FURTHER STUDIES ON COMPOSTING IN THE TROPICS.

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INTRODUCTION

The addition of organic manures to the soil is practically universal under all systems of permanent agriculture. It is true that recently the use of artificial, inorganic fertilisers in Western Agriculture has tended, in some cases, to replace the more expensive farmyard manure. However, it is still generally believed that the maintenance of fertility of most soils is only possible where organic manures are used to balance losses of humus from the soil.

Under systems of mixed agriculture the production of farmyard, or pen manure is usually sufficient to keep up the humus content of the soil. However, where stock are scarce, or absent, other method have to be resorted to. Green manuring presents one alternative, but better results have been obtained by the use of artificial organic manures, or "composts". Such manures may be prepared by the decomposition of crop residues, and other waste materials, until a product resembling soil humus is obtained.

Under the supervision of Professor R.C. Wood, several students have studied the process of composting at the Imperial College of Tropical Agriculture, Trinidad. This dissertation gives an account of the continuation and amplification of that work during the period of October 1936 to June 1937.

In part one all relevant previous work has been reviewed and discussed. Experiments on composting conducted by the writer on the College Farm are described in part two, while field experiments, designed to test some of the composts made, are described in part three. Finally, the results of these experiments are discussed in the light of previous work on the subject.

I. REVIEW OF PREVIOUS WORK.

1. Foreword.

The volume of literature on composting is such that an exhaustive survey would assume alarming proportions, consequently the writer has found it necessary to select only the most important works for consideration. This selectivity proved to be especially necessary when studying the chemical and biochemical aspects of the subject.

This review of relevant literature has been facilitated by reference to recent reviews by Jenkins (33), Beckley (6), Howard and Wad (29), Tambe and Wad (58), Kettlewell (42), Webster (74), Masefield (46) and Johnson (39).

2. The Function of Humus in the Soil.

Since this work describes methods of returning organic matter to the soil, it is highly important to decide whether or not this practice can be replaced by the use of inorganic manures. The question is a highly controversial one and has been so ever since Liebig suggested that the mineral constituents of plants supplied all that was necessary for their growth. A modified form of this theory claims many advocates possessed of what Howard terms an "N.P.K. mentality". These men point to the success of mechanized cereal production as evidence supporting their claim.

On the other hand, the great majority of agricultural scientists come down in favour of organic manures, and they have produced a great mass of evidence to bear out their contention. Thus Baver (5), Keen (41) and Salter (56) show how humus keeps the soil in a healthy physical condition: organic matter opens up the soil improving drainage and aeration, and at the same time increases the water holding capacity of the soil, which minimises the danger from erosion; it is also shown that humus increases the base exchange capacity of the soil, and buffers soil reaction. Since exchangeable cations and unsaturated acids are divided between the clay and the humus portions of the absorbing complex then it is evident that acid soils can remain fertile provided their humus content is high. Soil organic matter also increases the solubility of some of the inorganic soil constituents, and encourages the activities of soil micro-organisms.

Waksman and Hutchings (65) showed that organic matter with a C/N ratio of more than 11 : 1 prevented loss of nitrogen by the soil.

Anstead (2) claims that food crops manured only with artificial manures are deficient in vitamins, so it may be that humus supplies auximones without which the healthy growth of plants is impossible. The same author also states that the viability of seeds grown at Coimbatore, South India, is greater where organic manures were used instead of inorganic ones.

Jackson, Wad and Panse (36) consider that the main effect of compost is the maintenance of a healthy physical condition in the soil. Thus they claim that, at Indore, the yields of Indian cottons can be doubled, and of American cottons trebled, merely by preserving an open texture in the soil.

In Nigeria, Hartley and Greenwood (28) have conducted field experiments in which a dressing as small as one ton per acre of farmyard manure has produced considerable increases in the yield of guinea corn. Furthermore, they showed that an equivalent dressing of inorganic nitrogen and phosphate, when applied with unrotted organic matter, failed to produce a corresponding increase. However, this work can be criticised on several points: first the addition of unrotted organic matter would immobilise much, if not all, of the available nitrogen, and thus have a harmful effect on the crop's growth; secondly, although the soil analysis showed an apparently adequate supply of potash, it may have been that this or some other element present in the farmyard manure constituted a limiting factor in the plant growth.

Wood (78) and Swynnerton (57) give an account of the yields obtained from the permanent manurial plots on the College farm. The results over a number of years show that a dressing of ten tons of compost per acre is consistently superior to a complete dressing of artificial manures, with or without the addition of lime. Furthermore, the addition of this dressing to the compost does not lead to an appreciable increase in yield, except in the case of certain dry season crops. While this experiment loses much from the absence of replication, yet the value of the results is considerable owing to the experiment being continued over a number of years.

It is possible that a great deal of the value of organic manures is due to their supplying minor elements necessary in small quantities for healthy plant growth. A recent survey of the literature on this subject (37) revealed the fact that up to the date of the survey forty elements had been described as having caused deficiency diseases in plants by their absence from the soil. Since organic manures are formed mainly by the decomposition of plants, it may be argued that such manures will contain traces of all the elements present in those plants. Hence their application to a crop represents an insurance against the deficiency of minor elements, and such a practice has much to recommend it until the details of plant nutrition are more clearly understood.

3. Compost Versus Green Manure.

Having decided in favour of adding organic material to the soil, there remains the choice between rotted composts and unrotted green manures. In this connection the term green manure is used for any type of undecomposed plant materials, from immature, succulent, green plants to crop straws.

In the preparation of composts, as in the decomposition of plant material in nature, the organic matter is first fermented to produce humified residues which constitute humus, then this humus is slowly oxidised, releasing nitrogen and other plant nutrients. That the first process of fermentation is best carried out outside the soil is pointed out by Anstead (2), Howard (29), and many others, although this fact was realised centuries ago by the Chinese (43). The disadvantage of ploughing in green manures is that unless they are immature their C/N ratio is so high that the soil nitrates are temporarily immobilised (6). This is due to the fact that the addition of organic matter possessing such a C/N ratio provides energy for the growth of soil micro-organisms, without providing adequate nitrogen for the synthesis of their protoplasm. Hence these micro-organisms compete with crop plants for the soil nitrogen. The condition is less serious where leguminous green manures are ploughed in, as then extra nitrogen is released by the death and decay of the root-nodule bacteria.

Collinson and Conn (10) conclude that the harmful effect of ploughing in straw is due partly to the immobilisation of soil nitrogen and partly to toxic decomposition products which act on plants immediately after germination, although this action is not important in the presence of much colloidal matter, as in clay soils. Furthermore, they claim to have detected salicylic acid, vanillin, and dihydroxystearic acid in the decomposition products of cereal straw.

As Beckley points out later (7), the use of green manures is beneficial if planting is carried out at just the right period after ploughing in the green manure. However, the practice is unreliable because decomposition may, for some reason, have been delayed, in which case the crop is sown too soon, germination is poor and growth is retarded. Alternatively rain may delay planting and plant nutrients, especially nitrogen, will be leached out of the soil. The same worker considers that green manuring may safely be used for perennial crops provided they are not allowed to become too mature. Under these conditions the immobilisation of soil nitrogen is only very temporary, while the crop remains in the ground and eventually benefits from the practice. This is contrary to the opinion of Howard (31) who maintains that the soil should not be asked to do two jobs at the same time. It should be noted (65) that the very reasons which militate against green manuring just before sowing a crop, favour that practice where the land is lying fallow for some reason. Thus besides the obvious benefit of a cover crop in preventing erosion, especially in the tropics, the ploughing in of material with a high C/N ratio prevents the leaching out of nitrogen from the soil.

The immobilisation of soil nitrogen by the decomposition of mature plant residues can, both in theory and in practice, be counteracted by applying a nitrogenous fertiliser before ploughing in. Murray (48) found that as much as six per cent of the dry weight of the straw had to be added as available nitrogen to prevent the locking up of the soil nitrogen. Murray, however, ground his straw finely and it would seem that Flieg's (16) figure of two per cent is more representative, as apparently long straw decays more slowly. Because of this large amount of nitrogen necessary, Gilbert and Pember (21), and Gerlach (20) consider that the practice is not feasible, especially because much of the nitrogen is lost by leaching where it is applied in one dose. However, experiments by Flieg and Grosz (17), and others at Rothamsted (54) indicate that the application of straw with a nitrogenous fertiliser, results in yields and residual effects which are at least as great as those obtained from a dressing of farmyard manure.

Summing up the evidence, it would seem that the practice of ploughing in green manures and crop residues may, in some cases, produce results equal to those obtained from an application of organic manure. However, the latter practice is the more reliable, and is therefore preferable.

4. The Biochemistry of Composting.

The raw materials of composting consist of plant residues of varying degrees of maturity which are decomposed in the compost heap by the agency of micro-organisms.

The structural constituents of the living plant consist of celluloses, hemi-celluloses, pectins, lignin and cutin, while the non-skeletal constituents include sugars, gums, starches, fats and waxes (19). In straw, or other farm residues, the celluloses and hemi-celluloses may represent sixty per cent or more of the whole; these are rapidly decomposed in the presence of sufficient nitrogen and other minerals. The fifteen to twenty per cent of lignins present are considerably more resistant to decomposition. Water soluble substances constitute five to twelve per cent of the whole, while proteins and ash are present in small amounts, the proportion of the former increasing during decomposition (73).

Rege (52) has shown that decomposition is initiated by the activity of certain fungi, whose growth is favoured by high temperatures, and that bacteria become important later. On the other hand Vandecaveye and Allen (60) found that the bacteria took the lead in decomposing straw in soil, while actinomycetes and fungi were of secondary importance. However, in the compost heap it would seem that fungi are the most important agents of decomposition.

Young plants contain more water soluble nitrogenous compounds, and less cellulose and lignin, than do mature plants, hence they are more rapidly decomposed than the latter (61), (71).

Considerable difficulty is usually experienced in composting highly lignified materials. However, Waksman and Tenney (72) and other workers (50) have shown that under aerobic conditions lignin may be decomposed in the soil almost as fast as celluloses and pentosans. Thus in the decomposition of oat straw (49) more than forty per cent of the lignin was removed in twelve months, though the difficulty of estimating lignin in plant materials makes the demonstration of this very difficult. Waksman and Hutchings (66) were unable to demonstrate or isolate any products of lignin decomposition. The same workers (67) later showed that lignin was only decomposed when a mixed culture of micro-organisms, which included actinomycetes, was present.

Evidence that lignin is a parent material of humus was summarised by Comber (11). Thus du Toit and Page (59) showed that under neutral aerobic conditions the formation of humus in the soil was more closely correlated with the change in lignin content than with the change in content of the other groups of plant constituents which they estimated. Apparently nitrogen is present in the humus complex as a protein; but it is known that proteins are readily attacked by soil micro-organisms, whereas humus is markedly resistant; however, Wakman and Tyer (68) were able to show that lignin combined with proteins, thus rendering them resistant to decomposition. They also synthesised a ligno-protein in the laboratory, which they later (69) showed to be similar to soil humus in character. This ligno-protein possessed a much greater capacity for base exchange than did free lignin (70), though this capacity was considerably influenced by the bases present. However, the chemical nature of natural soil humus is similarly influenced by the soil type (64).

The conditions favouring the composting process were first laid down by Hutchinson and Richards (32), and were emphasised and elaborated by all subsequent workers. A sufficiency of air and moisture is of primary importance, but adequate nitrogen and other nutrients must also be present. The high temperature necessary for the rapid growth of micro-organisms in the heap is usually ensured by the heat energy released in the rapid breakdown of the more readily decomposed substances. Approximate neutrality is essential since an acid reaction favours the formation of silage.

The next section describes how these conditions are satisfied in practice.

5. Methods of Composting.

For centuries the peasants of China and Japan have been making sufficient compost to maintain the fertility of their intensively cultivated lands (43). In contrast to the practice in the West, nothing is allowed to waste; all kinds of animal or vegetable refuse are carefull collected and heaped in shallow pits which may, or may not, be covered. Night soil from the great cities is collected every day and transported to the farms either by river, by cart, or by baskets carried as head loads. This night soil is thoroughly mixed with the heaps of refuse; canal mud and wood ashes are added; then the materials are thoroughly wetted and allowed to ferment. At intervals the heaps are turned and remixed, and water may be added. Under these conditions decomposition is favoured and excellent composts are obtained.

The practice of composting in the West dates from 1921, when Hutchinson and Richards (32) described a method of preparing "artificial farmyard manure" by heaping straw, and other plant residues, and applying water, powdered chalk and soluble nitrogen compounds to layers of the heap. This method was patented and the mixture of chemicals was put on the market by the "Adco" Company. Chance inoculation with fungi and bacteria seems to be sufficient to make the process successful, since no inoculatum of micro-organisms is added.

About this time an interesting process was evolved in Mauritius whereby a much greater quantity of crop residues could be incorporated into organic manure than went into ordinary pen manure. In this method, described by Hardy (23), the cattle pen was filled to a depth of two feet with cane trash, chaffed maize straw or other crop residues and the cattle allowed to trample this material at night. After about a fortnight the material, now well wetted with urine and mixed with dung, was removed and made into a store heap for further fermentation. Care was taken to compact the heap thoroughly so as to prevent "fire-fang", since at that time the value of aerobic fermentation was not realised, mainly because it led to loss of nitrogen from normal pen manure, which has a comparatively narrow C/N ratio.

A great advance in composting in the tropics was made when Howard and Wad (29) published a description of the Indore method. In this process, further elaborated by Howard (30 and 31), the raw materials are plant residues, wood ashes, dung slurry, urine saturated earth and previously rotted compost. Since the Indore soil is rich in lime and phosphate it counteracts any acidity developed and improves the mineral content of the compost. In the dry season the compost is made in pits so as to minimise evaporation, while in the wet season it is made in heaps so as to prevent water-logging. The method proceeds to a rigid timetable and the compost is watered and turned at fixed intervals; subsequently, another inoculation is made to ensure the presence of abundant micro-organisms.

The Indore method is very expensive in labour and a more economical modification was suggested by Jackson, Wad and Panse (36). Here rainwater provided the only source of moisture and, although the temperatures attained were lower than where the standard method was used, it was claimed that decomposition was almost as rapid. These workers also devised an ingenious method of adding nitrogen to the heaps by growing Sunnhemp (Crotalaria juncea) on them and later turning the green plants under. This practice was also found to accelerate decomposition in Kenya (6).

Fowler's "Activated Sludge" method of composting (19) depends on building up a large quantity of actively decomposing material, to which small quantities of fresh material are added at intervals. The activator is first obtained by heaping waste material and adding an inoculum of sewage sludge, urine, dung or night soil. Once fermentation has started the process is practically continuous since any compost removed is replaced by fresh material.

A simple, cheap modification of the Indore method is practised on the College Farm. By far the most important raw material consists of chaffed maize straw; but sorghum straw, weeds, cane trash, sweet potato vines and other materials are used when available. However, chaffed maize straw is usually the only material which is used unmixed. The drain which runs through the composting yard is dammed with earth and a pool of water is allowed to form. Into this pool forkfuls of the raw material are thrown and thoroughly wetted before heaping. Old compost, dung or washings from the oxen stalls may or may not be added.

Within two or three days the temperature in the heap rises to as much as 75° C., or more, after which it drops steadily for about a fortnight, when the heap is turned, re-wetted and remade. Sometimes the resulting temperatures may exceed the original maximum, but in any case the same steady cooling occurs, and after three months, when the compost is ready for use, the temperature in the heap is usually 30°- 40°C.

In the first few days of fermentation fungus mycelium soon appears as a white growth in the interior of the heap. The genera most commonly present appear to be Aspergillus and Coprinus, and fructifications of the latter fungus occur frequently on the surface of the heaps.

During decomposition dry matter is lost as carbon dioxide and by some leaching out of the soluble constituents. Moisture is lost and the density of the heaps increases. The nitrogen content increases slowly but the C/N ratio of the resulting compost never falls below 10 : 1. The final product obtained after about three months fermentation consists of a dark, humified matrix in which are embedded particles of the more resistant fibrous materials. The matrix is almost gelatinous when moist but dries to a granular earthy material, with a not unpleasant smell.

The striking fact about the compost heaps during fermentation is the absence of flies which cannot breed in the hot material. The high temperatures attained within the compost apparently kills all seeds, because weeds rarely grow on the surface of the heaps, except before the first turn in the wet season.

A recent development in composting technique may be mentioned here. Pizer (51), a commercial mushroom grower, was able to convert inefficient greasy composts into highly productive granular ones, by incorporating one to two per cent of gypsum, which apparently coagulated the dispersed humic colloids in the composted stable manure. This opens up an entirely new line of research and merits further attention. It may be, however, that coagulation of the colloids decreases the water-holding capacity of the resulting composts.

6. Materials Used in Composting.

A very great variety of organic materials have been successfully composted, from sewage, and other human waste, to every type of plant residue. According to Rege (52) the ease of decomposition of raw materials is determined by the ratio of pentosans (energy factor) to lignin (inhibitory factor). Provided this ratio is 1 : 1 or higher, then the residues are easily decomposed, but with a ratio of 1 : 2, or less, they are markedly resistant. However, there is no advantage in increasing this ratio, by adding more material rich in pentosans, since little humus results. Instead highly lignified materials appear to be the right type of raw material for humus manufacture (58), although this has only recently been realised.

At Indore (29) any kind of plant residues, such as cereal straws, fallen leaves and weeds have been successfully composted. Very woody materials, such as cotton and pigeon pea stalks, are spread out on farm roads until thoroughly crushed and broken up by the passage of carts over them. Wood shavings are more readily composted after a preliminary soaking in water.

In general, mixtures are more easily fermented than are single materials. Thus Tambe and Wad (58) were unable to compost cane trash by the Indore method unless it was well mixed with weeds.

Fowler (18), at Cawnpore, made compost from ten species of local weeds, banana stems, sunnhemp, and town refuse. In Kenya, Beckley (6) used weeds, straw, chaff, maize stover, green manures, coffee pulp and leaves.

A modification of the Indore method has been described by Bagot (3) to deal with tea estate wastes in Ceylon. Here, as elsewhere, the method has been adjusted to suit local conditions and to effect economy.

Jackson and Wad (35) were able to effect a sanitary disposal of habitation wastes by the Indore method and at the same time produce an excellent organic manure.

Wood (79) in Trinidad, made successful compost from village waste, but the high proportion of tins, broken glass, and rubber shoes rendered the method uneconomical.

Fowler (19) claims that if a sufficiently large amount of activator is used almost anything can be composted. However, attempts at decomposing coconut husks have met with little success in Trinidad.

7. The Control of Moisture.

All workers are unanimous in agreeing that water is an essential factor in the composting process. In fact, unless an adequate supply is available composting is impossible. Thus Brunton (8) considered that the quantity of water necessary for the composting of cane trash made the Adco process unsuitable for Trinidad cane farmers. Some idea of the amounts necessary per ton of raw material may be gauged from Table I, which was taken from Webster (74).

Table I.

Workers	Ref.	Materials	Gallons per ton
Adco	1	Cereal straws	800
Halversen and Torgensen (1928)	27	Cereal straws	1120
Mundy (1925)	47	Chaffed maize straw	1344
" "	"	Fresh green grass	613
" "	"	Grass hay	576
Brunton (1927)	8	Cane trash	333 plus rain
Howard and Wad (1931)	29	Mixed residues, hot weather	1120
" " "	"	Mixed residues, cool weather	746

At Indore (29) water is applied by sprinkling in layers as the heaps are built. However, Jones (40) found considerable difficulty in wetting cane trash as the water ran off the smooth leaves. The same difficulty was experienced at the College Farm where the method described in Section five was found to result in a more thorough wetting.

Beckley (7) found that a preliminary fermentation gave a colloidal coating to the particles of new material which rendered them easier to wet.

It should be noted that excess moisture, besides being wasteful, leads to anaerobic conditions in the heap which inhibit decomposition. Thus at Indore (29), compost is made in pits in the dry season, and in heaps in the wet season. The first method reduces water loss to a minimum, while the second method prevents waterlogging.

Where the original material already contains excess water, some difficulty is experienced in preventing anaerobic conditions unless some other dry residues can be mixed with it (6). However Beckley was able to produce usable composts from unmixed coffee pulp and sisal waste by building very low, loosely packed heaps. As soon as the outside had dried, it was turned in, and a quick growing legume grown on the heaps. This was allowed to grow for a month when the green material was incorporated into the heaps by a second turn.

In experiments on the College Farm, Kettlewell (42) found that the incorporation of dung into the heaps greatly improved their water holding capacity. He also showed that insufficient water resulted in worse compost where it was made in heaps rather than in pits.

Masefield (46) found that, in the wet season, there was scarcely any difference in moisture content between heaps turned once a week and heaps not turned at all. The same experiment repeated in the dry season caused the heaps turned once a week to lose thirty per cent of their weight in water.

Johnson (39) found that when a heap was kept under cover and given no preliminary wetting, then the initial fermentation was rapid but ceased after a few days. He concludes that a preliminary wetting is always necessary and that subsequent waterings, though beneficial in the dry season, may not be economical.

8. The Control of Aeration.

The air and water factors in compost making cannot really be considered apart, since practices controlling one will usually upset the other. Thus where compost is made in pits to reduce loss of water aeration is impaired. Similarly, if heaps are made aeration is usually sufficient, while the loss of water by evaporation and drainage is increased.

Russell and Richards (55) laid great stress on the undesirable effects of aerobic conditions in a manure heap, as indicated by fire-fang. They noted that where conditions favoured aeration the ammoniacal smell present under anaerobic conditions disappeared. This was attributed to the oxidation of the ammonia by aerobic bacteria, to produce gaseous nitrogen which was lost from the heap.

It is now known (6), however, that aerobic organisms encourage the breakdown of lignins, celluloses, and other plant constituents. Ammonia, instead of being lost, is actually fixed as bacterial and fungal protoplasm, and eventually becomes available through the death and decay of these organisms in the soil.

Aeration of heaps depends on their size and shape, their compaction and on the nature and particle size of the materials used. Thus Howard (30) declares that heaps should not be trampled and that they should not be built more than two feet high. This figure would seem to be unnecessarily low, and most authors indicate that aerobic conditions can be maintained in a heap five or more feet high. In practice this figure is determined by the openness and wetness of the raw materials, and by the prevailing weather conditions.

Where anaerobic conditions occur in a heap they usually do so in the centre and near ground level. To overcome this, Lambert and Davis (45) used ventilating tiles at ground level. Similar methods have been suggested by Howard (31) who found that ventilating channels in the composting floor covered over with bricks gave good results. Howard also suggested that heaps should be built over v-shaped, corrugated, iron partitions, these being removed later leaving ventilating shafts in the compost.

Masefield (46) and Johnson (39) both studied the effects of turning on the temperature of compost heaps. Johnson found that turning was beneficial in promoting decay and making for uniformity. He noted that the improved aeration after turning usually led to a rise in temperature. Masefield, who made temperature readings the day before, and the day after turning, concluded that a rise in temperature was not invariable. However, this result can be ignored, since the graphs in Appendix II show that turning is followed by a drop, and then a rise, in temperature. Where the rise had not occurred by the day after turning, Masefield would not have recorded it.

In connection with particle size, Webster (74) found that where maize straw was chaffed into lengths three-eights of an inch long, excessive compaction led to anaerobic conditions. This was remedied by adjusting the chaff cutter to cut the straw into one-inch lengths.

9. Inoculation.

The addition of some sort of fungal or bacterial culture to the raw materials of composting is universal amongst the workers in India. The materials most commonly used for inoculation are actively rotting compost, dung, night soil emulsion and sewage sludge. Fowler (18) correlated the efficiency of different inoculums with their bacterial populations and found that dung contained twenty times as many bacteria as old compost. He fails to point out however, that it is only the latter medium which contains any appreciable quantity of fungi. It is also possible that, of the bacteria contained in dung, some considerable proportion of them might be anaerobes. Masefield (46) tested this point in experiments where dung and old compost were compared as inoculums in quantities proportional to their bacterial contents. However, the amounts of inoculum proved to be insufficient to have any considerable effect on the differential rates of decomposition. A tendency was noted for dung to increase the nitrogen content of the heaps, while old compost improved the water retaining capacity of the material.

Joachim and Kandiah (38) found from experiments in Ceylon that best composts resulted from the use of night soil as inoculum. Cattle manure was slightly superior in efficiency to old compost.

Howard and Wad (29) recommend a second inoculation in the Indore method sixteen days after the initial one. The value of this practice is uncertain, although both Kettlewell (42) and Webster (74) suggest that the high initial temperatures attained in fermentation might prove lethal to the micro-organisms in the compost. There seems, however, no experimental evidence to justify this theory, and in view of the fact that the high temperatures, which result from the activities of these micro-organisms, do in fact remain high for a considerable time, then the present writer considers such a theory to be untenable.

Recently Johnson (39) made observations on the effect of inoculation, and found that it accelerated decomposition at first, but that later the uninoculated heaps caught up with the inoculated ones. Hence he concluded that inoculation is only beneficial where the time factor is important.

It is notable that in the Adco process no inoculation is made, reliance being placed on the provision of the optimum conditions for bacterial and fungal growth.

10. The Addition of Inorganic Nutrients.

From the considerations dealt with in Section 3 of this work it is evident that the micro-organisms effecting decomposition of plant residues require a supply of available nitrogen. This fact was established by the laboratory work of Hutchinson and Richards (32), which led to the Adco process, in which a proprietary mixture, containing soluble nitrogen, is added to the raw materials.

The amount of nitrogen added is important since an excess inhibits decomposition and results in some being lost. Most workers agree that the optimum amount of nitrogen in the decomposition of cereal straws is in the neighbourhood of one per cent of the weight of dry straw. This concentration is obtained by the addition of approximately 0.7 per cent of nitrogen. In the absence of figures for other materials this ratio may also be used, but much less should be added where compost is made from the residues of leguminous crops.

Inorganic nitrogen is usually added in the form of sulphate of ammonia but the acidity which develops from the use of this compound must be controlled by some means (see section II). Carberry and Linlow (9) found that ammonium phosphate gave better results than sulphate of ammonia; it did not induce acidity, and it improved the phosphate content of the compost. However, it is doubtful whether these advantages outweigh the extra cost of that compound.

Where no extra nitrogen is added, compost can still be made although decomposition is slower. For this reason Beckley (6) considers that the addition of nitrogen is only economic where the time factor is important. In this connection it is interesting to note that Fowler showed that fixation occurred in heaps where the nitrogen content was below the optimum (18). However, Hutchinson and Richards (32) and Hardy (24) considered this to be unimportant.

Halversen and Torgerson (27) and Johnson (39) observed a loss of nitrogen where an addition was made. For this reason Johnson considered that it would be more economical to apply the nitrogen direct to the crop as an inorganic fertiliser.

Besides nitrogen, other nutrients are required by the micro-organisms responsible for decay, however, phosphate is apparently the only other one which is likely to be deficient. For this reason Hutchinson and Richards (32), Hardy (25) and Wood (77) all recommend the addition of from ten to twenty pounds of superphosphate per ton of raw material. There is no direct evidence in favour of this practice but where soils are known to be deficient in phosphate, as in Kenya (6), additional phosphate may just as well be applied in the compost as direct to the crop, since it is not likely to be leached out.

11. The Control of Acidity.

All workers have noted the necessity of adding some form of ground limestone or chalk to neutralise the acidity which develops when nitrogen is added as sulphate of ammonia. The quantity usually recommended is one hundredweight per ton of dry, raw material.

At Indore the soil contains lime and it is therefore added to the compost heaps (29). Wood ashes are also used to counteract acidity at Indore, Kenya (6) and elsewhere.

Johnson (39) found that, where acidic conditions already existed in a heap, the addition of ground chalk did little to ameliorate that state. Even where the lime was added with the sulphate of ammonia, Masefield (46) found that the development of acidity was not entirely checked, although the use of lime apparently resulted in a higher degree of humification.

Where no inorganic nitrogen was added to the compost Masefield (46), Joachim and Kandiah (38) and others found that there was no benefit in adding lime, although White, Holben, and Jeffries (75) noted that lime increased the number of micro-organisms in the soil.

It should be noted that acidity also develops as a result of anaerobic conditions in the heaps or pits. In this case, decomposition is checked and silage is formed, but active fermentation can be reestablished by improving aeration.

12. Addition of Organic Nutrients.

Most of the world's compost is made without any addition of inorganic nitrogen. However, an adequate supply of that and other nutrients is obtained from the dung, urine, night soil or sewage sludge which also provide the micro-organisms responsible for decay. Little is known with regard to the amounts of such materials which should be used, but Fowler (19) advises the addition of sufficient to raise the nitrogen content up to two per cent of the dry material. Not only is the use of organic nitrogenous material much less expensive than the addition of inorganic nitrogen, but such materials also act as inoculums, and improve the water holding capacity of the compost heaps.

As an indirect method of supplying nitrogen Jackson, Wad and Panse (36) and Beckley (6) grew leguminous plants on the surface of the heaps between the first and the second turns. In each case sunnhemp (*Crotalaria juncea*) grew most vigorously and produced the greatest number of root nodules.

Another method of stimulating decomposition in the compost heap is to increase the ratio of the energy factor to the inhibitory factor (52). This was accomplished by Tambe and Wad (58), who added dilute molasses to a six months old heap of cane trash, and only by this means was decomposition started. The same result, however, was not obtained when molasses was added to the fresh material. In this connection it is interesting to note the work of Dhar (12) who claimed that nitrogen fixation was induced by the photochemical or bacterial oxidation in the soil of energy rich compounds such as molasses.

13. Measurements of the Progress of Decomposition.

Prior to analysing the final product of composting, some idea of the stage of decomposition can be gauged by taking a number of criteria into consideration.

The temperature within the heap is considered by most workers to be an index of the intensity of biochemical reactions. Masefield (46) and Johnson (39) both recorded temperatures by inserting a hollow bamboo into the heap and lowering a thermometer down into this on a string. Soil probe thermometers were also tried, but were found to be very slow in reaching an end point. The methods used by the writer are dealt with in Part II.

Carbon dioxide evolution was studied by Masefield, who devised a method whereby this could be measured in the farmyard. The errors obtained, however, were high owing to the variability of the samples.

The same worker made estimates of the micro-organisms present, using a modification of the plate count method outlined by Waksman and Fred (63). The results from this work were disappointing owing to the high sampling error.

Probably the most generally useful of all criteria for assessing the stage of decomposition is judgment by hand and eye. In general, as decomposition proceeds the colour darkens and the material tends to lose its structure. The breaking strain of fibrous material is a good indication of the amount of rotting to which it has been subjected.

Other measurements depend on accurate sampling methods and may be dealt with more appropriately in the next section.

14. Measurements of the Manurial Value of Composts.

(a) Chemical Analyses.

When the compost heaps are finally broken up for carting to the field accurate sampling is made possible. By continued sub-sampling, a small amount of compost may be taken for analysis which can be considered as a representative sample.

In the laboratory a pH determination may be made on the fresh material. This is then dried to give the percentage moisture present. A portion of the dry material is set aside for determination of the degree of humification, and of the carbon content, while the rest is ignited to give the ash content and hence, by difference, the percentage of organic matter. The ash is further analysed to estimate the potash and phosphoric acid. The total nitrogen content is determined on the fresh material by Kjeldahl's method.

The most important of the analytical figures obtained are the ash content, the carbon/nitrogen ratio and the degree of humification. The ash content has been shown by Lamb (44) to undergo a progressive increase during the decomposition of composted materials. This is due to the oxidation of the organic matter and the consequent loss of carbon; hence the proportion of ash in the dry matter increases. For similar reasons the carbon/nitrogen ratio furnishes another useful index of decomposition: this ratio shows a steady decrease, until a value of ten to one, or slightly less, is attained, after which it remains steady.

The determination of the degree of humification by Robinson and Jones' method (53) is one of the routine analyses made by the Chemistry Department on College Farm compost. This was considered by Masefield (46) to provide the most reliable single index of decomposition. The method depends on the fact that, if the material is treated with hydrogen peroxide under standardised conditions, then only a portion of the organic matter is oxidised.

Since this method was first described it has been seriously criticised on the grounds that not only is the humified material oxidised, or brought into solution, but also much of the more resistant organic matter. However, of the modifications or alternative methods suggested, many are too laborious, while others give no more reliable results than does the original method of Robinson and Jones.

It has already been noted in section 4 that the capacity for base exchange of organic matter increases with an increasing degree of humification. Hence a determination of this figure (34) for compost will reflect its degree of humification.

All the analytical figures vary considerably according to the parent material used and the method of compost adopted. Thus the nitrogen content is considerably increased where additions are made in the form of Adco, urea or sulphate of ammonia. Similarly the ash content is particularly high in the case of Indore composts since they are more thoroughly decomposed than by other methods. As a result these composts are especially finely divided, and Howard claims that eighty per cent of the material will pass through a sieve of six meshes to the linear inch.

A number of typical analyses of pen manures and composts are given in tables II and III.

TABLE II

ANALYSES OF COMPOSTS.

Ref. No.	No. of Samples averaged	Material	Moisture percentage	Percentage on dry matter basis.					Degree of Humification
				Organic Matter	Ash	Total Nitrogen	P_2O_5	K_2O	
77	--	I.C.T.A. compost	-	59	40	2.1	-	-	84
38	15	Refuse night soil compost	41.8	23.2	65.0	0.88	0.70	0.70	-
38	4	Indore compost	44.2	21.9	67.9	0.84	0.61	0.41	-
38	10	Pit compost	36.5	19.9	77.7	0.54	0.57	1.16	-
26	2	Adco compost (cane trash)	76.25	64.45	35.55	2.21	-	-	58.4
47	--	Adco compost (maize straw)	72.40	58.88	41.12	1.99	1.30	1.01	-
58	--	Habitation waste compost	21.29	28.50	71.55	1.56	2.74	2.20	-
58	--	Farm compost, Indore	41.39	19.25	80.75	0.91	0.68	2.81	-
58	5	Cane trash compost	62.53	35.66	64.58	0.82	0.32	0.32	-
22	--	I.C.T.A. compost (maize straw)	85.3	-	-	1.47	-	-	35.84
22	--	ditto (woolly pyrol)	83.0	-	-	2.32	-	-	46.22
57	--	ditto (maize straw)	42	63	-	1.36	1.09	2.13	50
39	--	ditto (town refuse)	39.82	36.02	63.99	1.06	0.62	1.11	-
39	--	ditto (maize straw)	77.65	59.15	40.85	1.50	1.10	2.10	-

TABLE III.

ANALYSES OF PEN MANURES.

Ref. No.	No. of Samples averaged	Material	Moisture percentage	Percentage on dry matter basis.					Degree of Humification
				Organic Matter	Ash	Total Nitrogen	P_2O_5	K_2O	
77	--	English Farmyard Manure	75	72	25	2.3	1.0	2.4	-
77	--	Trinidad Pen Manure	76	68	30	2.0	-	-	58
77	--	I.C.T.A. Pen Manure	69	67	33	1.8	-	-	58
38	3	Ceylon Pen Manure	57.3	39.6	60.4	1.17	0.49	1.27	-
26	2	Trinidad Pen Manure (cane trash)	74.25	55.86	44.14	2.23	-	-	53.7
58	--	Indore Farmyard Manure	16.95	16.32	83.68	0.58	1.03	2.30	-
22	--	I.C.T.A. Pen Manure	69.4	-	-	1.03	-	-	43.65
57	--	ditto	78	52	-	1.49	1.13	1.90	56
39	--	ditto	62.63	75.91	24.09	2.11	0.89	3.33	-

(b) Field Experiments.

The most convincing tests of the value of composts are field experiments comparing the yields obtained from the applications of pen manures, composts and artificial fertilisers. Unfortunately, very few statistically reliable results have been published, in fact, very few results of any sort. Extraordinary claims are made by Howard for the manurial value of composts at Indore but until these claims are substantiated by reliable experimental results little attention need be paid to them.

In 1933-34 Swynnerton (57) compared the effects of three different dressings of compost with and without artificials, on maize. However, the only significant result obtained was an increase in yield of straw resulting from the application of artificials.

Gisborne (22) in 1934-35 compared pen manure with two kinds of compost in an experiment with sorghum. The manures were applied in dressings of five tons and fifteen tons to the acre. Since no significant differences were obtained it was concluded that the pen manure was not superior to the composts. The value of this experiment would have been considerably increased if the control plots had received no organic manure. It would then have been possible to decide whether the pen manure and the composts had produced equal responses in yield, or whether they had produced no increase at all.

In the season 1935-36 Johnson (39) conducted two experiments on the effect of composts applied to maize. In the first experiment the main treatments were:-

1. No manure.
2. Organic manure, single dressing.
3. Organic manure, double dressing.

4. Complete artificials.

5. As 4, plus organic manure, single dressing.

6. As 4, plus organic manure, double dressing.

The main plots of treatments 2, 3, 5 and 6 were split for the application of two kinds of compost, and pen manure.

The results showed that treatment five was the only one which effected a significant increase in yield of cob. The organic manured plots yielded significantly better than those not dressed with organic manures. A significant interaction showed that the supplement of artificials increased the yield with the single, but not with the double, organic dressing.

The analysis of the effect of the sub-treatments showed that one type of compost, made from maize straw, gave a significantly lower yield than either the pen manure or the other compost, which was made from town refuse.

In the other experiment performed by Johnson, compost was tested against undecomposed chaffed maize straw. Apart from a tendency for the composted plots to give a higher yield of straw, there were no significant differences in this experiment.

Recently Ball (4) has conducted some interesting experiments in Kenya. In one of these, three different dressings of compost (eight and a half tons, six tons and three tons per acre) were tested against control in an experiment with maize. The results showed that all the dressings of compost yielded significantly better than the control, and that the largest dressing was significantly superior to the other two. Residual effects were tested for in the following year, when it was found that the largest dressing was significantly superior to both the three tons per acre and the control.

Another experiment was conducted by the same worker with maize, the treatments being:-

1. Control.
2. Trash ploughed in.
3. Trash and compost ploughed in.
4. Trash and superphosphate, 200 lbs. per acre.

The results showed that treatment four was significantly superior to the other three. Thus it would seem that the supply of available nutrients in the compost did nothing to compensate for the hypothetical immobilisation of the soil nitrogen during the decomposition of the trash. However, the yield from trash only was equal to that from the control: hence it would seem that any such immobilisation of nutrients was unimportant, except possibly in the case of phosphates.

15. Costs of Making Composts.

Besides figures published by previous workers on the College Farm, there is little information regarding the cost of making compost. However, Anstead (2) remarks that compost made by the activated sludge method could be sold in Mysore for four shillings a ton.

Brunton (8) and Jones (40) both give figures for the manufacture of Adco compost on cane farms in Trinidad. The former worker made compost from cane trash for $3.44 per ton but calculated that on a larger scale it could be made for $3.04 per ton. Jones' figure for similar compost is $3.29 per ton. Both these workers obtained between two and three tons of manure from one ton of dry parent material. It should be mentioned that the Adco mixture, in the recommended quantity, costs $1.62 per ton of compost obtained.

Webster (74) and Kettlewell (42) both give the same figures for three different samples of compost. They assumed a yield of 1.4 tons of compost per ton of parent material and their average cost came to $1.96 per ton of compost. As this included the use of artificials costing $1.16, compost could be made by them, using dung, for 80¢.

Masefield (46) and Johnson (39) both assumed a yield of compost equal to the weight of raw material used. Using artificials the first worker made compost for $3.14 per ton, but when dilute urine was used to replace the artificials this figure was reduced to $1.42 a figure similar to Johnson's $1.27.

It is interesting to note that Johnson's figure includes 72¢ for the cost of chaffing, which accounts for approximately 56.7 per cent of the total.

16. Discussion.

Recently the writer of this thesis received a letter from a certain Professor of Agriculture, who referred to Waksman's authoritative book on "Humus" (62):- "from its four hundred pages I merely learned that nothing is known about the organic matter in the soil". It may be that readers of this much less authoritative review of literature, relevant to composting, will have reached a similar conclusion. However, a true knowledge of ignorance is a great asset in all scientific work, and leads to the adoption of an open and receptive mind, so essential for all research.

It should be realised that much of the work reviewed, especially in sections 3 and 4, refers to research conducted under temperate or sub-tropical conditions. This is important because recent experiments (13) have shown that, in the humid tropics, humus is much less stable, and organic matter decomposition proceeds to a much more advanced stage, than in temperate regions.

In spite of this cautious approach to the literature, a few provisional conclusions may be drawn. Thus the available evidence suggests that the presence of humified organic matter in the soil is necessary for the proper growth of plants in that soil. Furthermore it would seem that the supply of such humus is best effected by allowing the initial decomposition of organic matter to take place outside of the soil, rather than by the more natural method of permitting the humification to proceed in the soil.

With regard to the materials from which compost is made, it would seem that the maximum amounts of lignified materials should be used, although sufficient easily decomposable materials should also be included, to induce a rapid and complete decay.

Different methods of composting, and the control of individual factors in the process, show how economical considerations may or may not render composting feasible. Thus the supply of water in regions of low rainfall may be the factor determining the possibility of preparing composts. Similarly the price of labour decides the amount of attention and handling which is possible.

It would seem that the benefits accruing from the practice of adding artificial nitrogen to the parent material are not commensurate with the extra cost of the compost obtained. For this reason it is important to investigate the possibility of supplying the nitrogen, and other nutrients necessary for the proper metabolism of the micro-organisms

II. EXPERIMENTS ON COMPOSTING.

1. Foreword.

Part II of this dissertation is concerned with the description of experiments conducted with a view to the discovery of cheaper and more efficient methods of composting. The scope of these experiments is comparatively limited, but it was thought preferable to concentrate on a few aspects of the preparation of composts, rather than to study superficially the complete process. For this reason none of the experiments are directly concerned with inoculation, the supply of nitrogen or the control of acidity. However, all these aspects have been considered, where they were relevant to the problems dealt with.

The method of composting normally practised on the College Farm has already been described (page 12). Because of this, the composts which were used in the field experiments (described in Part Three) are not considered here, unless their preparation involved some special technique.

2. Measurements and Criteria Used.

In the experiments described here, reliance has been placed on judgment by hand and eye, and temperature studies, as indices of the progress of decomposition. However in the case of some of the composts, analyses of the final products were very kindly undertaken by the Chemistry Department, in which case the assessment of their values was greatly facilitated.

Counts of micro-organisms, and measurements of carbon dioxide evolution were not made, as it was considered that the results obtained by Masefield from these studies were not of sufficient value to justify their repetition.

With regard to the method of taking temperatures, mention must be made of the one practised by Masefield and Johnson, where a hollow bamboo was inserted into the heap and a thermometer lowered into this on the end of a string. This method was tried, but it was found to possess several disadvantages. First the temperature inside a freshly inserted bamboo took a very long time to reach equilibrium and all such readings were much too low. Furthermore, if a number of bamboos were used and left in the heaps, the temperatures recorded were higher; however errors arose from the fact that the aeration within the heaps was greatly increased by the bamboos, also it was not possible to distribute the temperature readings over all parts of the heap.

Soil probe thermometers were tried but they were soon discarded, mainly because they were only graduated to 52°C. and therefore they could not be used in the early stages of decomposition.

Quite the most accurate method of recording temperatures in compost heaps, and the one which was used for all temperature studies, was the insertion of a thermometer into a hole in the heap previously made by an iron crowbar. By this means the aeration was not interfered with to any great extent, because the holes soon closed up again; consequently, it was found possible to make large numbers of readings, and yet use a fresh hole for each individual one.

For the sake of consistency in results, practically all temperature readings were made at a level of the length of a thermometer (i.e. approximately one foot) below the surface of the heaps and not nearer to the edges than nine inches. For this reason it was not essential to tie a length of string to the thermometer, however this practice was advisable to guard against the possibility of the thermometer dropping too far down the holes.

It should be mentioned that the use of a crowbar to make a hole is essential as a precaution against breakages. Thus before this method was evolved, it was suggested by certain critics that the incorporation of so much broken glass might seriously affect the quality of the composts.

3. Experiments on the Composting of Unchaffed Material.

(a) Preliminary Experiments.

It has already been noted that, where the normal College farm method of composting is practised, the process of chaffing accounts for more than fifty per cent of the total cost. Consequently it was decided to attempt the composting of unchaffed maize straw by a modification of the Mauritian system (see page 10).

It was proposed to cart the long maize straw straight from the field to the pen and to leave it there, prior to heaping, until it was thoroughly trampled and wetted by the cattle. Accordingly two preliminary trials were carried out in October and November, to investigate the possibility of such a method.

In the first trial long maize straw was carted into the pen and left for a fortnight, before being heaped at the side of the pen. However, the material was much too wet and lack of aeration prevented the heaps from heating up. In a later trial, in November, long maize straw was left in the pen for four days and then heaped outside. In this case the heaps heated up well, and eventually produced good compost.

The success of this second trial was considered to justify further study of the method. Consequently a more precise experiment was carried out which is described here.

(b) Main Experiment.

In January the maize straw on field 27C was cut and carted into the pen, in which there was already a small amount of accumulated dung. After a week the contents of the pen were carted out to the compost yard and two large heaps were built. These were about twelve feet long, by five feet wide, by five feet high.

The day after the completion of the heaps, temperature studies were commenced, and continued for approximately ten weeks. On about six days a week five temperature readings were taken in each heap between 11 a.m. and 12 noon; the average daily temperatures have been plotted on Graph one, Appendix II.

From the graph it will be seen that the average temperatures reached a maximum five days after heaping, then there was a gradual drop in temperature, until the heaps were turned when twelve days old. The day after turning the temperatures had fallen, but they rose rapidly to reach a maximum, still higher than the first one, after three days.

The temperatures recorded were remarkably high and even after five weeks the average temperature in both heaps was over 60°C. Actually the maximum individual temperature recorded was 78°C. in heap one, two days after its completion.

It will be seen from the graph that, during the first five weeks, the average temperatures of the two heaps were remarkedly similar, a fact which illustrates the value of such studies, providing that a sufficient number of readings are made.

During the period from February 15th to March 4th heap two was watered daily, at about 4 p.m., with approximately ten gallons of water. For the first week of this treatment no temperature differences were noted between the two heaps (at one foot below the surface). However after that the temperature in the watered heap fell considerably below that in the unwatered one and this difference was found to extend throughout the heap.

During the month of February an attempt was made to grow Sunflower (Helianthus annuus), Woolly Pyrol (Phaseolus mungo), Sword Bean (Canavalia ensiformis) and Bengal Bean (Stizolobium aterrimum) on the surface of the heaps. However the attempt was a complete failure since, in the very dry weather, and in spite of surface waterings the seeds failed to germinate.

Early in March the heaps were turned a second time. As before the temperatures in the heaps fell and then rose again; however this time they did not reach a maximum until five days afterwards.

On March 4th temperature readings were taken twice in each hole, first at one foot, then at two feet below the surface. The results (Table IV) suggest that at two feet below the surface some factor - presumably aeration - tends to hinder bacterial and fungal activities.

Table IV.

Heap	Depth	Temperature readings in degrees C.					Average
One	one foot	60	62	61	60	59	60.4
	two feet	57	59	60	55	54	57.0
Two	one foot	54	56	57	58	58	56.6
	two feet	52	54	54	58	56	54.8

During the entire experimental period the fungal growth within the heaps was really excellent, with little indication of insufficient aeration as shown by patchiness.

The temperature studies show that biochemical action was intense , yet there was never any suggestion that the heat developed proved lethal to the micro-organisms.

The final product, as judged by hand and eye, was a really well rotted compost and equal in quality to anything made on the farm from chaffed maize straw. The method may therefore be considered successful, especially as it is more economical. Actually it was estimated that one ton of compost prepared by this method cost $1.31, whereas the standard farm method, using chaffed maize straw, cost approximately $1.55. Details of these costs are given in Appendix III.

(c) <u>The Experiment on Field 25</u>.

This experiment is dealt with fully in Part three, but brief mention must be made here of the methods by which the composts, for the field trial, were prepared.

The main treatments in the experiment were:-

1. Compost made from long maize straw previously trampled in the pen.
2. Compost made from long maize straw as in 1., but with an equal amount of chaffed maize straw incorporated.
3. Compost made from chaffed maize straw only.

The long maize straw was left in the pen for five days before being heaped, but the short maize straw was freshly chaffed.

After the first turn, Sunnhemp (Crotalaria juncea) was sown on the surface of half of the heaps as a sub-treatment. This germinated well after two days and was allowed to grow for a further fortnight. However after the third day of growth, when the seedlings were two to three inches high, there was little further increase in height. Very vigorous root systems were developed, which penetrated more than twelve inches into the heaps; however in spite of this no root nodules were observed, possibly owing to the absence of the causative bacteria.

It was unfortunately found necessary to use the composts when they were only four weeks old. At this stage the heaps containing long maize straw were superior in appearance to those made from short straw only. This difference was reflected in the experimental results (see Part three) as treatments one and two proved superior to treatment three.

According to the chemical analyses the growth of sunnhemp on the heaps showed a slight tendency to increase their nitrogen contents, so it may have been that some root nodules were formed after all. With regard to the effect of this sub-treatment on the yields little can be concluded as the results were rather complex. However, it has been established that a legume can be grown on compost heaps in the Trinidad wet season and it would seem desirable to study the effect of this practice in a more precise trial.

4. The Composting of Rice Straw.

An experiment was started in November on the composting of rice straw, as some difficulty had been experienced in previous years in preventing anaerobic conditions in this material.

For comparison three heaps were built and a different technique used in each case. Thus heap one was built of fresh long straw well wetted with dilute urine. Heaps two and three were built of long straw which had previously been trampled in the cattle pen for four days; however long maize straw was also incorporated into heap three in an attempt to improve aeration. The first heap was built about five feet high, and the other two about four feet high. After a week heaps two and three had settled down to half their original height, while heap one had remained unchanged. It is rather interesting to note that heap two had settled unevenly and temperature studies showed that the more compact portions were much hotter than where the material was more open.

All three heaps were turned when they were a fortnight old and again one month later. Between the two turns all the heaps had settled down to a compact mass, and the temperature in all of them was under 40°C. After the second turn, the dry weather favoured aeration and considerable decomposition took place. Finally the heaps were sampled for chemical analysis when they were twelve and a half weeks old. The analyses of all three composts and of the fresh rice straw are given in Table V, on the following page.

When judged by hand and eye heap two was easily the best, as it was very dark in colour and practically structureless. The matrix of heap three was similar to the material in heap two, but the long maize straw had scarcely decomposed at all. The material from heap one had quite a good appearance but the structure of the flattened straws was perfectly evident.

The few temperatures in table VI give some idea of the progress of decomposition.

TABLE V.

ANALYSES OF RICE STRAW COMPOSTS.

Material	Percentage on the fresh weight basis						Percentage on the dry wt. basis					C/N ratio	Degree of humification
	moisture	organic matter	ash	total nitrogen	P_2O_5	K_2O	organic matter	ash	total nitrogen	P_2O_5	K_2O		
Fresh Rice Straw	71.2	23.8	5.0+	0.18	0.13	0.44	82.8	17.2+	0.63	0.45	1.52	-	-
Heap one	62.5	17.2	20.3	0.58	-	-	46.0	54.0	1.55	-	-	14.5	80.0
Heap two	55.5	20.7	23.8	0.74	-	-	46.6	53.4	1.67	-	-	12.6	73.2
Heap three- matrix	58.6	16.9	24.5	0.64	-	-	40.7	59.3	1.55	-	-	12.9	77.5
Heap three- maize stalks*	80.3	-	-	-	-	-	-	-	-	-	-	-	-

N.B. *In heap three the maize stalks constituted 33.6% of the wet sample and 19.4% of the oven-dried sample.

+ 80.3% of the ash consisted of insoluble material.

Table VI

Temperatures in Rice Straw Heaps in Degrees Centigrade.

(averages of ten readings).

Heap	After one week	After two weeks	After four weeks	After eight weeks
One	32.2	38.3	39.4	42.2
Two	58.1	38.0	35.2	38.4
Three	44.2	40.3	36.6	41.2

It will be seen that decomposition was slow in starting in heap one, and that heap two showed the greatest signs of lack of aeration in the later stages. However, the compost from heap two was probably the best in spite of heavy rain during the early stages of decomposition. Probably in drier weather the inferiority of heap one would have been still more marked, owing to the difficulty of wetting the untrampled rice straw.

The incorporation of long maize straw with the trampled rice straw presumably increased aeration, but there was some indication from temperature studies that this was excessive in the early stages.

5. The Use of Molasses in Composting.

In the wet season in Trinidad very good composts can be made by the standard farm method of wetting chaffed maize straw with dilute urine, - possibly with the addition of some dung or old compost. This method is less satisfactory in the dry season, unless very large heaps are built, because decomposition is slower in commencing and the material tends to dry out. Accordingly attempts were made to accelerate decomposition by applying molasses to the straw before heaping, as there was some evidence (see page 23) that this might have the desired effect.

(a) First Experiment.

On January 14th a heap containing about 1260 lbs. of chaffed maize straw was built, to which four gallons (approximately 57 lbs.) of molasses were added, after having been diluted with sixteen gallons of water. The next day a similar heap was built to which twenty gallons of water, - but no molasses - were added. The dimensions of each heap were approximately eight feet, by three feet, by three feet, (i.e. about 72 cubic feet in volume).

Five temperature readings were taken daily on each side of each heap, as the longer axes of the heaps pointed north and south. The average temperatures have been plotted on graphs two and three (Appendix II) for a period of ten weeks.

It will be evident from the graphs that, in the early stages, there was little difference in biochemical activity between the two heaps. However, after the first fortnight, when both heaps were turned, the temperatures in the molassed heap were consistently higher than in the unmolassed one. Furthermore this difference was greatly increased after the second turn, when more molasses (eight gallons) was added to the first heap.

It is interesting to note that, in each heap, temperatures were consistently lower on the windward (East) side than on the leeward side. However, after the second application of molasses this difference was less marked in the first heap than in the unmolassed one. Thus it would seem that the addition of molasses had a beneficial effect on heap one by increasing the moisture - retaining capacity of the material. This fact was corroborated when the heaps were turned for a third time, as heap one was dark in colour, moist and supported an excellent growth of fungi. Heap two, however, was very dry with a poor fungal growth.

Temperature readings were discontinued on March 20th, as it was decided that the heaps were too small for the material to rot completely in the very dry weather. In spite of this the experimental results were considered to be of sufficient interest to merit further study of the problem in another experiment.

(b) Second Experiment.

On March 20th a large heap (approximately ten feet, by six feet, by four feet) was built of chaffed maize straw, well wetted with water, and with about ten per cent of dung incorporated as inoculum. Two days later a similar heap was built, without dung, but with the inclusion of twenty gallons of molasses. The capacity of this heap was approximately 255 cubic feet.

Temperature stuies were made on the two heaps and some of the average readings are reproduced in Table VII.

Table VII.

Average Temperatures in Degrees Centigrade.

Age	Molassed heap	Unmolassed heap
After two days	63.4	68.8
" four "	65.0	72.0
" six "	61.2	71.4
" eight "	66.2	67.6
" two weeks	60.8	63.2
" three "	59.2	60.4
" four "	58.6	59.2
" six "	60.6	54.8
" eight "	49.8	50.4
" eleven "	31.8	57.8

It is apparent from these figures that, in the early stages, decomposition was more vigorous in the standard heap. After four weeks when the heaps were turned and a second application of molasses (ten gallons) made, conditions apparently improved in the molassed heap. However the standard heap was unmistakably superior in appearance, being dark in colour, moist and well compacted. In contrast, the molassed material was light coloured, dry and very loosely packed.

The heaps were turned a second time after eight weeks, but there had been little improvement in the state of the molassed material, although it supported quite a good growth of fungi. However, when the two heaps were finally sampled after eleven weeks, it was apparent that decomposition had been almost completely arrested in the molassed heap as the material was cold, devoid of fungus, and practically unchanged.

The final product of the standard method was a really well-rotted compost and the difference between this and the molassed material was much greater than the temperature readings suggest. A much better comparison of the two products is given by the figures in Table VIII.

Table VIII.

Heap	Age	wet weight (grams)	percentage moisture	pH	Nitrogen % on dry weight.
Standard	After four	2110	80.3	7.8	--
Molassed	weeks	1150	29.2	3.8	--
Standard	After eight	2510	72.2	8.2	--
Molassed	weeks	935	37.1	5.6	--
Standard	After eleven	2445	59.2	7.3	1.75
Molassed	weeks	725	36.4	2.5	1.05

Since all the samples taken were of approximately equal volumes (one "fourteen pound" bagful), the wet weights give some indication of the density of the material. Thus while the density of the molassed material remained constantly low, that of the standard compost showed a steady increase.

The pH determinations show that the use of molasses induced highly acidic conditions in the heap, - a fact which is quite sufficient to explain the failure of such material to decompose. Unfortunately, similar determinations were not made in the first experiment but, - judging from the appearance of the composts made - it seems most unlikely that molasses had a comparable effect on the reaction.

It may have been that, in the earlier experiment, the tendency of molasses to cause acidity was counteracted by the highly aerobic conditions in the heaps. However the inferior aeration obtaining in the larger heaps of the second experiment was quite sufficient to keep the reaction just alkaline where no molasses was added.

There is another possible explanation for the different effect of molasses in the two experiments: in the first case the initial application of molasses was only half the size of the subsequent one; however, in the second trial two-thirds of the total was applied in the earlier dressing, and one-third in the later one. This is interesting in view of the fact that earlier workers (58) were only able to accelerate decomposition where molasses was added to partly rotted material (page 23).

For comparison the proportions of molasses to parent material in the two experiments are given in Table IX.

Table IX.

		Proportions of molasses to maize straw
First Experiment	First application	1 gallon molasses to 18 cubic feet
	Second "	1 " " " 9 " "
	Total "	1 " " " 6 " "
Second Experiment	First application	1 " " " 12.75 " "
	Second "	1 " " " 25.5 " "
	Total "	1 " " " 8.5 " "

The analysis of the molasses used in the two experiments is given in Table X on the following page.

Table X.

Analysis of Molasses.

Hydrometer Brix	81.30
Specific Gravity	1.42
Total Solids	79.39
Ash	4.80
Moisture	20.61
Organic Matter	74.59
Sucrose	34.97
Glucose	24.79
Total Reducing Sugars	59.76
Total Nitrogen	0.36
P_2O_5	0.13
K_2O	1.06

III. FIELD EXPERIMENTS ON THE MANURIAL VALUE OF COMPOSTS.

1. Statistical Methods.

In both the experiments described below, care was taken to ensure that the arrangement of the treatments was randomised, and that each treatment was sufficiently replicated to enable a reliable estimate of the experimental error to be made. According to the size of this error, a difference had to be larger or smaller in order to be considered significant.

The theories involved in such methods are discussed by Fisher in his "Statistical Methods for Research Workers"(14) to which constant reference has been made. In connection with the practical application of such statistical methods, the reader is referred to a recent publication by Wishart and Sandars (76). Some use was also made of a paper (15) dealing with the arithmetical treatment of experimental results.

2. The Experiment on Field 21.

(a) Object of the Experiment.

This experiment was laid down to test the effect on maize of ploughing in composts of different ages against the use of the unrotted parent material, - in this case unchaffed maize straw.

If it appeared that the more mature composts proved superior to the less decomposed ones and to the unrotted material, then it could be assumed that the arguments against the use of green manures, which are valid in temperate regions, apply also in the tropics. On the other hand, if all the dressings produced similar increases in yield, then it would indicate that, - under hot, humid conditions - any immobilisation of soil nitrogen was too ephemeral to militate against the ploughing in of undecomposed crop residues.

In order to shed further light on the differential effects of rotted and unrotted organic manures, it was decided to superimpose a heavy dressing of inorganic nitrogen on to the main treatments.

(b) Previous History of the Field.

The cropping of field 21 during the three years prior to the experiment was:-

May 1933 to May 1936	Fodder grass, mainly experimental.
May 1936 to October 1936	Canavalia grown for seed.

That portion of the field which constituted the experimental area received the following applications of manures:-

May	1933	Compost	at 10 tons per acre.	
June	1933	Sulphate of Ammonia	" 2 cwt. " "	
November	1933	Blood Meal	at 2½ " " "	
November	1933	Muriate of Potash	" ½ " " "	
February	1934	Blood Meal	" 2½ " " "	
February	1934	Muriate of Potash	" ½ " " "	
January	1935	Compost	" 10 tons " "	
January	1935	Blood Meal	" 2½ cwt. " "	
January	1935	Muriate of Potash	" ½ " " "	
August	1935	Blood Meal	" 2½ " " "	
August	1935	Muriate of Potash	" ½ " " "	

No manures were applied to the Canavalia crop in 1936.

(c) Treatments.

There were five main treatments in the experiment:-

1. old compost.
2. middle-aged compost.
3. young compost.
4. chaffed maize straw.
5. control, no manure.

The composts were applied at a rate of ten tons per acre, and the fresh maize chaff at a rate calculated to supply an equivalent weight of dry material.

Each main plot was halved for the sub-treatments:-

1. sulphate of ammonia at 3.9 cwt. per acre.
2. control, no artificial manure.

When the composts were applied the old compost had been rotted for 56 days, the middle-aged for 32 days and the young for 14 days. The maize straw was applied one week after chaffing.

No chemical analyses were made on the organic manures but the old and the middle-aged composts were well rotted, the former being darker in colour. The young compost was very light in colour, but some decomposition had taken place.

(d) Lay-out.

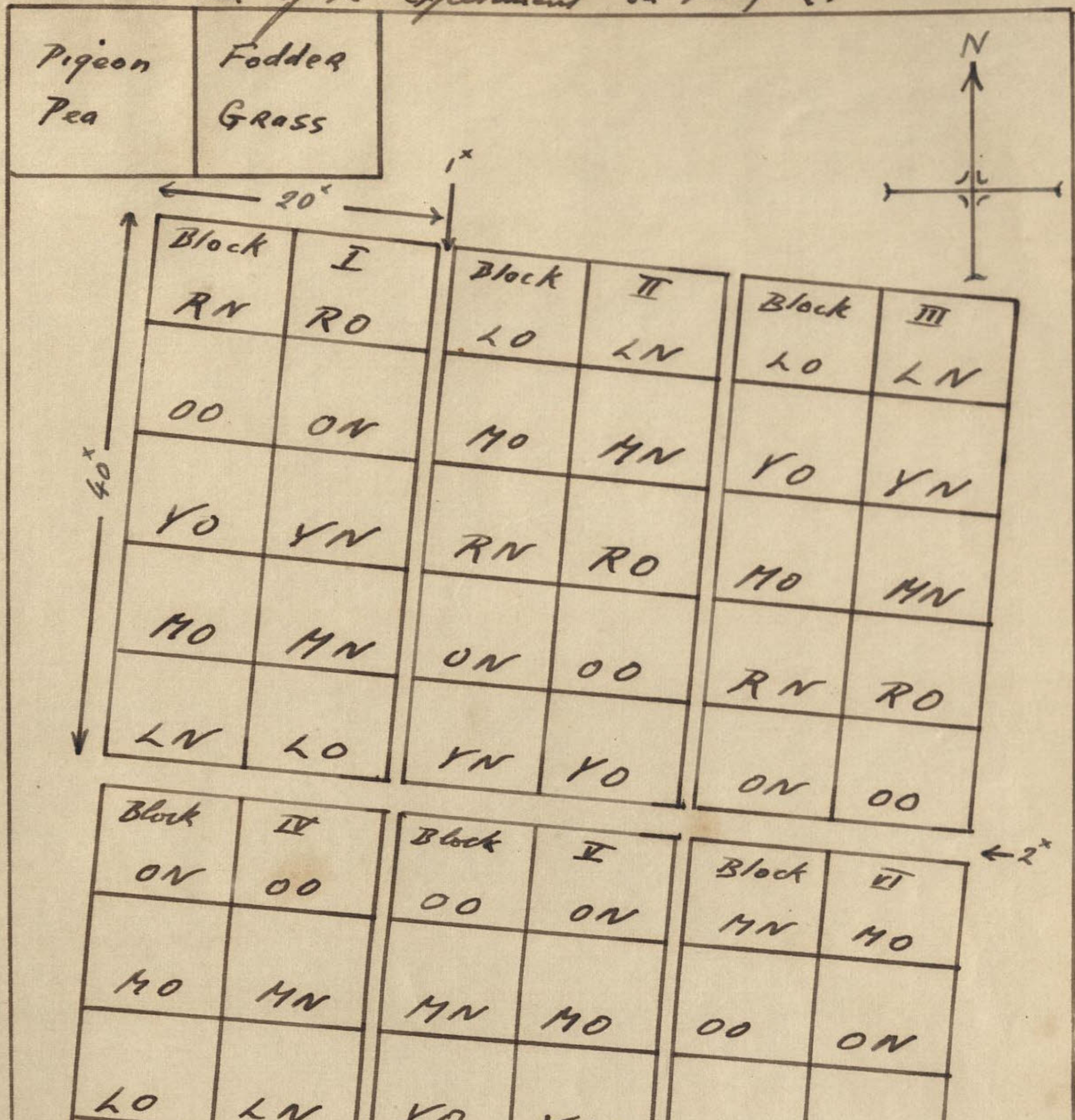
The experiment took the form of seven randomised blocks, each divided into five main plots, which were further split into two sub-plots each.

The two discards running north and south between Blocks I to VI were one yard wide, while the one running east and west was two yards wide. There were no discards between plots or sub-plots.

The total experimental area covered 5600 square yards, or approximately $1\frac{1}{6}$ acres. Thus each of the seventy sub-plots was 80 square yards in area, or $\frac{2}{121}$ acre.

The plan of the experiment is given on the following page.

Plan of the Experiment on Field 21



Legend:

L Old Compost.
M Middle-aged compost.
Y Young compost.
R Raw material, - chaffed straw.
O Control.

N. Sulphate of Ammonia,
O. Control.

(e) Diary of Operations and of Crop Growth.

10th	September	1936:	Old compost heaped.
			Old compost turned.
5th	October	1936:	Middle-aged compost heaped.
23rd	"	1936:	Middle-aged compost turned.
24th	"	1936:	Young compost heaped.
30th 31st	" "	1936) 1936)	Canavalia harvested.
31st	"	1936:	Maize straw chaffed.
3rd	November	1936:	Field 21 ploughed and harrowed.
5th	"	1936:	Experiment marked out and pegs put in.
6th 7th	" "	1936) 1936)	Compost carted to field and spread.
8th	"	1936:	Compost disc-harrowed in.
9th	"	1936:	Maize sown by hand.
10th	"	1936:	3.65 inches of rain.
13th	"	1936:	Seed germinated.
18th	"	1936:	Maize supplied
20th	"	1936:	Sulphate of ammonia applied.
21st	"	1936:	Plant and gap count made.
27th	"	1936:	Field horse-hoed and the crop singled. One hundred singlings collected from each plot for drying and weighing.
30th	"	1936:	Bags of singlings put into the grain dryer shed.
1st	December	1936:	All the sub-plots which had been dressed with sulphate of ammonia could be detected by their dark green colour.
7th	"	1936:	A fire built in the grain dryer shed.
9th	"	1936:	Singlings left in the sun all day.
10th	"	1936:	Singlings weighed.
4th	January	1937:	First tassels noted. The crop was about 7' high.
9th	"	1937:	The crop was examined from the top of a 12' ladder. The sub-plots which had received nitrogen were still a darker green than the rest of the crop. No difference between treatments was evident. Tasselling was fairly uniform except for two strips running east and west across the field, where the crop was stunted and backward, apparently due to trends of poor fertility in the soil.

10th January 1937) 11th " 1937)	Considerable lodging caused by very heavy rain.
24th February 1937:	An estimate of lodging made. Little damage from pests and diseases noted, but many of the cobs on laid plants had been gnawed, presumably by rats.
25th " 1937:	Discards cut out.
26th " 1937:	Harvesting operations begun. The whole crop was cut down, and much of the corn husked. The cobs from Blocks V and VII were weighed and carted to the maize crib.
27th " 1937:	Cobs from Blocks I, II, IV and VI husked, weighed and carted to the maize crib. The cobs were arranged methodically in the maize crib, those from each sub-plot being kept separate.
1st March 1937:	Cobs from Block III husked, weighed and carried. All the cobs stored away in the maize crib. The straw on each sub-plot was arranged in three bundles to facilitate weighing. The straw from Blocks II, III, VI, VII and half of V was weighed
2nd " 1937:	Weighing of straw concluded.
8th " 1937) 10th " 1937) 12th " 1937) 13th " 1937)	Twelve sample cobs from the maize crib were weighed on each of these days to determine when t they were dry enough for threshing.
15th-16th March 1937:	The cobs from each sub-plot were counted, weighed and threshed separately, and the grain from each weighed.

(f) Experimental Methods.

(1) Composting. All the composts were made by the standard farm method of wetting chaffed maize straw with the washings from the oxen stalls.

(2) Marking out. The experiment was marked out in the field with the aid of a prismatic compass, a measuring chain and a number of wooden pegs.

Owing to the bad ploughing of the northern corners of the field the blocks had to be arranged at an angle with the sides of the field.

(3) Applying Compost. Before carting, each different age of compost was thoroughly mixed. About one-seventh of each pile was loaded into a cart - which had previously been weighed -

and taken to the weighbridge, there the correct quantity was weighed out, the load taken to the field and unloaded in the centre of a plot. The compost was then spread uniformly over the plot by boys with forks. Spreading was facilitated by marking the boundaries of each plot with lengths of string stretched round the four corner pegs.

(4) Sowing. The crop was hand-sown by a gang of one man, one boy and about twelve women. Small pegs were arranged at one yard intervals on each side of each block, and a measuring chain stretched tight by the man and the boy between each corresponding pair of these pegs. At each joint in the chain the women made a small hole in the ground, with a stick or cutlass, and dibbled in three seeds. As each row was completed the chain was moved on to the next pair of pegs. Care was taken to project the rows across the discards and to each side of the field.

By this means the field was sown in rows three feet apart, with seeds at every one foot in the rows. The rows ran east and west over most of the field, but owing to the fact that Block VII was arranged at a right angle with the rest of the experiment, the rows at the southern end of the field ran north and south.

(5) Applying Sulphate of Ammonia. Thirty-five dressings of sulphate of ammonia, each 7.2 lbs., were weighed out into paper bags, which were then carried to the field and the contents of each bag applied to one sub-plot in each plot. The method of application was to sprinkle it along the rows at ground level, being careful not to drop any into the leaf bases of the seedlings.

(6) Plant and Gap Count. Two rows in each plot were selected at random and the plants and gaps counted. Since there were eight rows per plot, this was a sample of twenty-five per cent. Actually the randomisation was done beforehand with the

help of a pack of playing cards.

(7) Horse-hoeing and Singling. The horse-hoeing was done by one man, one mule and a three tined, single-row horse-hoe. When rows between plots or blocks were hoed, the pegs were replaced immediately afterwards.

After hoeing, the plants were singled by a gang of six women. They had instructions to leave all the uprooted seedlings on the plot from which they were taken.

(8) Weighing of Seedlings. It was suggested by Professor Wood that a sample of seedlings should be taken from each plot and weighed, to give some idea of the effect of treatments on the vigour of growth. Consequently, after the crop was singled, one hundred seedlings were collected from each plot, the soil knocked off their roots and each sample placed in a numbered paper bag. These were collected and taken to the farm to dry. Some difficulty was experienced in drying the seedlings, as the weather was rather wet and they were eventually left in the grain drying shed for eight days, a fire being built in the shed on one occasion. However, two days of fine weather facilitated uniform drying of the material; the samples were then taken from their bags, any earth still adhering to their roots was removed and they were weighed to the nearest one gram.

(9) Lodging Estimate. The lodging estimate was made two days before harvest by walking into the centre of each subplot and making an estimate of the percentage of plants not standing. All the estimates were made by the writer, so any personal error would be constant for the whole experiment. Actually it was found, by judging some sub-plots twice, that the estimates, if not absolute, were at least consistent.

(10) Harvesting: Harvesting operations were commenced with the assistance of Professor Wood and the first year Diploma students.

Discards were first cut out between blocks, then pathways were cut between all plots and sub-plots. In the latter case, care was taken to throw all the cut plants on to the sub-plots to which they belonged. When all the sub-plots had been isolated by pathways, the maize on each was cut by cutlass and made into a pile in the centre.

The cutting gang was followed by a gang of students or women, who removed the cobs from their husks and put those from each sub-plot into a sack. Each sack of cobs was weighed, in the field, on a spring balance hanging from a wooden tripod; after weighing, the bags, - each containing one labelled cob - were taken by donkey-cart to the maize crib, where the contents of each bag were piled methodically into a separate wire compartment. When all the cobs had been dealt with, the straw on each sub-plot was arranged into three bundles by a gang of women. These bundles were tied round the centre with a length of rope and weighed on the spring balance.

Care was taken to subtract the weight of one sack - in the case of the cobs - or three ropes, - in the case of straw - from each sub-plot total.

(11) Grain Drying. The carting of the cobs into the maize crib was completed on March 1st, they were so arranged on the wire shelves that they all lay parallel, to allow for the maximum passage of air between them.

On March 8th twelve sample cobs were weighed and set aside for subsequent weighing, in order to determine when drying was complete. The weights of these cobs on five different days are given in Table XI.

Table XI.

Loss in Weight of Twelve Cobs During Drying.

Date	Weight in grams	Loss in weight	% loss in weight
March 8th	2350	-	-
" 10th	2250	100	4.4
" 12th	2145	105	4.9
" 13th	2120	25	1.2
" 15th	2085	35	1.7

The cobs were considered to be sufficiently dry for threshing on March 15th, when they had lost 1.7 per cent in weight, through drying, in the previous two days.

(12) Threshing. The cobs from each compartment in the maize crib were counted into sacks and carried to the threshing room. There, the cob number was entered up in a book, the sack of dry cobs weighed, the cobs threshed and the grain poured back into the sack and weighed. The weight of one sack was subtracted from all weights. Finally the grain was taken outside and spread out on a canvas sheet in the sun, before being taken to the store.

(g) Experimental Results and Discussion.

The yields or counts from each main treatment are given in Table XII, in each case expressed as a percentage of the yield from the control.

For all details of these results the reader is referred to the Analyses of Variance in Appendix I.

None of the developmental studies, or yields of grain or cob, gave differences even approaching significance; however, all three dressings of compost and the application of chaffed straw led to yields of straw which were significantly (at 1%)

TABLE XII.

MAIN TREATMENT RESULTS.

Measurement	L.	M.	Y.	R.	O.	Error # per cent	Significance
Plant count	96.0	99.1	97.1	96.1	100.0	5.37	Insignificant
Gap count	94.3	92.7	104.1	100.0	100.0	22.63	Insignificant
Weight of 100 seedlings	123.4	100.3	119.2	107.8	100.0	19.48	Insignificant
Lodging estimate	90.9	64.3	114.8	96.0	100.0	69.76	Insignificant
Cob weight	107.4	112.1	104.0	107.3	100.0	15.55	Insignificant
Straw weight	110.4	119.1	109.9	114.7	100.0	13.97	L.M.Y.R. $>$ 0 at $P = 0.01$
Cob number	100.3	104.1	101.2	104.8	100.0	11.37	Insignificant
Dry cob weight	108.3	110.9	104.5	105.0	100.0	15.25	Insignificant
Grain weight	109.2	112.8	105.4	104.9	100.0	14.89	Insignificant

Error per cent = $\sqrt{\text{Mean Square of Error}}$, expressed as a percentage of the General Mean.

greater than the yield from the control plots.

The yields from the two sub-treatments are given in Table XIII; they are also expressed as percentages of the control. In no case was an interaction between main and sub-treatments significant.

Table XIII.

Sub-Treatment Results.

Measurement	N.	O.	Error per cent	Significance
Lodging estimate	155.7	100.0	44.16	N. > O. at P = 0.01
Cob weight	105.9	100.0	12.28	Insignificant
Straw weight	115.1	100.0	13.60	N. > O. at P = 0.01
Cob Number	101.7	100.0	10.81	Insignificant
Dry cob weight	105.5	100.0	17.33	Insignificant
Grain weight	104.6	100.0	12.54	Insignificant

It will be seen that the application of sulphate of ammonia led to a significant increase in lodging and yield of straw, but had no effect on the yield of grain.

Thus from this experiment it can be concluded that neither the presence of organic matter, nor a supply of available nitrogen, were limiting factors in the production of grain. However, this is just what might be expected from the previous cropping and manuring of the field: the decomposition of the roots of the fodder grass would supply organic matter, while the leguminous crop,- although grown for seed - would probably increase the nitrogen content of the soil.

The fact that significant responses in yield of straw were produced, show that there was no fault in the method of application of the manures. However, perhaps the sulphate of ammonia would have led to a response in the yield of grain if if had been applied at a later stage in the growth of the crop.

It should be noted that no conclusion can be drawn with regard to the relative effect of composts and undecomposed straw, except that both types of organic matter produced similar responses in the yield of straw. It is, however, apparent that the application of straw led to no harmful effects as a result of an immobilisation of soil nitrogen. This can be explained by the hypothesis that the preceding leguminous crop left the soil sufficiently rich in available nitrogen to nullify any such effects.

In conclusion it would seem desirable to repeat this experiment on land known to be deficient in soil nutrients and humus. Possibly the effect of applying sulphate of ammonia at different stages in the growth of the crop would lead to interesting results, especially in view of the effect - in temperate regions - of varying the time of application of a nitrogenous top dressing to winter cereals.

3. The Experiment on Field 25.

(a) Object of the Experiment.

This experiment was designed with a view to determining the relative values of compost made from long maize straw, previously trampled in the pen, (see page 40) and of compost made from chaffed maize straw by the normal farm method. At the same time, it was decided to test the effect of sowing a leguminous crop on the surface of the compost heaps.

(b) Previous History of the Field.

During the three years before this investigation the portion of field 25 which was occupied by the experimental blocks was cropped as follows:-

June 1933: Canavalia sown.
November 1933: Canavalia harvested.
December 1933: Maize and Red Bean sown.

March	1934:	Red Bean harvested.
April	1934:	Maize harvested.
July	1934:	Woolly Pyrol sown.
September	1934:	Woolly Pyrol ploughed in and Maize sown.
January	1935:	Maize harvested.
May	1935:	Canavalia sown.
August	1935:	Canavalia ploughed in and Maize sown.
December	1935:	Maize harvested and Sunnhemp sown.
March April	1936) 1936)	Sunnhemp harvested.
June	1936:	Canavalia sown.
August	1936:	Canavalia ploughed in and Maize sown.
November	1936:	Maize harvested.

During the same period the manuring of the field was as follows:-

June	1933:	Ground Limestone	at 7	tons	per	acre.
September	1933:	Sulphate of Ammonia	" 1/3	cwt	"	"
December	1933:	Muriate of Potash	" ½	"	"	"
October	1934:	Nicifos	" 1	"	"	"
October	1934:	Blood Meal	" 2	"	"	"
October	1934:	Superphosphate	" 1½	"	"	"
October	1934:	Muriate of Potash	" 1	"	"	"
July	1935:	Sulphate of Ammonia	" 1 1/3	"	"	"
August	1935:	Sulphate of Ammonia	" 2	"	"	"
June	1936:	Sulphate of Ammonia	" 2/3	"	"	"
June	1936:	Nicifos	" 1/3	"	"	"
August	1936:	Sulphate of Ammonia	" 2	"	"	"
August	1936:	Muriate of Potash	" 1	"	"	"

(c) The Treatments.

The main treatments in this experiment were:-

L. Compost made from heaping long maize straw after it had been trampled in the cattle pen for five days.

M. Compost made half from long maize straw, as in 1., and half from chaffed maize straw.

S. Compost made from freshly chaffed maize straw only.

Four heaps of each type of compost were built and, after the first turn, Sunnhemp was sown on two heaps of each type, as a sub-treatment H. The total amount of seed sown was six pounds (i.e. 1 lb. per heap).

The composts were applied, when only four weeks old, at the rate of 6.7 tons per acre. They were then ploughed in before sowing the experimental crop of maize.

The chemical analyses of the six types of composts are given in Table XIV. It will be seen that sample S.O. was markedly inferior to the others, being especially deficient in potash. This is due to the fact that all the other composts were prepared from maize straw grown on field 25, while the S.O. type was made from straw from the crop on field 27A. This was regrettable, especially because the S.O. compost was made one week after the others, but the unexpectedly low yield of straw from field 25 left no other alternative.

(d) Lay-out.

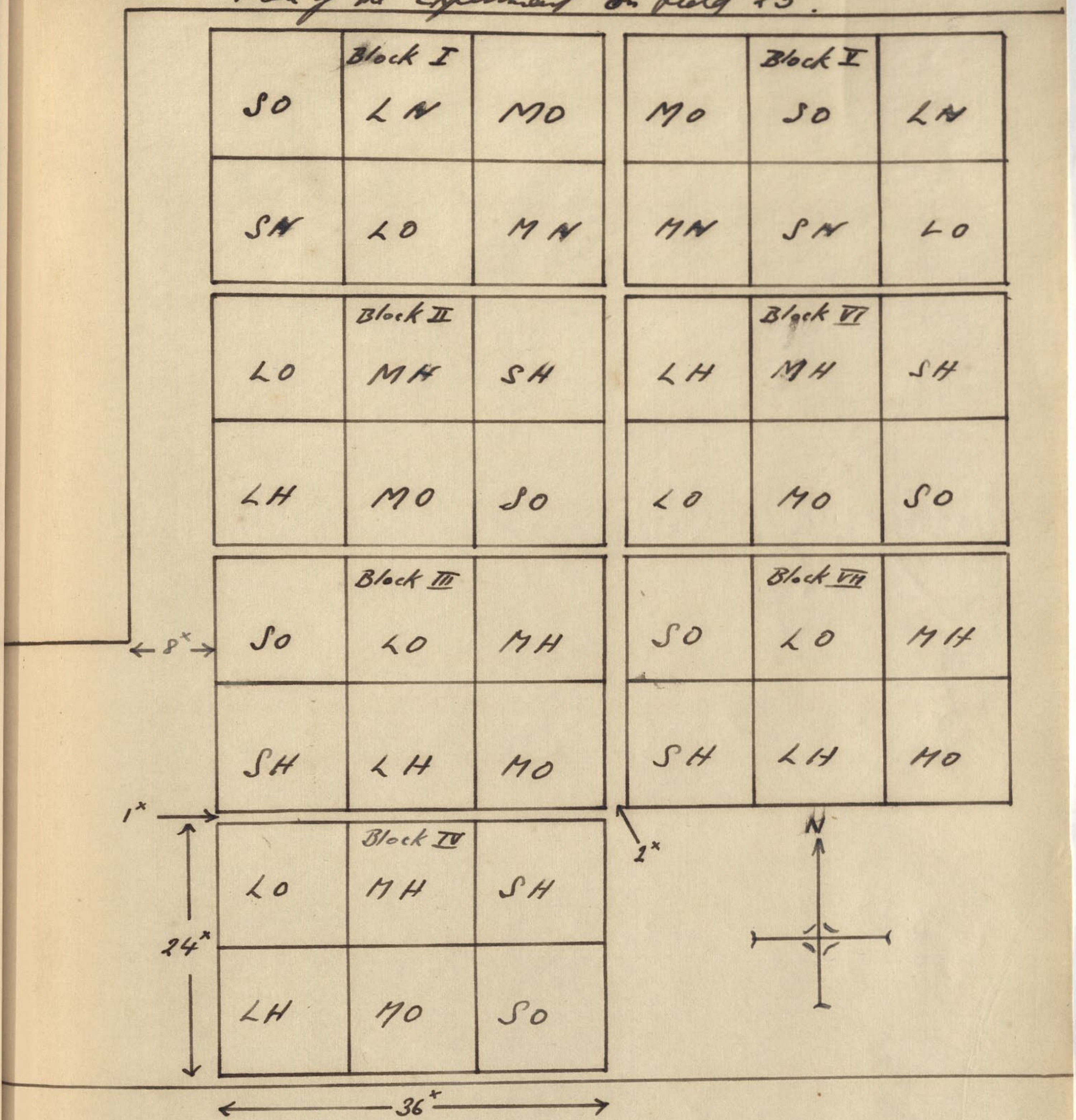
As in the experiment on field 21, there were seven randomised blocks, each of these being divided into three main plots, which were halved for the sub-treatments.

The discards running east and west were one yard wide between the blocks and two yards wide at the edge of the field. The one which ran north and south between the blocks was two yards wide, and there was a discard of eight yards on the western edge of the field. There were no discards between plots or sub-plots.

The experimental blocks - not including discards - covered 6048 square yards, or approximately 1¼ acres. Thus each sub-plot was 144 square yards in area, or approximately $^1/_{34}$ acre.

The plan of the experiment is given on the following page.

Plan of the Experiment on Field 25.



Legend:

L. Compost made from long maize straw previously trampled in the cattle-pen.

M. Compost made half from long and half from chaffed maize straw.

S. Compost made from chaffed maize straw.

H. Sunn Hemp grown on the heaps

O. Control.

TABLE XIV.

ANALYSES OF THE COMPOSTS USED IN THE EXPERIMENT ON FIELD 25.

Compost	On the fresh weight basis						On the dry weight basis						C/N ratio	Degree of Humification %
	Moisture %	Organic Matter %	Ash %	Total Nitrogen %	P_2O_5 %	K_2O %	Organic Matter %	Carbon %	Ash %	Total Nitrogen %	P_2O_5 %	K_2O %		
L H	78.9	15.8	5.3	0.38	0.23	0.82	74.8	41.0	25.2	1.82	1.11	3.89	22.5	49.1
L O	77.3	16.7	6.0	0.41	0.26	0.83	73.6	39.1	26.4	1.82	1.13	3.69	21.5	48.9
M H	73.9	17.2	8.9	0.54	0.36	1.12	65.8	34.2	34.2	2.09	1.41	4.31	16.4	54.5
M O	69.4	22.1	8.5	0.58	0.35	1.17	72.1	34.4	27.9	1.89	1.17	3.83	18.2	48.2
S H	83.6	12.5	3.9	0.32	0.22	0.84	76.4	40.0	23.6	1.97	1.32	5.09	20.3	56.1
S O	71.5	22.1	5.4	0.41	0.25	0.48	81.2	43.5	18.8	1.42	0.88	1.67	30.6	54.3

(e) Diary of Operations and of Crop Growth.

24th November 1936) 26th " 1936)	Maize on field 25 harvested and the straw carted into the pen and to the composting yard.
27th " 1936:	Maize straw in the composting yard chaffed.
30th " 1936:	Long maize straw carted from the pen. Two heaps of long maize straw built.
1st December 1936:	Two more heaps of long maize straw built, also two heaps of mixed long and chaffed straw.
2nd " 1936:	Two more heaps of mixed long and chaffed straw built, also two heaps of chaffed straw only.
8th " 1936:	Maize on field 27A harvested, the straw carted to the composting yard and chaffed.
9th " 1936:	Two more heaps of chaffed maize straw built.
10th " 1936) 11th " 1936)	All the heaps turned except the two made on 9th December 1936.
12th " 1936:	Two heaps of each kind (six in all) were well watered and one pound of Sunnhemp seed sown on each of them and trampled in.
15th " 1936:	Good germination of Sunnhemp, especially on the heaps made from long straw only.
16th " 1936:	Seedlings 2-3 inches high.
20th " 1936:	Little further growth in height of the Sunnhemp but the roots had penetrated deeper. No root nodules could be found.
28th " 1936:	Experiment marked out on field 25, and the pegs put in. Samples of the heaps weighed to give an estimate of the amount of compost available. Compost well mixed and samples taken. Carting to the field and spreading started.
29th " 1936:	Carting and spreading completed. Ploughing of field started with two of Ransomes' "Sabul" ploughs. These ploughs covered the compost very evenly.
30th " 1936:	Ploughing completed. Light harrowing started. Blocks V and VI hand sown.
31st " 1936:	Harrowing completed and the head lands forked. Blocks VII, IV and III were sown in that order. Sowing on Block III was interrupted by very heavy rain, but it was found possible to complete the block.
2nd January 1937:	Heavy rain in the morning.
3rd " 1937:	No rain today but the land was too wet for sowing.
4th " 1937:	Sowing completed (Blocks I and II). The maize on Blocks V and VI had germinated.
6th " 1937:	All the crop had germinated except on Blocks I and II.

9th January 1937:		Uneven germination on Blocks I and II.
10th " 1937) 11th " 1937)		Very heavy rain. Standing water on patches of Block I.
12th " 1937:		Crop supplied; sowing conditions good. Germination and gap counts made.
21st " 1937:		Field hoed with a Straddle hoe pulled by a pair of oxen. The rows with pegs in them were hand-hoed. Crop singled. One hundred seedlings were collected from each sub-plot, placed in labelled paper bags and taken to the store-room for drying.
12th February 1937) 13th " 1937) 15th " 1937)		On each of these days the seedlings were taken out of their bags and left in the sun all day.
16th " 1937:		Seedlings weighed.
4th April 1937:		Tassel count made on the whole experiment.
27th " 1937:		Harvesting operations commenced. The discards were cut out and the crop cut on Blocks IV, V, VI and VII. The cobs on these blocks were husked, weighed and carted to the farm.
28th April 1937:		The rest of the crop was cut and most of it husked, weighed and carted. Arranging of straw into four bundles per sub-plot was started.
29th " 1937:		Husking, weighing and carting of cobs completed. Straw weighed from Blocks I, II, V, VI and VII.
30th " 1937:		Weighing of straw completed.

(f) Experimental Methods.

The methods of comparing the composts have already been dealt with, so they need not be considered here. In the plant and gap count three out of twelve rows were counted in each sub-plot. However, in the tassel count the entire crop was counted.

There was little lodging at harvest time so no estimate of this was made.

In the previous experiment a study of the weights of dried cob and grain and of the cob number yielded no results of value, so such studies were not repeated.

All other experimental methods were similar to those practised on field 21 and they need not be described again.

TABLE XV.

MAIN TREATMENT RESULTS.

Measurement	L.	M.	S.	Error # per cent	Significance.
Plant count	110.7	103.2	100.0	15.41	Insignificant
Gap count	79.1	94.8	100.0	34.23	Insignificant
Weight of 100 seedlings	114.8	118.0	100.0	11.65	L $>$ S at $p = 0.05$; M $>$ S at p 0.01
Tassel count	125.2	125.9	100.0	39.80	Insignificant
Cob Weight	114.8	113.9	100.0	11.70	L and M $>$ S at $p = 0.01$
Straw weight	109.5	112.2	100.0	10.94	L and M $>$ S at $p = 0.05$

Error per cent = $\sqrt{\text{Mean Square}}$ of Error, expressed as a percentage of the General Mean.

(g) Experimental Results and Discussion.

The counts and yields for the main treatments are given in Table XV, in each case expressed as a percentage of the count or yield from treatment S.

No significant differences were obtained from either the plant, gap or tassel counts. However, treatments L. and M. were both significantly superior to treatment S. in the yields of cob and straw produced. Moreover this superiority was evident at the time of singling. In no case was a difference between L. and M. noted.

In Table XVI the yields from the sub-treatment H. are expressed as a percentage of the yields from O.

Table XVI.

Sub-Treatment Results.

Measurement	H.	O.	Error # per cent	Significance
Plant count	98.0	100.0	10.74	Insignificant
Gap count	98.2	100.0	24.17	Insignificant
Weight of 100 seedlings	101.9	100.0	13.35	Insignificant
Tassel count	117.4	100.0	37.80	Insignificant
Cob weight	98.0	100.0	11.50	Insignificant
Straw weight	105.9	100.0	7.57	$H > O$ at $p = 0.05$

#Error per cent = $\sqrt{\text{Mean Square of Error}}$, expressed as a percentage of the general Mean.

The significant difference in the case of the straw weight is difficult to explain with the data from the chemical analyses. On the fresh weight basis little differences are apparent between the H. and O. composts; however, the former shows a higher degree of humification, and the S.O. compost is inferior to all the others.

In the Tassel count and Straw weight the interaction between main and sub-treatments is significant. This is illustrated by the sub-treatment totals in Table XVII.

Table XVII.

Sub-Treatment Totals.

Measurement	L H	L O	M H	M O	S H	S O	Significance
Tassel count	70	99	100	70	86	49	p = 0.05
Straw weight	1239	1204	1244	1259	1208	1023	p = 0.05

It will be evident from the table that the two interactions do not yield similar results. Thus H. made tasselling earlier on M. and S. plots, but later on L. plots. However, the yield of straw was increased by H. on the L. and S. plots, but decreased on the M. plots. These findings are most surprising and the writer is quite unable to offer a reasonable explanation to account for them.

In conclusion, it should be noted that the results of this experiment point to the superiority of composts, made by trampling long straw in the pen, over those made by the standard farm method from chaffed maize straw. However, the value of this finding is considerably reduced in view of the poor quality of the S.O. compost.

SUMMARY AND CONCLUSIONS.

1. A brief review was made of the literature relevant to the preparation and use of composts.

2. The function of humus in the soil was discussed and methods of supplying it considered. It would seem that, - at least in temperate regions - the use of composts is preferable to the practice of ploughing in green manures or other unrotted plant residues.

3. The process of composting was examined from a biochemical aspect. Recent research has shown that highly lignified materials,- although difficult to decompose - produce the best composts. It was found that a decomposition product of lignin resembled natural soil humus in its physical and chemical properties.

4. Different methods of preparing composts were described and the individual factors in the process discussed. The main factors determining rate of decomposition and quality of end product are parent material, a supply of air, moisture and nutrients - especially nitrogen -, and the presence of the micro-organisms responsible for decay. Aeration is determined by the choice of parent material, the shape and size of the heaps or pits used and the amount of moisture present. The supply of sufficient water may be an insurmountable obstacle in regions of low rainfall. Excess moisture induces anaerobic conditions. The supply of nitrogen as sulphate of ammonia may induce acidity and greatly increases the cost of composting; an organic supply of nitrogen has neither of these two disadvantages. Inoculation accelerates decomposition in its early stages but the micro-organisms responsible for decay are practically ubiquitous, and the end product after three months is the same whether or not an inoculum is added.

5. In Part II experiments conducted by the writer are described which aim at improving the methods of composting on the College farm. Temperature studies and the general appearance and texture of the composts were the main criteria used in judging relative rates of decomposition.

6. It was found possible to prepare good composts from long maize straw which was built in large heaps, after being trampled in the cattle pen for several days. The estimated cost of such a method amounted to $1.31 per ton of compost, as compared with $1.55 when the normal farm method was used.

7. Good compost was prepared from rice straw in spite of the tendency of such material to compact. The incorporation of long maize straw did little to improve aeration in heaps made from this material.

8. An investigation was made into the use of molasses in accelerating decomposition in the compost heap. The results indicated that the addition of molasses, after a preliminary decomposition of the raw material, speeded up decomposition and increased the water retaining capacity of the material. Where excess molasses was used, especially when added to the fresh material, the reaction in the heaps became highly acidic and decomposition was suspended.

9. In Part III a field experiment is described which was designed to test the relative effects of different ages of compost and of unrotted maize straw when applied to a maize crop, with or without the addition of sulphate of ammonia. The only significant effect of the organic material was to increase the yield of straw, but this increase was independent of the form in which such material was added. The application of sulphate of ammonia led to an increased yield of straw and induced lodging.

10. A second field experiment was described which was designed to compare the value of composts made from long maize straw - previously trampled in the cattle pen - with those made by the standard farm method. A study was also made of the effect of growing Sunnhemp (Crotalaria juncea) on the compost heaps. Composts made from long maize straw were found to be significantly superior to those made by the standard method, as the former increased the vigour of growth of maize and resulted in higher yields of cob and straw. Apparently better composts were made when Sunnhemp was grown on the heaps, as the yield of straw was increased by such a method. This practice apparently had a differential effect on the different types of compost but no reasonable explanation of this can be put forward.

APPENDIX I.

Tables of Plot Yields and Analyses of Variance.

Fifteen analyses of variance are given here for the experiments on fields 21 and 25. In each case the plot yields are given, so that any of the figures can be checked.

A summarised "z" table is given in Table XVII to enable all conclusions to be checked.

Table XVII.

Points of the Distribution of "z".

		5 per cent points				1 per cent points			
N_2		12	18	24	30	12	18	24	30
N_1	1	0.7788	0.7424	0.7246	0.7141	1.1166	1.0572	1.0285	1.0116
	2	0.6786	0.6341			0.9677	0.8970		
	3			0.5508				0.7757	
	4			0.5106	0.4947			0.7197	0.6954

(1) Experiment on Field 21. Plant Count.

Treatments	I	II	III	IV	V	VI	VII
L	192	197	203	210	201	219	183
M	202	192	213	211	206	199	228
Y	184	211	201	211	201	201	212
R	190	203	197	199	226	200	192
O	209	207	226	205	201	194	222

Analysis of Variance. Plant Count.

	D.F.	S.S.	M.S.	
Blocks	6	800.2	-	
Treatments	4	559.9	139.97	Insignificant
Error	24	2,882.1	120.09	
Total	34	4,242.2		

(2) Experiment on Field 21. Gap Count.

Treatments	I	II	III	IV	V	VI	VII
L	17	19	19	14	18	9	20
M	15	15	22	10	20	19	13
Y	21	15	19	17	18	21	17
R	15	17	19	20	10	22	20
O	15	21	13	15	15	23	21

Analysis of Variance. Gap Count.

	D.F.	S.S.	M.S.	
Blocks	6	51.89	-	
Treatments	4	18.69	4.67	Insignificant
Error	24	366.11	15.26	
Total	34	436.69		

(3) Experiment on Field 21. Weight of 100 Seedlings.

Treatments	I	II	III	IV	V	VI	VII
L	139	85	98	106	139	73	94
M	87	84	67	90	90	72	107
Y	104	105	75	132	113	98	82
R	149	82	75	114	70	77	74
O	112	103	85	94	83	70	48

Analysis of Variance. Weight of 100 Seedlings.

	D.F.	S.S.	M.S.	M.S/M.S.Error	"z"
Blocks	6	7018.0			
Treatments	4	2301.0	560.3	1.6846	0.26079
Error	24	7981.4	332.6	insignificant	
Total	34	17300.4			

(4) Experiment on Field 21. Lodging Estimate.

Treatment	I	II	III	IV	V	VI	VII
L N	20	15	30	45	60	45	25
L O	35	5	5	40	30	35	10
M N	60	10	5	45	25	15	15
M O	25	5	3	30	20	5	20
Y N	65	70	20	40	25	35	30
Y O	50	30	35	25	25	20	35
R N	35	20	25	45	50	25	25
R O	15	2	35	35	40	7	25
O N	40	80	80	15	35	35	15
O O	25	10	25	5	40	30	5

Analysis of Variance. Lodging Estimate.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	2242.57			insignificant
Treatments	4	1895.80	473.95	1.1798	0.08277
Error(a)	24	9641.50	401.73		
N v O	1	2740.63	2740.63	17.018	1.41713**
Interaction	4	478.65	119.66	insignificant	
Error(b)	30	4832.22	161.07		
Total	69	21831.37			

**Significant at $p = 0.01$

Conclusion: N > O.

(5) Experiment on Field 21. Cob Weight.

Treatments	I	II	III	IV	V	VI	VII
L N	140	160	172	144	126	120	141
L O	130	154	166	156	140	176	131
M N	136	156	180	148	130	156	146
M O	145	156	170	143	159	150	147
Y N	154	127	150	182	156	144	171
Y O	113	122	170	135	130	173	147
R N	157	170	152	108	170	156	173
R O	145	160	166	156	140	163	132
O N	164	137	144	176	136	128	153
O O	141	144	141	161	137	138	149

Analysis of Variance. Cob Weight.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	917.11	-		
Treatments	4	396.03	99.01	1.0444	insignificant 0.02173
Error(a)	24	2275.20	94.80		
N v O	1	223.21	223.21	3.7755	insignificant 0.66428
Interaction	4	205.43	51.36	insignificant	
Error(b)	30	1773.56	59.12		
Total	69	5790.54			

(6) Experiment on Field 21. Straw Weight.

Treatments	I	II	III	IV	V	VI	VII
L N	139	120	117	113	95	102	126
L O	73	85	92	105	95	88	104
M N	105	114	157	81	95	101	140
M O	138	101	122	95	111	82	127
Y N	104	93	111	111	107	102	125
Y O	103	82	92	101	111	101	104
R N	130	122	112	119	113	97	147
R O	89	94	101	102	88	104	93
O N	99	79	111	120	87	73	138
O O	109	71	77	97	62	93	101

Analysis of Variance. Straw Weight.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	5372.6			
LMYR v O	1	1815.6	1815.6	8.5586	1.07347**
Between LMYR	3	694.1	231.4	insignificant	
Error(a)	24	5091.1	212.1		
N v O	1	3744.9	3744.9	18.6120	1.46191**
Interaction	4	1300.8	325.2	1.6153	0.23972 insignificant
Error(b)	30	6036.3	201.2		
Total	69	24055.4			

**Significant at $p = 0.01$

Conclusion: L, M, Y and R > 0

N > 0.

(7) Experiment on Field 21. Cob Number.

Treatments	I	II	III	IV	V	VI	VII
L N	140	160	172	144	126	120	141
L O	130	154	166	156	140	176	131
M N	146	156	180	148	130	156	146
M O	145	156	170	143	159	150	147
Y N	154	127	150	182	156	144	171
Y O	113	122	170	135	130	173	147
R N	157	170	152	108	170	156	173
R O	145	160	166	156	140	163	132
O N	164	137	144	176	136	128	153
O O	141	144	141	161	137	138	149

Analysis of Variance. Cob Number.

	D.F.	S.S.	M.S.	
Blocks	6	2247.49		
Treatments	4	586.06	146.52	insignificant.
Error (a)	24	6929.94	288.75	
N v O	1	108.13	108.13	insignificant.
Interaction	4	797.37	199.84	insignificant.
Error(b)	30	7824.00	260.80	
Total	69	18494.99		

(8) Experiment on Field 21. Dry Cob Weight.

Treatments	I	II	III	IV	V	VI	VII
L N	55	54.5	50.5	44	37	39.5	49
L O	40	49	50.5	49	44	46.5	44.5
M N	44.5	50	58	42	43	47.5	49
M O	52.5	46.5	54.5	38	49.5	43	51
Y N	44	36.5	45	56.5	46	47.5	50
Y O	39.5	33.5	42	43.5	46	49.5	50.5
R N	51	51.5	48	38.5	49.5	44	58.5
R O	39.5	41.5	42.5	41.5	38	49.5	39.5
O N	50.5	32.5	40	49	39.5	33	62
O O	45	39	38.5	51	35.5	44.5	43

Analysis of Variance. Dry Cob Weight.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	327.89			
Treatments	4	178.53	44.63	insignificant	
Error(a)	24	1156.97	48.21		insignificant
N v O	1	103.21	103.21	1.6564	0.25233
Interaction	4	109.58	27.40	insignificant	
Error(b)	30	1869.21	62.31		
Total	69	2745.39			

(9) Experiment on Field 21. Grain Weight.

Treatment	I	II	III	IV	V	VI	VII	
L N	43	43	38.5	33	28.5	30	38.5	
L O	31	37.5	39.5	38	34	36	34.5	
M N	34	29.5	44	34	33	36	37.5	
M O	41.5	36	42.5	33	38	32.5	39	
Y N	34	28.5	34.5	43.5	35	36.5	39	
Y O	31.5	25.5	32	33.5	35.5	38.5	40	
R N	39	39	36.5	29	37.5	34.5	45	
R O	30	33	32	31.5	29	38.5	30.5	
O N	39	25	31.5	37	30	24	48	
O O	35	30.5	30	39.5	27	34	32	

Analysis of Variance. Grain Weight.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	203.50			
Treatments	4	141.32	35.33	insignificant	
Error(a)	24	657.93	27.41		insignificant
N v O	1	44.04	44.04	2.2654	0.040888
Interaction	4	69.87	17.47	insignificant	
Error(b)	30	583.21	19.44		
Total	69	1699.87			

(10) Experiment in Field 25. Plant Count.

Treatment	I	II	III	IV	V	VI	VII
L H	167	140	140	143	211	189	158
L O	157	150	149	150	199	180	198
M H	171	124	109	162	155	180	187
M O	159	136	118	139	194	173	165
S H	121	157	134	155	152	152	164
S O	152	139	168	159	144	121	187

Analysis of Variance. Plant Count.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	9202.01			insignificant
Treatments	2	1924.91	962.46	1.6374	0.24653
Error(a)	12	7053.42	587.79		
H v O	1	103.71	103.71	insignificant	
Interaction	2	72.43	36.22	insignificant	
Error(b)	18	5134.86	285.27		
Total	41	23491.34			

(11) Experiment on Field 25. Gap Count.

Treatment	I	II	III	IV	V	VI	VII
L H	32	28	26	19	9	15	14
L O	28	24	25	21	12	21	14
M H	21	35	42	19	23	15	12
M O	25	28	49	23	18	18	17
S H	40	30	29	24	21	24	16
S O	37	22	38	16	27	30	10

Analysis of Variance. Gap Count.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	2009.95			insignificant
Treatments	2	223.48	111.74	1.6925	0.26312
Error(a)	12	792.19	66.02		
H v O	1	1.93	1.93	insignificant	
Interaction	2	8.14	4.07	insignificant	
Error(b)	18	592.43	32.91		
Total	41	3628.12			

(12) Experiment on Field 25. Weight of 100 Seedlings.

Treatment	I	II	III	IV	V	VI	VII
L H	35	30	46	60	92	102	82
L O	28	31	62	77	86	107	79
M H	31	28	61	63	116	92	92
M O	35	27	61	77	94	95	71
S H	23	28	55	77	76	92	61
S O	31	23	41	50	101	78	63

Analysis of Variance. Weight of 100 Seedlings.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	26855.81			
Treatments	2	841.34	420.67	7.7384	1.0231**
Error(a)	12	652.33	54.36		
H v O	1	14.88	14.88	insignificant	
Interaction	2	105.33	52.66	insignificant	
Error(b)	18	1705.29	71.41		
Total	41	30174.98			

**Significant at p = 0.01

Treatment Totals

L	917
M	943
S	799

Significant difference (p = 0.05) = 85.01

Significant difference (p = 0.01) = 119.18

Conclusion: L > S at p = 0.05 (just misses p = 0.01)

M > S at p = 0.01

(13) Experiment on Field 25. Tassel Count.

Treatment	I	II	III	IV	V	VI	VII	Totals
L H	0	2	2	7	22	27	10	70
L O	0	1	7	23	34	23	11	99
M H	2	0	8	14	35	26	15	100
M O	0	0	6	14	28	17	5	70
S H	0	0	6	17	17	32	14	86
S O	0	1	3	7	15	16	7	49

Analysis of Variance. Tassel Count.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	3699.57			
Treatments	2	56.71	28.36	insignificant	
Error(a)	12	242.29	20.19		insignificant
H v O	1	34.38	34.38	1.8825	0.31631
Interaction	2	187.77	93.89	5.1560	0.82008**
Error(b)	18	327.85	18.21		
Total	41	4548.57			

**Significant at p = 0.05.

Conclusion: H > O on M and S.

O > H on L.

(14) Experiment on Field 25. Cob Weight.

Treatment	I	II	III	IV	V	VI	VII
L H	87.5	79	74	88	110	83.5	56
L O	81.5	80	73	83.5	87.5	63	65
M H	83.5	79.5	67.5	87.5	88	78.5	59
M O	93	82.5	66	82	106	72	58.5
S H	67.5	92	71	74	68	88	55
S O	63.5	59	68	63.5	78.5	61.5	59

Analysis of Variance. Cob Weight.

	D.F.	S.S.	M.S.	M.S./M.S.Error	"z"
Blocks	6	3338.49			
LM v S	1	920.05	920.05	11.704	0.88405**
L v M	1	2.29	2.29	insignificant	
Error(a)	12	943.34	78.61		
H v O	1	195.00	195.00	2.5648	insignificant 0.47094
Interaction	2	244.91	122.46	insignificant	
Error(b)	18	1368.46	76.03		
Total	41	5644.07			

**Significant at p = 0.01

Conclusion: L and M > S.

(15) Experiment on Field 25. Straw Weight.

Treatment	I	II	III	IV	V	VI	VII	Totals
L H	196	177	126	166	199	195	180	1,239
L O	189	171	111	185	185	179	184	1,204
M H	188	166	141	191	184	180	194	1,244
M O	204	162	146	170	196	215	166	1,259
S H	152	185	142	198	167	211	153	1,208
S O	127	145	125	156	157	159	154	1,023

Analysis of Variance. Straw Weight.

	D.F.	S.S.	M.S.	M.S/M.S.Error	"z"
Blocks	6	12459.92			
LM v S	1	2788.78	2788.78	7.9746	1.03813**
L v M	1	128.57	128.57		
Error(a)	12	4190.65	349.71		
H v O	1	1000.60	1000.60	5.9870	0.89480**
Interaction	2	1547.61	773.81	4.6300	0.76628**
Error(b)	18	3008.29	167.13		
Total	41	25124.42			

**Significant at $p = 0.05$.

Conclusion: L and M > S

H > O

H > O on L and S

O > H on M.

APPENDIX II.

Temperature Graphs.

Graph One: Average temperature readings in two heaps of long maize straw.

Graph Two: Average temperature readings in two heaps in the first molasses experiment.

Graph Three: Average temperature readings on each side of the two heaps in the first molasses experiment.

Graph I

Main Experiment on Composting of Unchaffed Material — Average Temperatures in degrees Centigrade

Each figure an average of five readings.

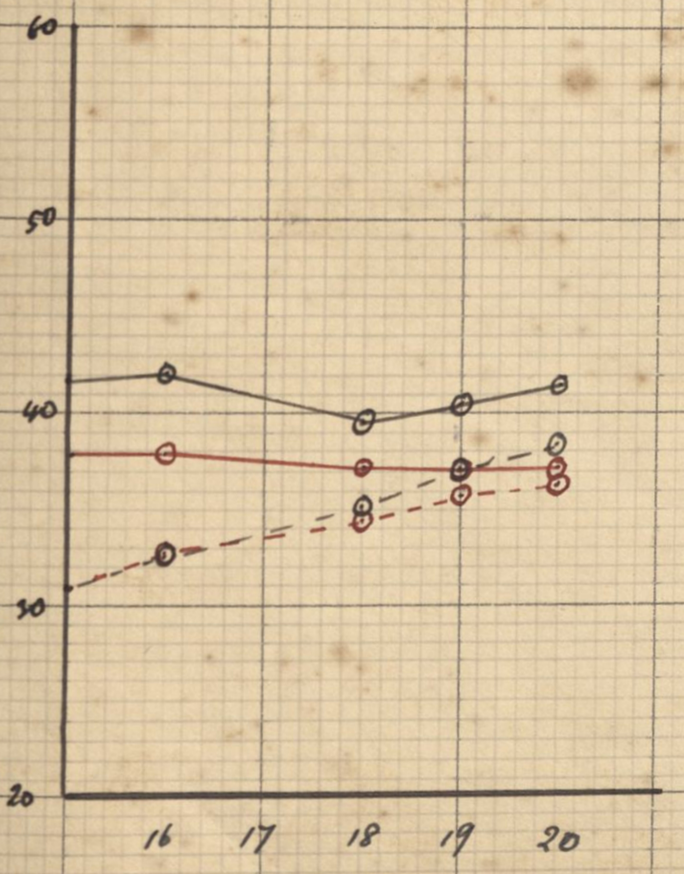
Graph II
First Experiment on the Use of Molasses in Composting —— Average Temperatures in degrees Centigrade
Each figure an average of ten readings.
Molassed Heap 14.1.37
Unmolassed Heap 15.1.37
Heaps turned
Heaps turned
Molasses added to heap I
Heaps turned
70
60
50
40
30
20
Jany 18 19 20 21 22 23 24 25 26 27 28 29 30 31 Feb 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 Mar 1 2 3 4 5 6 7 8 9 10 11 12 13 14
60
50
40
30
20
March 15 16 17 18 19 20

Graph III

First Experiment on the Use of Molasses in Composting — Average Temperatures on each side of each Heap.

Each figure an average of five readings

Molassed Heap, East Side	———	14.1.37
Molassed Heap, West Side	- - -	14.1.37
Unmolassed Heap, East Side	———	15.1.37
Unmolassed Heap, West Side	- - -	15.1.37



APPENDIX III.

Costs.

A. Composting Long Maize Straw.

Four operations are involved in the composting of unchaffed maize straw: first the straw is carted from the field to the pen; then later it is dug out of the pen and carted to the composting yard; then it is built into heaps, and finally it is turned twice.

It is assumed that the straw on the field has no value and that unit weight of compost is produced from unit weight of dry straw.

The number of loads of straw which can be carted into the pen in one day, by one cart, depends entirely on the distance of the field from the farm. However, Johnson's figure of 12 loads per day may be taken as a reasonable average but those loads would only be about 5 cwt. each, (i.e. a total of 60 cwt.)

Cost per day, 1 man and 1 mule = $0.98

Cost per ton of compost made = $0.33

The composting yard is very close to the pen, so about sixteen loads can be taken, by one cart, from the pen to the yard. However, the digging out and loading of the long straw is most laborious and the carter would require the assistance of two men in the pen. The straw, being well trampled, would be more dense and a load would weigh about 7 cwt. (i.e. a total of 112 cwt.)

Cost per day, 3 men and 1 mule = $1.78

Cost per ton of compost made = $0.32

The building of a heap, which would eventually rot down into two tons of compost, takes two men about six hours.

Cost of 12 man-hours of labour = $0.60

Cost per ton of compost made = $0.30

The first turn would take one man about nine hours, and the second one about five and a half hours.

Cost of 14½ man-hours of labour = \$0.72

Cost per ton of compost made = \$0.36

The total cost of preparing compost by this method would therefore be \$1.31:-

Carting to pen =	\$0.33	per ton of compost made.
Carting to yard =	\$0.32	" " " " "
Building =	\$0.30	" " " " "
Turning twice =	\$0.36	" " " " "
	\$1.31	

B. Composting Chaffed Maize Straw.

By this method straw is carted from the field to the yard, chaffed into one-inch lengths, wetted and heaped.

The carting of the straw to the yard would cost approximately the same amount as carting it to the pen. Johnson's figure for chaffing of 72¢ per ton of straw is a reasonable one and may be used here. The heaps would take as long to build as those made from long maize straw; the latter material is admittedly difficult to handle but the chaffed straw has to be well wetted.

When the material is chaffed turning the heaps is much easier: thus, a heap of two tons could be turned by two men in two and a half hours, while the second turn would only take about one and a half hours.

Cost of 8 man-hours of labour = \$0.40

Cost per ton of compost made = \$0.20

The total cost of preparing compost by this method would therefore be \$1.55 per ton:-

Carting to yard	$0.33	per ton of compost made.
Chaffing	0.72	" " " " "
Building	0.30	" " " " "
Turning twice	0.20	" " " " "
	$1.55	

Masefield's figure was $1.42 and Johnson's $1.27; however, errors in estimate of costs are inevitable, but in the above estimations it can be assumed that personal errors cancel out and that the figures of $1.31 and $1.55 give a reasonable indication of the relative costs of the two composting methods.

APPENDIX IV.

Suggestions for Future Work.

1. It is suggested that further studies be made into the method of composting unchaffed maize straw. Considerable economy could be effected by removing the material from the pen with a steel drag or rake pulled by oxen and by building the heaps just outside the pen. A step in this direction has been made by cutting out a gate on the west side of the pen, but it would be desirable to have a cement composting floor built there with drains running back into the pen.

2. The results of the first experiment on the use of molasses in composting suggest that such a practice, - if properly understood - might well facilitate the decomposition of resistant materials. Hence it is suggested that such a problem merits further study.

3. Further investigation into the growing of legumes on compost heaps may well produce results of value. Possibly the inclusion of some soil in the heaps - or on their surface - would introduce the bacteria responsible for the formation of root nodules.

4. Little is known with regard to the effect of gypsum on colloids: possibly the addition of a small amount would effect an improvement in the physical condition of compost. A study of this problem is therefore recommended.

5. It is strongly recommended that the experiment on field 21 be repeated on some other field known to be deficient in humus and soil nutrients. Furthermore, it is suggested that the sulphate of ammonia be applied at several different stages in the crop's growth.

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BIBLIOGRAPHY.

1. Adco. "Synthetic farmyard manure" - pamphlet.

2. Anstead, R.D. (1934) "Agricultural Wealth from Waste. Activated Composts". Trop.Agric. II, 69.

3. Bagot, A.G.D. (1936) "Composting tea estate wastes". The Times of Ceylon Co.,Ltd.

4. Ball, R.S. (1937) "Experimental work with crops and pastures in the Rift Valley and Molo areas of Kenya, 1934-36". East Afric.Agric.Jl. 2, 254.

5. Baver, L.D. (1930) "The effect of organic matter upon several physical properties of soils". Jl.Amer.Soc.Agron. 22, 703.

6. Beckley, V.A. (1934). "Organic manures with special reference to composts". Kenya Dept. Agric. Bull. No.9, 1934.

7. Beckley, V.A. (1937) "Composts and Composting". East Afric.Agric.Jl. 2, 384.

8. Brunton, L.A. (1927) "Report on the manufacture of "Adco" synthetic farmyard manure at the St.Augustine Experiment Station". Proc.Trinidad Froghopper Com. 1, 192.

9. Carberry, M and Finlow, R.S. (1928) "Artificial farmyard manure". Agric.Jl. India, 23, 80.

10. Collison, R.C. and Conn, H.J. (1925). "The effect of straw on plant growth". N.Y.State Agric.Experiment Stat. Tech. Bull. 114.

11. Comber, N.B. (1934) "Pedology (Humus)". Science Progress 28, 696.

12. Dhar, N.R. (1935) "A new method of nitrogen fixation and conservation and reclamation of alkali lands". Proc. Indian Acad.Sci. Presidential Address Dec. 19.

13. Duthie, D.W. (1937) "Studies in tropical soils IV. Organic transformations in soils, composts and peat". Jl.Agric.Sci. 27, 162.

14. Fisher, R.A. (1932) "Statistical methods for research workers". 4th Edition. Oliver and Boyd, Edinburgh.

15. Fisher, R.A. and Wishart, J. (1930) "The arrangement of field experiments and the statistical reduction of the results". Imp.Bur.Soil Sci.Tech.Com. 10

*16. Flieg, O. (1930). "Investigation on the preparation and action of artificial farmyard manure". Ztschr. Pflanz. Dung B.9 193.

*17. Flieg and Gross.(1934) "Experiments on straw manuring". Ibid. B.13, 380.

18. Fowler, G.J. (1930). "Recent experiments on the preparation of organic manure. A review". Agric.Jl.India, 25, 363.

19. Fowler, G.J. (1934). "An introduction to the biochemistry of nitrogen conservation". Macmillan, London.

*20. Gerlach. (1925). "The influence of straw manure on the yield". Ztsch.Pflans.Dung. B.4, 534.

21. Gilbert, B.E. and Pember, F.R. (1933). "Influence of rye and oat straws upon the growth and yield of certain vegetables". Soil Sci. 35, 115.

22. Gisborne, J.H. (1935) "Experiments on the use of organic manures in the tropics". I.C.T.A. Thesis (unpublished).

23. Hardy, F. (1924) "Mauritian pen manure". Trop.Agric. 1, 116.

24. Hardy, F. (1925) "Synthetic farmyard manure". Ibid, 2, 108.

25. Hardy, F. (1928) "Synthetic organic manure". Ibid. 5, 172.

26. Hardy, F. and Rodriguez, G. (1927). "The composition of "Adco" manure made in Trinidad". Proc. Trinidad Froghopper Com. 1, 196.

27. Halversen, W.V. and Torgerson, E.F. (1927) "Production of artificial farmyard manure by fermenting straw". Jl.Amer.Soc. Agron. 19, 577.

28. Hartley, K.T. and Greenwood, M. (1933) "The effect of small applications of farmyard manure on the yields of cereals in Nigeria". Emp.Jl.Expt.Agric. 1, 113.

29. Howard, A. and Wad, M.D. (1931) "The waste products of agriculture: their utilisation as humus". Oxford Univ. Press.

30. Howard, A. (1933) "The waste products of agriculture: their utilisation as humus". Jl.Roy.Soc.Arts, 82, 84.

31. Howard, A. (1935) "The manufacture of humus by the Indore process". Ibid. 84, 25.

32. Hutchinson, H.B. and Richards, E.H. (1921) "Artificial farmyard manure". Jl.Min.Agric. 28, 398.

33. Jenkins, S.H. (1935) "Organic Manures". Imp.Bur.Soil Sci.Tech. Com. 33.

34. Jacks, G.V. and Lawrence, A.J.L. (1934) "The determination of exchangeable bases in soil". Ibid. No.30.

35. Jackson, F.K. and Wad, V.D. (1934) "The sanitary disposal and agricultural utilisation of habitation wastes by the Indore process". Inst. of Plant Industry, Indore, Bull. 1.

36. Jackson, F.K., Wad. Y.D. and Panse, V.G. (1934) "The supply of humus to soils". Emp.Cotton Growing Review, 11, 111.

37. Jealott's Hill. (1936). Agricultural Research Bull. 5, B.277.

38. Joachim, A.W.R. and Kandiah, S. (1934) "Chemical studies on compost manure". Trop.Agriculturalist, 83, 277.

39. Johnson, C.E. (1936) "Field studies on composting in the tropics". I.C.T.A. thesis (unpublished).

40. Jones, G.A. (1927) "Report on "Adco" pen manure on the estate of the St. Madeleine Sugar Co.,Ltd." Proc. Trinidad Froghopper Com. 1, 173.

41. Keen, B.A. (1927) "Symposium on soil organic matter. 1. Some physical and physico-chemical properties of soil organic matter". Jl.Amer.Soc.Agron, 19, 362.

42. Kettlewell, R.W. (1933) "The preparation of composts under tropical conditions". I.C.T.A. thesis (unpublished).

43. King, F.H. (1926) "Farmers of Forty Centuries". Jonathan Cape, London.

44. Lamb, J. (1933) "A study of chemical composition of synthetic manure as compared with that of natural soil organic matter". I.C.T.A. thesis (unpublished).

45. Lambert, E.B. and Davis, A.C. (1934) "Distribution of oxygen and carbon dioxide in mushroom compost heaps as affecting microbial thermogenesis, acidity and moisture therein". Jl. Agric.Research, 48, 587.

46. Masefield, G.B. (1935) "Studies on the fermentation of compost manure". I.C.T.A. thesis (unpublished).

47. Mundy, H.G. (1925) "Preliminary report on artificial farmyard manure". Rhodesian Agric.Jl. 22, 447.

48. Murray, T.J. (1921) "The effect of straw on the biological soil processes". Soil Sci. 12, 233.

49. Norman, A.G. (1935) "The decomposition of lignin in plant materials". Trans.Third Internat.Cong.Soil Sci. 3, 105.

50. Phillips, M., Weihe, H.D. and Smith, N.R. (1930) "The decomposition of lignified materials by soil micro-organisms". Soil Sci. 30, 383.

51. Pizer, N.R. (1936) "Note on mushroom growing". Gardeners' Chronicle, 100, 112. (See Applied Chemistry Reports, 21, 582).

52. Rege, R.D. (1927) "Biochemical decomposition of cellulosic materials, with special reference to the action of fungi". Ann.Applied Biol. 14, 1.

53. Robinson, S.W. and Jones, J.O. (1925) "A method for determining the degree of humification of soil organic matter". Jl.Agric. Sci. 15, 26.

54. Rothamsted Experimental Station Annual Reports 1929-35.

55. Russell, J. and Richards, E.H. (1917) "The changes taking place during the storage of farmyard manure". Jl.Agric.Sci. 8, 495.

56. Salter, F.J. (1927) "Symposium on soil organic matter. 5. The chemical composition of soil organic matter as related to its effectiveness". Jl.Amer.Soc.Agron. 19, 397.

57. Swynnerton, R.J.M. (1934) "Some aspects of manuring in the tropics". I.C.T.A. thesis (unpublished).

58. Tambe, G.C. and Wad, V.D. (1935) "Humus manufacture from cane trash". Inst. of Plant Industry, Indore; bull. 3 of 1935.

59. du Toit, M.M.S. and Page, H.J. (1930) "Studies on the carbon and nitrogen cycles in the soil. III The formation of natural humic matter".

60. Vandecaveye, S.C. and Allen, M.C. (1935) "Microbial activities in soil". II Activity of specific groups of microbes in relation to organic matter transformation in Palouse silt loam". Soil Sci. 40, 331.

61. Waksman, S.A. (1927) "Principles of soil microbiology". Balliere, Tindall and Cox; London.

62. Waksman, S.A. (1936) "Humus, origin, chemical composition, and importance in Nature". Balliere, Tindall and Cox; London.

63. Waksman, S.A. and Fred, E.B. (1922) "A tentative outline of the plate method for determining the number of micro-organisms in the soil". Soil Sci. 14, 27.

64. Waksman, S.A. and Hutchings, I.J. (1935) "Chemical nature of organic matter in different soil types". Ibid. 40, 347.

65. Waksman, S.A. and Hutchings, I.J. (1935) "The role of plant constituents in the preservation of nitrogen in the soil". Ibid, 40, 487.

66. Waksman, S.A. and Hutchings, I.J. (1936) "Decomposition of lignin by micro-organisms". Ibid. 42, 119.

67. Waksman, S.A. and Hutchings, I.J. (1937) "Associative and antagonistic effects of micro-organisms: III Associative and antagonistic relationships in the decomposition of plant residues". Ibid, 43, 77.

68. Waksman, S.A. and Iyer, K.R.N. (1932) "Contribution to our knowledge of the chemical nature and origin of humus. I. On the synthesis of the 'humus nucleus'". Ibid, 34, 43.

69. Waksman, S.A. and Iyer, K.R.N. (1932) Ditto. II. The influence of 'synthesised' humus compounds and of 'natural humus' upon soil microbiological processes". Ibid, 34, 71.

70. Waksman, S.A. and Iyer, K.R.N. (1933) "Contribution to our knowledge of the chemical nature and origin of humus. III. The base-exchange capacity of 'synthesised humus', (ligno-protein) and of 'natural humus' complexes". Ibid, 36, 57.

71. Waksman, S.A. and Tenney, F.G. (1928) "Composition of natural organic materials and their decomposition in the soil. III. The influence of nature of the plant upon the rapidity of its decomposition". Ibid, 26, 155.

72. Waksman, S.A. and Tenney, F.G. (1929) Ditto. IV. The nature and rapidity of decomposition of the various organic complexes in different plant materials, under aerobic conditions". Ibid, 28, 55.

73. Waksman, S.A., Tenney, F.S. and Diehm, R.A. (1929) "The chemical and microbiological principles underlying the transformation of artificial manures". Jl.Amer.Soc.Agron. 21, 533.

74. Webster, C.C. (1933) "The Composting of crop residues in the tropics". I.C.T.A. thesis (unpublished).

75. White, J.W., Holben, F.J. and Jeffries, C.D. (1934) "Influence of soil acidity upon the decomposition of organic matter in soils". Soil Sci. 37, 1.

76. Wishart, J. and Sandars, H.G. (1935) "Principles and practice of field experimentation". Empire Cotton Growing Corporation; London.

77. Wood, R.C. (1933) "A notebook of tropical agriculture". I.C.T.A. Trinidad.

78. Wood, R.C. (1934) "Potash starvation and the cotton plant". Emp. Cotton Growing Review II, 25.

79. Wood, R.C. (1936) "Village Waste". Emp.Jl.Expt.Agric. 4, 365.

N.B. An asterisk denotes that the original was not consulted, but only the summary in Jenkins' paper (33).