these covers grow (1) need periodical cultivation and aeration, (2) get "sick" as the result of growing one particular crop. For the latter reason it is advisable to have a rotation of green manure crops. Bush green manures depending on the particular species will need replanting once in two to four years. Tree green manures can be left to grow for several years, but they should be rooted out if attacked by disease.

Cover crops should be ploughed under in alternate rows across the slope of the land once every year or so. Where the green manure crop is a heavy one, it should be cut up with a disc-harrow or rolled before ploughing in. Bush green manures should preferably be planted in contour belts. When planting out green manures for the first time a heavier seed rate than is normally required, especially if seed is plentiful and comparatively cheap, is recommended. By this means a cover will be more quickly established and weeds more effectively suppressed. Generally speaking it is preferable to plant green manure seed in rows. A mixture of seed generally gives better results than seed of one variety. The seed bed should receive careful preparation. Planting should be carried out at the beginning of the rains and weeding should be done in the early stages in order to give the green manures a start.

When using a green manure as the main source of nitrogen, the inclusion of an organic manure such as groundnut cake or blood meal in the artificial mixture is not recommended; but the application of a small quantity of a concentrated nitrogenous fertiliser such as cyanamide along with the green manure is advised. The reason for this is that as the carbon/nitrogen ratio of the soil has been found to remain constant at about 10 to 1 [2], and as green manures have a much higher carbon/nitrogen ratio, some concentrated nitrogenous fertiliser would appear necessary if a permanent improvement in the nitrogen content of the soil is to be effected. Further, only about half the nitrogen contained in green manures is available in a short time. It is also advisable to plough in some cattle manure along with the green manure as the large number of bacteria present in the former will hasten the decomposition of the latter.

(5). *Some limiting factors in green manuring.*—As with all other farm practices, green manuring has its limitations, and these are governed by crop and climatic conditions, cost of seed and of application, insect pests and fungus diseases of both the green manure crop and the main crop, and inadequate monetary returns [6]. Climatic conditions essential for green manuring have already been dealt with. As regards crop conditions it is known that some green manures will not grow under the heavy shade of the main crop, such as rubber, others in the open, as in young clearings. Again, certain green manures of the tree type will be unsuitable for young plantations. Others again have a climbing tendency and, therefore, should not generally be grown in new plantations, or if they are, they should be kept away from the young plants. In Ceylon, suitable green manures for all crops under all conditions are available and there is no crop which will not benefit by green manuring, judiciously carried out. The cost of seed is a factor of importance at the start. Once green manuring has been adopted, however, this difficulty may be overcome as seed becomes available. The initial expenditure on green manuring may be fairly high, but this will more than be compensated for by a saving on the fertilisers purchased. Seed of all kinds can be obtained comparatively easily and cheaply in Ceylon. Though the cost of application, in which is included the cost of cutting and forking in, if the latter is carried out, will be found to vary in the different districts, it is not prohibitive.

The question of fungus diseases and insect pests both of the green manure crop and of the main crop in which they are grown in Ceylon will be dealt with in separate chapters.

Green manuring will not be an economic proposition if adequate monetary returns are not secured. The nett result should not be measured by the returns of produce obtained after one or two years, because the residual and cumulative effects of green manuring are considerable, and apart from directly benefiting the crop, soil conditions will also be greatly improved. As far as the main Ceylon crops are concerned, the satisfactory returns obtained by the judicious use of green manures in tea, cocoa, and paddy cultivation are recognised. Evidence to prove that green manuring benefits rubber and coconuts is also being obtained, and the practice with reference to these crops will be considered in detail in the chapters to follow.

(6). *Green manuring practices on Ceylon estates, and suggestions for their improvement where desirable.*—It may be well briefly to outline some of the practices followed by estates, and to indicate in which ways, if any, they may advantageously be modified. Tree green manures, e.g., dadap and *Gliricidia*, are lopped on nearly all estates from once to two or three times a year, and even more often. More frequent lopping is certainly preferable for the reasons that firstly a greater amount of easily decomposable green material and much less decomposable woody material is obtained and secondly, as the direct effects of green manures do not last for more than five or six months under Ceylon conditions, a continuous supply of nitrate nitrogen will be available to the plant if lopping is frequently carried out. On one estate as many as six loppings are done, the method adopted being to slash the green manure trees across as is now done to tea in the low-country. The loppings are left as a mulch on the surface either across the slope of the land or down the rows of the crop. Some estates envelope-fork all loppings into the soil each time the trees are lopped either in every row or in alternate rows. Others fork in the loppings from certain cuttings only, e.g., along with artificial manures; at other times the loppings are left as a surface mulch. Others again fork in the leaves and more tender branches only, the more woody branches being used either for supplying vacancies or as firewood. Many estates use the tender leaves and stems for filling into supply holes. The loppings are either cut into small pieces or left as they are; or again, they are buried in deep trenches or holes between the rows of the main crop. Whenever this is done a layer of soil should be placed over a layer of the green material. The practice of burying in trenches is not one to be generally recommended, as it is likely that only the trees or bushes immediately adjacent to the trenches would profit most by it. Loppings may however be buried in large shallow trenches between the rows of the main crop as in the case of coconuts. The practice of forking in the loppings above each bush has distinct merits. Some estates plant out green manures on the manured areas between the rows of the main crop, e.g., coconuts. This is a mistake, for as pointed out already, if a leguminous crop is given a source of available nitrogen it will make no effort to obtain the nitrogen it requires for its use from the air. Further, the green manure crop will even temporarily compete with the main crop for some of the other available fertilising constituents contained in the manure mixture applied. Green manures should in these cases be grown in the unmanured areas.

Whenever it is possible and economical for green material to be turned into the soil, especially in districts with adequate rainfall where dry weather alternates with rain, this should be done. The woody portions of the loppings should not be forked in, but preferably left on the surface of the soil across the slope of the land, used for filling in vacancies or where either of these practices is not convenient or advisable, burnt and the ashes forked in. The reasons for not burying the woody loppings are that they take a very long time to decompose in the soil owing to their high lignin and low pentosan contents; secondly that they contain only very small amounts of nitrogen, so that in the process of decomposition the bacteria responsible for bringing it about will utilise some of the available soil nitrogen required by the crop and thus cause a temporary setback to the latter; and finally because of the danger of pests and diseases. If the green material is not turned in, a large percentage of the nitrogen and organic matter it contains may be lost [23]. The best practice would be to fork in the leaves and tender stems either along with artificial manures or alone during periods of light rainfall. The loppings cut at the beginning of a period of drought may be left on the surface as a mulch, especially in dry districts, and the leafy material later forked in, if necessary. It need hardly be stated that tree green manures should not be left unlopped and the more frequent the loppings the better. Big trees like *Grevillea* and *Albizzia* are generally not lopped, the natural leaf fall affording sufficient organic material for forking in.

Bush green manures as boga and *Crotalaria* should be treated in the same way as the tree types.

The practices governing the use of cover crops vary a great deal and more experience with these needs to be obtained. Some estates leave the cover untouched for two years or more, except perhaps when manures are being supplied; others envelope-fork the covers perodically depending on the growth and nature of the cover. In some cases the cover is cut and artificial fertilisers may or may not be added at the time of forking in. In other cases the cover crop is cut and buried in trenches. Others again cut and envelope-fork in the green manure in alternate lines. The best practice would be to fork in alternate contour bands of the cover crop every year. This may not be convenient in the case of all crops, but it can always be adopted in some modified form. By so doing the cover acts as an effective soil conserver and also adds to its fertility.

SUMMARY

In the preceding pages an account has been given of the necessity for, the importance of, and the advantages of green manuring in tropical countries generally and in Ceylon in particular. It has been indicated that by the judicious use of green manures, which term includes cover crops, the nitrogen and carbon contents of the soil can be maintained, its physical condition improved, its moisture-retaining capacity enhanced and erosion effectively prevented. The analytical composition of certain plants, leguminous as well as non-leguminous, used in Ceylon for green manuring is tabulated and compared, and the conditions under which either class may be used as green manures explained. The results of investigations on the variation of composition with age are also briefly summarised. The principles underlying the decomposition of green manures in soils under both aerobic and anaerobic conditions are then discussed, and the results of experimental work on the subject in Ceylon are outlined. The chapter concludes with discussions on certain practical green manuring problems, viz., soil and climatic conditions suitable for the growth of green manures, the

optimum time for cutting and forking in green manures, measures to be adopted for securing good growth of green manures, some of the limitations of green manuring, and green manuring practices on Ceylon estates and the respects, if any, in which they may be advantageously modified.

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