SOILS AND MANURES.

ARTIFICIAL FARMYARD MANURE.

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As a consequence of the campaign for increased production during the War, and the resulting extension of the area under cereal crops, it was thought that, even after making allowances for disposal through the usual channels, there might still remain a surplus of straw which could not be utilised for feeding or for conversion into manure. It was therefore determined to investigate the possibility of converting straw into manure without the intervention of live-stock, and a special grant in aid of the investigation was made to the Rothamsted Experimental Station by the late Food Production Department. Apart from war conditions, the possibility of adding to the supply of organic manure deserves consideration. In the case of market gardens particularly, the difficulty of obtaining adequate supplies of stable manure is increasing. The investigations described below indicate a method by which straw can be converted into a substance having many of the properties of stable manure. Further experiments to test the economic value of the process when conducted on a large scale are in progress at Rothamsted. Lord Elveden has also generously provided assistance and facilities for experimental work on his Pyrford Estate.

Of a considerable number of preliminary experiments to secure obvious breakdown and colour changes in fermenting straw, the most promising results were obtained when straw was subjected to the action of a culture of aerobic cellulose-decomposing organisms (e.g., *Spirochaeta cytophaga*). Further enquiry showed, however, that this effect was not due simply to the provision of an organism capable of breaking down cellulose, but rather to the indirect effect of the mineral substances contained in the culture fluid. From this point on, the question of food supply—as distinct from the addition of any particular species of organism—received special attention, and, as will be seen later, led to results possessing both theoretical and practical importance.

Without entering into a detailed account of the various stages of the investigation, we may state here that the most essential factors making for the production of well-rotted artificial farmyard manure are air supply, suitable temperature, and a suitable supply of soluble nitrogen compounds.

(1) *Air Supply.*—It has been found invariably that characteristic breakdown changes in straw remain suspended when a free supply of air is excluded either by intense consolidation or by immersion of the straw in liquid. The fermentation appears, therefore, to be an essentially aerobic one, at least in its early stages, and the typical disintegration of the straw

with the production of dark-coloured plastic material does not take place in the absence of air. Moreover, the colour of aerobically produced manure is rapidly reduced when oxygen is excluded. The great importance of air supply is shown by the following experiment, in which four lots of straw were fermented under aerobic and anaerobic conditions for three months at 37°C. (99°F.).

Loss of dry matter.

	Straw without Nitrogen.	Straw with Nitrogen.
Without Air Supply	16·3 per cent.	17·1 per cent.
With Air Supply	40·1 ,,	59·8 ,,

The data explain what may be seen in the ordinary heap of farmyard manure, viz., that straw submerged in liquid urine, and therefore protected from air, remains in an unchanged state for long periods. On the other hand, the practice of carting manure from the yards and boxes and storing it in heaps in the field, although carried out for other reasons, provides better conditions for rotting than are likely to prevail where the dung is consolidated by trampling and saturated with urine.

(2) *Suitable Temperature.*—Except in those cases where straw is being fermented under otherwise unfavourable conditions, special measures to maintain a favourable temperature for fermentation are not called for. In common with other fresh fermentable materials, moist straw rapidly undergoes a preliminary fermentation during which the temperature may rise to upwards of 65°C. (149°F.). It is, however, in the subsequent stages that the effect of treatment becomes most evident in maintaining the temperature. Experience has shown that a supply of nitrogen, by increasing the energy of fermentation, leads to an increase of 15-20°C. (59-68°F.) in favour of straw which has received a sufficient supply of nitrogen, as compared with untreated straw.

(3) *A Supply of Soluble Nitrogen Compounds in suitable Concentration, and possessing a neutral or slightly alkaline reaction.*—Repeated experiments have shown that the most rapid breakdown of straw occurs when some source of nitrogen in an available or indirectly available form was supplied, and then only in those cases where the reaction of the solution was neutral or slightly alkaline. Hence the supply of nitrogen in the ammonium sulphate alone fails to lead to definite breakdown since the medium soon becomes markedly acid, while, on the other hand, the supply of an alkaline compound alone, such as caustic soda, is equally ineffective, since a source of nitrogen is lacking. The addition of nitrogen in the form of urine, urea, ammonium carbonate, or peptone within certain concentrations immediately sets in train rapid decomposition changes, and results within the period of a few weeks in the production of dark-coloured, well-disintegrated, structureless material closely resembling well-rotted manure. That this should be the case with urine was perhaps not remarkable, although the factors which operate in the essential dung-making process had not then been individually worked out, but that an essentially characteristic product could be obtained without the use of urine or of the fæcal portion of the manure as ordinarily produced was at once suggestive. On the basis of subsequent work, it may indeed be claimed that, in the production of normally well-rotted farmyard manure, the mass inoculation

of the litter with the large bacterial population of the fæces does not exert any marked contributory influence on breakdown changes; that the urine, as such, apart from being the carrier of nitrogen, does not induce any characteristic changes in the straw, while the typical smell and colour of stale urine from the manure heap may be successfully reproduced from straw treated with ammonium salts.

Although it is important that available nitrogen should be present for the rotting process, it is also not less essential that the quantity of nitrogen should not exceed a definite amount both actually as well as in concentration. In other words, if the concentration of ammonium carbonate produced from the decomposition of urine or urea exceeds a definite limit not only are straw-breakdown changes definitely held up, but they continue to be inoperative until by volatilisation, and consequently loss of nitrogen to the air, the concentration or alkalinity has been reduced to the upper limit of growth of micro-organisms. *This must be regarded as particularly important, since the highest concentration for rapid breakdown is appreciably below that of the weakest undiluted urine.*

It follows that it is quite impossible to produce well-rotted dung by the use of neat urine without considerable losses. This fact may be illustrated by the following table, and, incidentally, is shown by all the investigations that have been carried out on the making of farmyard manure.* Three equal portions of straw were saturated either with water or urine and allowed to ferment for three months in the laboratory, the two portions with urine being subjected to different temperatures. As will be seen from the following table, these two portions fermented to different degrees—the dry matter losses being 49 and 60 per cent. respectively, *but the final nitrogen-content was almost identical*, and practically three-fourths of the nitrogen supplied as urine was lost.

	Temp.	Loss of dry Matter. per cent.	Nitrogen Initial mgrm.	Nitrogen Final mgrm.	Loss—or Gain+ mgrm.
Straw with water	(36°C.=97°F.)	40·1	71	97	+26
Straw ,, urine	(26°C.=80°F.)	49·1	507	178	—329
Straw ,, ,,	(36°C.=97°F.)	59·8	507	176	—331

It would be erroneous, however, to assume that such losses are inevitably connected with a satisfactory breakdown of straw, or that the conditions ordinarily obtaining in the farmyard at all represent optimum proportions between the straw which is to be decomposed, and the concentration of nitrogen in the urine which eventually serves for this decomposition. That equally good rotting may be obtained without loss of nitrogen is shown by the cases given in the table below. In the experiments to which the table refers, straw was incubated with urine in different concentrations for periods up to 86 days. Even after this period the losses that occurred with satisfactory rotting and within the lower concentrations were only about 4 per cent. of the total nitrogen of the final product. The ordinary losses of the manure heap are frequently more than tenfold this amount.

* See, for example, Russell & Richards, Journ. Agric. Sci., 1917, Vol. VIII, p. 495.

	Number of Experiment.				
At beginning	(1)	(2)	(3)	(4)	(5)
Straw and urine nitrogen	77·5	157·6	237·6	317·6	397·6
After 86 days					
Total nitrogen	77·3	153·1	226·8	262·1	308·0

In addition to *the two phases already mentioned*, (*a*) in which straw overloaded with nitrogen loses it to a definite. degree, and (*b*) in which straw with the requisite amount of nitrogen may undergo rotting without appreciable loss and is therefore in a state of equilibrium, there exists *a third phase* in which under-saturated straw, by the agency of micro-organisms, exhibits a well-marked property of picking up nitrogen, particularly in the form of ammonia, until the same final content of nitrogen in the rotted product is attained. Hence we might expect that in two different but adjacent portions of fermenting straw, the one overloaded with, and the other lacking, nitrogen, the former portion loses and the latter accumulates nitrogen until a common level is approached. That such is actually the case is illustrated by the following data. Ten portions of straw were moistened to the same extent, and while one received water only, the others received additions of soluble nitrogen in the form of urea in varying quantities, until the last portion was saturated with a solution similar in concentration of nitrogen to that of horse urine (1 per cent. of nitrogen.) The different portions were then kept in an incubator for 3 months, at the end of which time it was evident that, contrary to expectation, the straw, without, or merely with low doses of nitrogen, had passed through a marked rotting process. On analysis, however, it was found that there had been a definite accumulation of nitrogen in the lower members of the series, while the higher members had lost in some cases the greater portion of their original nitrogen.

The Decomposition of Straw in the Presence of Varying Quantities of Nitrogen as Urea.

	Number of Experiment.									
Treatment	1	2	3	4	5	6	7	8	9	10
At beginning										
Straw nitrogen mgrm.	71	71	71	71	71	71	71	71	71	71
Urea nitrogen ,,	—	5	10	24	48	97	243	486	729	973
Total nitrogen ,,	71	76	81	95	119	168	314	557	800	1,044
At end of 3 months										
Organic nitrogen mgrm.	180	177	174	190	192	171	245	269	181	134
Ammonia ,, ,,	—	5	2	4	4	29	74	68	71	76
Total ,, ,,	180	182	176	194	196	200	319	337	252	210
Gain or loss ,,	109	106	95	99	77	32	5	—220	—548	—134
Dry Matter, loss per cent.	49	46	45	49	47	53	51	48	19	14

In seven out of the ten cases the final nitrogen of the fermented straw varied only between 180 and 210 mgrm., irrespective of the nitrogen-content of the original mixture. It should also be noted that the extent of the rotting, *i. e.*, the loss of dry matter, in experiments 1-8 was very much greater than in 9 and 10 in which the straw was subjected to the action of solutions closely approaching the concentration of ordinary urine, the high alkalinity of the latter exercising a check on decomposition.

In the main, the nitrogen retained by super-saturated straw, or such as is accumulated by under-saturated straw, as in Nos. 1—6 in the above table, appears to be stored up in an organic or non-ammoniacal form. The maximum retention has been found to occur within the first four weeks, after which time breakdown of this organic nitrogen to ammonia and consequent loss by volatilisation seems to keep pace with loss of dry matter. Finally, the material assumes a "stabilised" condition—the loss of nitrogen becomes greatly diminished or may be absent altogether for long periods. Between the 60th and the 120th day little change is found to take place either in the amount of "stabilised" or "fixed" nitrogen or the proportion of this nitrogen and the ammonia which appears to be held by fermented material even at a high temperature (37°C. = 99°F.), and in spite of the frequent handling and exposure associated with sampling operations. In general, it may be stated that when straw has worked from an unsaturated to a "stable" phase little or no free ammonia is to be found, but straw which commences with a super-abundance of nitrogen appears to hold, when in a fermented state, upwards of 14 per cent. of its nitrogen in the form of ammonia so long as the material is in a moist condition. Desiccation leads almost to complete loss of ammonia, and in this respect as well as in the proportion of ammonia in the moist material, the artificial resembles the natural manure.

From the study of the inter-relations between nitrogen and straw, we have come to the conclusion that the amount of nitrogen necessary for pronounced rotting, and the amount which straw is capable of "fixing" in the form of ammonia are identical, and that, in general, the figure varies only between 0·70 and 0·75 parts of nitrogen per 100 parts of dry straw. Within these limits fermentation proceeds without loss of nitrogen, and it is obvious that, except in so far as the nitrogen-content of the original straw varies, the final "stabilised" product obtained when rotting has proceeded to the extent of 40 to 45 per cent. of dry matter must likewise exhibit comparatively slight variation in its nitrogen-content. In our experiments the "stabilised" product obtained from the fermentation of straw under a variety of conditions possesses a nitrogen-content of about 2 per cent. calculated on the dry material.

It thus becomes possible to estimate fairly accurately what the nitrogen-content of any particular sample of fermented straw will be when rotting has proceeded to an appreciable extent. If, for example, the nitrogen-content of the original straw is equal to 0·50 per cent., and we assume that the theoretical amount of ammonia nitrogen, equal to 0·72 lb. or nitrogen for 100 lb. of straw, has been fixed, then, with a loss of 40 per cent. of dry matter during fermentation, the resultant-rotted straw will contain $(0{\cdot}50 + 0{\cdot}72) \times 100 \div {\cdot}60 = 2{\cdot}03$ per cent. of organic nitrogen in the dry matter. An additional amount of ammonia nitrogen would probably result in a portion remaining as free ammonia which, as indicated above, would be liable to loss if the fermented straw were allowed to become dry. The data thus obtained enable us to turn to the process of inducing the fermentation of straw on a large scale, and are also capable of application to the conditions operating in the production of ordinary farmyard manure.

*Suggested Method for the Preparation of Artificial Manure.**—As regards large scale work, a number of factors have to be taken into account which did not operate in the laboratory experiments. Experience has shown that urea and ammonium carbonate are the most suitable carriers of nitrogen since they ensure a favourable alkaline reaction, and lead to rapid break-down, provided that they are not present in large excess. They are, however, far too expensive at the present time to admit of general use in farm work, although a reduction in the cost of manufacturing synthetic urea would create conditions favourable to its extended use. As an alternative source of nitrogen, cyanamide (nitrolim) and sulphate of ammonia have been used with success. Whilst cyanamide already contains sufficient free lime to keep in check any acid compounds formed during fermentation, sulphate of ammonia must be supplemented by the addition of a base, and for this purpose finely-ground chalk, ground limestone, or waste lime from causticising plant at soap works may be used. For general purposes it will be found that upwards of ¾ cwt. of sulphate of ammonia and 1 cwt. of finely divided carbonate of lime per ton of straw are sufficient to induce fermentation. The main obstacles to large scale operations at the present time arise from the great tardiness with which raw straw takes up the moisture necessary for fermentation. Where pits are available this difficulty may be overcome by allowing the straw to remain immersed for 2 to 4 days, after which the free liquid may be drained off. In the case of heaps or stacks on open ground no advantage appears to be obtained by continued wetting with large quantities of water, and we suggest, as a more effective method of securing the necessary saturation of the straw, sprinkling the heap comparatively lightly with water and allowing a couple of days to elapse before a second sprinkling is given. During this time a slight fermentation with increase in temperature sets in, rendering the straw more capable of absorbing a second slight application of water than would otherwise be the case. When examination has shown that the interior of the heap has become uniformly moist, the source of nitrogen may be applied in the form of solution, or in the case of cyanamide and other products, this may be broadcasted over the surface of the heap and watered in. The most convenient method of making the heap, wetting the straw, and supplying the necessary nitrogen for fermentation depends so much on local conditions that much must be left to the initiative of the farmer himself.

General Characteristics of Artificial Farmyard Manure.—Artificial farmyard manure prepared from straw is a well-disintegrated plastic material in which the tubular character of the straw has been to a great extent destroyed. There is an almost complete absence of smell, the little there is being slightly fusty or mouldy in character. When prepared through the agency of a compound in the presence of free lime, there is a tendency towards the production of a blackish colour, while if prepared from soluble alkalies such as ammonium carbonate, liquid ammonia, or compounds giving free ammonia

* This process, as well as its application to the purification of sewage, has been covered by letters Patent (British Pat: No. 152387).

such as urea or peptone, or in the presence of sodium hydroxide or sodium carbonate, the colour is dark brown, and differs only slightly from the natural product. The liquid which is gradually expressed from the fermenting straw as more and more dry matter is lost by fermentation, has a dark-brown colour and a smell which is indistinguishable from stale urine.—The Journal of the Ministry of Agriculture, Vol. XXVIII, No. 5.