

Sl. 314

Reprinted from *The Indian Medical Gazette*,

Vol. LXX, No. 4, (April 1935.)

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Sc. 34

Reprinted from *The Indian Medical Gazette*,

Vol. LXX, No. 4, April 1935, page 202

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UTILIZATION of all forms of organic waste including human excreta as manure has been a recognized item of agricultural practice in China and Japan for over four thousand years. The preparation of 'mud' composts (King, 1911) and the fermentation of night-soil in cisterns for direct application to fields are also of ancient origin in those countries though the scientific and sanitary aspects of the related processes were not investigated until recent years.

In many parts of India, it has long been the practice to utilize night-soil as manure without any previous treatment. It is also occasionally used for preparing 'poudrette' in combination with mud and refuse. In recent years, however, the desirability of preparing composts from night-soil and different forms of organic wastes under aerobic conditions is

being increasingly realized as efficient means of both disposal and utilization of such materials. Fowler (1927) suggested that night-soil might be dumped on refuse heaps and the mixture turned frequently so as to facilitate aeration. In a later publication he summarized the results of experiments in which night-soil was used both as a source of nitrogen and as a biological starter for the preparation of compost. Rao and Subrahmanyam (1932) conducted experiments with fresh as well as liquefied night-soil and found the latter to be cleaner and more convenient to handle than the former. Based on the previous work of Howard and Wad (1931) a method of disposing of municipal wastes has been worked out by Jackson and Wad (1932) on a big scale at Indore. Composting on a large scale is also in progress at Mysore and has been described by Mieldazis (1934).

Although much useful work has already been done in India alone, there are still various aspects of the problem which require elucidation. The present enquiry was undertaken therefore with the object of further standardizing the conditions so as to (a) prevent fly-breeding, (b) maintain high temperature in the compost heap, and thus kill out putrefactive and pathogenic organisms, (c) reduce the loss of nitrogen which invariably accompanies heavy applications of night-soil, (d) restrict the profuse decomposition of organic matter and improve the yield of the finished product, and (e) ensure maximum availability of the fertilizing ingredients present in the different components.

#### *Experimental*

*Treatment of refuse with fresh diluted night-soil.*— Three heaps (nos. 1 to 3) of refuse each 6 feet by 6 feet at the base, 6 feet by 4 feet at the top, and 2 feet high

were made. Each heap contained 5 cart-loads of town refuse, and the contents of each cart weighed from a quarter to one-third of a ton. The suspension of night-soil was prepared as follows. To about 15 gallons of freshly collected night-soil contained in a small drum attached to a hand cart, thrice the volume of sewage (septic-tank) effluent was added and the contents stirred together with wooden rods. As far as possible, the bigger lumps were also broken. The suspension which still contained leaves (originally used for clearing pit latrines) and other foreign bodies was applied as such to the three heaps, the contents of one drum being used for each heap. The heaps were opened longitudinally at the centre and the suspension distributed evenly along the sides of the gap thus created. The sides were then drawn in by means of manure forks, and the interior containing the night-soil carefully covered up. The surface of the heaps was kept moist from time to time by application of septic-tank effluent. At the end of one week, heaps 2 and 3 were again opened up and treated similarly with night-soil. At the end of the second week, only heap 3 received a third treatment of night-soil. All the heaps were turned once in every week. The temperature of the heaps was taken every day and was found to range from 40°C. to 50°C. for the first two weeks. Subsequently it came down to below 40°C. Except in heap 1 to which only one cart of night-soil was added, there were innumerable fly-larvæ after the first week. On opening heaps 2 and 3 it was also found that the added night-soil remained practically undecomposed while in heap 1 none of it could be seen. These observations would suggest that the fly-breeding observed in heaps 2 and 3 is due to the presence of undecomposed night-soil.

At the end of 10 weeks, when the decomposition was apparently complete, the heaps were sampled and analysed for nitrogen and ash according to Association of Official Agricultural Chemists (1930) methods (table I).

TABLE I

Heap number	PERCENTAGES	
	Total nitrogen	Ash
1	.. 0.75	82.0
2	.. 0.84	87.3
3	.. 1.18	83.3

The above experiments were subsequently extended adding 4 and 5 cart-loads of night-soil, but it was found that the nitrogen content remained practically the same (1.2 per cent). This would suggest that the nitrogen added in the later stages was almost entirely lost.

*Composting with alternate layers of refuse and night-soil.*—Three beds of refuse each 6 feet long, 3 feet wide and 3 inches high were prepared. One cart-load of night-soil was spread on each bed. This was covered by a layer of refuse 3 inches high over which another cart-load of night-soil was distributed. In this manner six alternating layers of refuse and night-soil were made up in each case and the entire heaps finally covered with thin layers of refuse. Septic-tank effluent was then sprayed on the surface of the heaps to maintain the moisture and to facilitate the fermentation. It was soon found however that the entire mass became hard and compact so that the effluent could not penetrate into the heaps. The fermentation was also slow and the temperature ranged between 40°C. and 50°C. On opening the heaps it was found that the night-soil remained largely undecomposed. There was a highly offensive odour and profuse fly-breeding after one week. Even heavy applications of lime, borax or Bordeaux mixture did not improve the condition of the heaps.

Since undecomposed night-soil occurred mostly in the form of lumps, it was considered desirable that some device should be adopted to break up such lumps and then to apply the night-soil in the form of an emulsion.

*Experiments with liquefied night-soil.*—It is a well-known Chinese method to dump night-soil into a well or cistern and allow it to undergo spontaneous fermentation prior to application

to land. The previous observations of Rao and Subrahmanyan (1932) also show that night-soil stored for even a few days undergoes liquefaction and after suitable dilution can be successfully used for treating refuse heaps. Some further experiments with liquefied night-soil were therefore carried out.

A cylindrical drum, capacity 40 gallons, was fitted up at the bottom with an iron pipe 6 inches long and  $1\frac{1}{2}$  inches in diameter. The pipe was provided with a valve and a hose. Night-soil, admixed with leaves and other foreign bodies, was introduced into the drum and stirred with thrice its volume of septic-tank effluent. The drum was then tightly closed with a lid. The contents of the drum were examined from time to time but otherwise left undisturbed for 10 days. It was observed that in the beginning there was frothing accompanied by the formation of a scum at the surface. In the later stages the fermentation became very much more vigorous and the liquid mass appeared as though it was boiling. After 10 days, the reaction subsided and a homogeneous brownish-yellow liquid was obtained. The leaves present along with the night-soil did not undergo fermentation but were found either floating at the surface or submerged in the emulsion. To treat refuse heaps, the emulsion was drawn through the hose by opening the valve of the outlet pipe. After the major part of the liquid had been drawn, fresh night-soil was added to the drum and again mixed with thrice its volume of septic-tank effluent. It was found on this occasion that the fermentation started very much more vigorously than before and that the liquefaction of the freshly added night-soil was complete within 72 hours. With repetition of this treatment, it was found that an increasingly active mass of liquefying organisms had been set up in the drum with the result that, in the later stages, the liquefaction was often complete within 24 hours. The undecomposed leaves were removed periodically using manure forks. Large quantities of night-soil were liquefied in this manner and used for treating refuse heaps.

*Mode of heaping; importance of loose packing in the early stages.*—It is well known that the maintenance of high temperature of the order of  $50^{\circ}\text{C}$ . for at least 24 hours is necessary in order to destroy weeds and pathogenic

organisms. The thermal death point of many organisms varies from 50°C. to 60°C. within which range they are killed out if exposed for even a few minutes. Thus, *B. typhosus* is killed in about 7 minutes at 55°C. If the temperature is lowered by 7 or 8 degrees, it may take several hours before all the cells are killed out. It is desirable therefore that in the compost heap, a high temperature (above 50°C.) be attained although only for a short period. The most favourable condition for a rise in temperature is provided by loose packing which ensures an adequate air supply for the active functioning of the thermophilic bacteria and fungi which are responsible for the fermentation. The importance of this principle is realized in the 'Edelmist' process developed by Kranz in Germany. The 'Beccari' process adopted in Italy consists in decomposing organic materials in closed cells provided with ventilation. According to that method, a temperature of 140°F. was recorded (Smith, 1924). In view of the above and other observations the heaps prepared for subsequent experiments were always packed loosely.

*Removal of non-organic matter.*—The collections of refuse from a town contain large amounts of non-organic matter such as stones, gravel, glass and tin which should be removed before any treatment is given. This is easily done by dumping the refuse at a place in long rows about 3 feet high and 3 feet wide at the base and then dragging the refuse by means of manure forks. Heavy materials like sand and stones are thus left behind. Lighter or smaller ones like pieces of glass or tin are picked up by hand and thrown away.

*Composting with liquefied night-soil.*—Four heaps (nos. 4, 5, 6 and 7) each measuring 6 feet long, 3 feet wide and 3 feet high were made. The materials were

left loose and no attempt was made to press the heaps during the formation. The top of each heap was also covered loosely with refuse keeping it in the form of a dome.

The night-soil emulsion was applied as follows:— The top layer of refuse was drawn aside by manure forks, keeping it all along the length of the heaps so that the flat surface was visible. Night-soil emulsion was then sprayed all over the surface of the heaps, wetting the material inside. Care was taken, however, not to add an excess which would soak down to the earth. For each heap of the size mentioned above, 8 gallons of emulsion were required for treatment on the first day. From the second day up to the eighth day 5 gallons per day were added and later up to the twenty-fifth day 4 gallons of emulsion per day were sprayed.

It was observed that within 24 hours of the first treatment there was rapid fermentation, the temperature rising to 52°C. Before the end of one week it had risen to 60°C. At the end of the week the heaps were turned so as to facilitate aeration and hence keep up the high temperature. The heaps were treated again with the emulsion in the same manner and turned every week. After twenty-five days the temperature gradually came to 45°C. and then to 40°C. and later still to that of the atmosphere (21°C. to 26°C). There was no fly-breeding in any of the heaps.

On the twenty-sixth day the treatment of heaps 4 and 5 was stopped while that of heaps 6 and 7 was continued until the sixtieth day in spite of the fact that the temperature did not show any rise. At the end of that period, the resulting manure was sieved through a half-inch-meshed expanded-metal screen, and analysed for total nitrogen.

TABLE II

Heap number	Total nitrogen, per cent
4	0.61
5	0.57
6	0.73
7	0.67

The nitrogen content was comparatively low in all the cases. Even prolonged application of night-soil for sixty days did not appreciably

improve the nitrogen content, thereby showing that a considerable part of the added nitrogen was lost.

In view of the probable error introduced by parallel heaps not fermenting at the same rates, the experiments were next repeated as follows:—

One big heap was treated with liquefied night-soil in the manner already described; after twenty-five days, the heap was divided into two (heaps 8 and 9). Heap 8 was sprayed with tap water and heap 9 with night-soil emulsion. After sixty days the resulting manures were sieved and the nitrogen and degree of humidification (Jones, 1927) estimated.

TABLE III

Heap number	Total nitrogen	Organic matter	Humidification
P e r c e n t a g e s			
8	0.69	26.2	73.5
9	0.77	23.1	72.2

These observations confirm the previous results and show that after twenty-five days the addition of night-soil may be stopped from both the point of view of sanitation and nitrogen conservation.

*Changes in reaction and nitrogen content during liquefaction of night-soil and aeration of the liquefied product.*—The night-soil was macerated with thrice its volume of tap water and the supernatant liquid decanted into a five-litre bottle. After determining the nitrogen content of a representative sample, the residue was left for ten days in the stoppered bottle to undergo liquefaction. After that period it was found that the volume of the liquefied product had not changed appreciably. The nitrogen content of the fresh suspension was 81.8 parts per 100,000 while that of the final product was 82.8 parts, thereby showing that there was no appreciable change during liquefaction.

An experiment was next carried out with night-soil diluted to about half the previous concentration in order to follow at daily intervals the H-ion concentration colorimetrically. The results (table IV) show that, with the progress of liquefaction, the reaction tended to become less acid.

TABLE IV

Days	pH	Days	pH
1	.. 6.8	6	7.4
2	.. 6.8	7	7.4
3	.. 7.0	8	7.4
4	.. 7.4	9	7.4
5	.. 7.4	10	7.6

It appeared probable that the change in reaction was due to production of ammonia, accordingly some trials were carried out adding sodium carbonate (5 g.) to 150 c.cm. of liquefied night-soil emulsion containing 44.8 parts of nitrogen per 100,000 and aerating the mixture. The gases were drawn through dilute mineral acid and, ammonia thus absorbed, they estimated by back-titration (table V).

TABLE V

Time of aeration in hours	Ammoniacal nitrogen, as parts per 100,000	Time of aeration in hours	Ammoniacal nitrogen, as parts per 100,000
2	1.5	14	13.8
5	3.0	17	14.7
8	6.6	19	15.9
10	10.8	22	16.5
12	12.6	24	17.4

It may be seen from the above that, with prolonged aeration, increasing quantities of ammonia are formed. This is probably partly due to the action of sodium carbonate on the albuminoids in night-soil, but the results suggest, nevertheless, that considerable quantities of nitrogen may be lost during aeration of the liquefied product by biological oxidation.

An analysis of the residue showed that it contained 26.5 parts per 100,000 of nitrogen, so that it may be seen that the difference is almost exclusively due to the removal of ammonia.

*Aeration of night-soil on a large scale.*—Partly with a view to breaking up big lumps and partly to remove offensive odours, some experiments were carried out aerating night-soil in a macerating tank.

The tank was 35 feet long, 6 feet wide and 7 feet deep and divided into two compartments one of which had slightly over three times the capacity of the other. The bigger compartment was first half-filled with sewage effluent after which forty cart-loads of night-soil were tilted in and the mixture stirred up. After the mass had liquefied, compressed air was sent in through diffusers fitted at the bottom of the tank and the mass kept well agitated. The aeration was stopped after three hours and the suspension allowed to stand undisturbed. After twenty-four hours, fresh sewage effluent was added to make up for any change in volume. The aeration was then resumed and continued for a further period of three hours. The treatment was thus continued for some time and samples examined at intervals. For chemical analysis, the samples were collected at the same spot and at a time when the liquid was being aerated, so that there was thorough stirring of the liquid during sampling.

Total nitrogen was estimated by the Kjeldahl method, total solids by evaporation at 100° and oxygen absorption (4 hours) by determining the unused permanganate in the usual way. The results have been presented in table VI.

Time in hrs.	Total solids, p. p. 100,000	Oxygen absorbed (4 hours), p. p. 100,000	Total nitrogen, as gms. per gallon	Loss of nitrogen, per cent
0	4,050	204.6	8.4	..
15	3,300	147.6	6.8	19.0
36	3,450	172.2	6.8	19.0
57	3,350	206.4	6.7	20.0
78	3,300	179.7	6.2	26.2

It was observed that after 15 hours the suspension had turned brownish-black and was almost odourless.

There was a marked decrease in total solids, oxygen absorption and total nitrogen. After that period there was not much change in total solids. The oxygen absorption showed a tendency to increase while total nitrogen showed further decrease.

The foregoing observations indicate the type of changes that are consequent on intermittent aeration of night-soil. The treatment represents a short period of aerobic condition followed by a long one of inadequate air-supply during which night-soil might partially revert to the septic condition. The results show that considerable loss of nitrogen will occur under such conditions.

*Vegetation experiments with manure prepared out of refuse and liquefied night-soil.*—Experimental pots were prepared in the usual way by mixing one part of sand with three of soil and the mixture (30 lbs.) treated with lime at 20 g. per pot. After about a week the following manures were applied on an equivalent nitrogen basis. (a) Farm-yard manure (N=0.31 per cent) at 72.5 g., (b) compost treated with night-soil emulsion for 25 days at 36.5 g. and (c) compost treated with night-soil for 60 days at 30.2 g. per pot, respectively. Two crops, ragi (*Eleusine coracana*) and barley, were raised. When the grains were ripe, the plants were carefully removed and the weights of grain, straw and roots determined. The results are given in table VII.

TABLE VII

Manure	Dry weights in grams		
	Grain	Straw	Roots
Experiments with ragi (average weight of 10 plants in each case)			
Farm-yard manure (a)	0.18	0.94	0.39
Compost (b)	.. 0.17	0.90	0.35
"   (c)	.. 0.29	1.43	0.61
Experiments with barley (average of 9 plants in each case)			
Compost (b)	.. 0.16	0.27	0.04
"   (c)	.. 0.13	0.25	0.04

It may be seen from the above that, in the case of ragi, refuse treated with night-soil for 25 days yielded a product which, on an equivalent nitrogen basis, is nearly as good as farm-yard manure while treatment for 60 days

yielded a much better product. This conclusion is not supported however by observations on barley which responded better to manure prepared after treatment for 25 days than to one receiving treatment for 60 days. This apparent discordance between the two sets of observations is presumably due to some difference in the nutritional requirements, and also the duration of the two crops. Further work is in progress to throw more light on this aspect of the problem.

#### *Discussion*

The results of the present enquiry have brought out some facts of practical interest and have indicated certain useful lines of future work.

The earlier experiments have shown that application of large quantities of fresh night-soil is not only unnecessary but also undesirable. After the second week, the rate of decomposition slackens and the temperature fails to rise above 40°C. with the result that fly-breeding proceeds unchecked. The heaps also begin to emit unpleasant odours so that it becomes necessary either to reduce the quantity of night-soil or to subject it to some pre-treatment, which would render it possible to compost large quantities of night-soil with limited amounts of refuse.

Although it has been suggested by us in a previous communication that different forms of waste vegetation can be used to supplement town refuse, it is not generally possible to command such facilities. Even if there are jungles in the neighbourhood, the cost of collecting and transporting the materials may be so considerable that it may not pay to prepare compost out of them. An alternative scheme

would be to grow the required vegetation and to use it, on the spot, for composting. This again is not generally feasible because most municipalities cannot find the space required for the purpose. Even if some land were available, it would be hardly practicable to raise fresh vegetation for composting in preference to market-garden and fodder crops which bring ready cash. It would be necessary therefore to devise other means to facilitate the composting of night-soil with town refuse only.

The experiments with liquefied night-soil have shown that large quantities of that product can be successfully applied at daily intervals for a period of 25 days. A high temperature ( $50^{\circ}\text{C.}$  to  $60^{\circ}\text{C.}$ ) is maintained throughout that period, so that there is no fly-breeding or danger of pathogenic or putrefactive organisms persisting under such conditions. The process of liquefaction proceeds spontaneously and requires no special attention. The liquefied product can be more easily diluted and is generally more convenient to handle than fresh night-soil. There is, no doubt, some smell especially at the time of removing the liquefied night-soil from the cistern, but the heaps composted with that product do not emit such offensive odours as those treated with the fresh material. It will be seen therefore that, from the sanitary point of view, the liquefied product is far more satisfactory to work with than the fresh material.

The experiments on aerating night-soil have shown that, although it is a useful method of removing offensive odours, it is nevertheless wasteful as it leads to loss of nitrogen as ammonia; this treatment would therefore appear to be undesirable. A similar observation would also apply to continued treatment of refuse

heaps with liquefied night-soil for even 25 days since it results in persistently high temperature and considerable loss of nitrogen. The resulting composts are very much poorer in nitrogen than those reported according to the Edelmist or the Beccari processes (*loc. cit.*). It is desirable therefore that the number of applications of night-soil should be reduced and the fermentation in the loosely-packed heap allowed to proceed for just the minimum period of time required to kill out weeds, seeds and insect larvæ. The subsequent fermentation should be so controlled that the loss of nitrogen is reduced to a minimum. Further work in this direction is in progress.

#### *Summary*

(1) Heavy applications of fresh night-soil at weekly intervals result in the slackening of fermentation after one week. The temperature does not rise above 40°C. and fly-breeding proceeds unchecked. After three weeks, the added nitrogen is also mostly lost.

(2) Composting with alternate layers of refuse and night-soil is undesirable as it leads to the hardening of the mass and consequent slackening in fermentation.

(3) Liquefaction of night-soil by spontaneous fermentation has been found to be a convenient way of breaking up big lumps and eliminating other associated waste materials. The details relating to the liquefaction of night-soil and its application to refuse heaps have been described.

(4) During liquefaction, the reaction of night-soil tends to become slightly alkaline. There is no significant change in the total nitrogen content.

(5) Liquefied night-soil can be applied to refuse heaps continuously for a period of 25

days. During the major part of that period the temperature of the heap ranges between 50°C. and 60°C. Application of night-soil after that period is undesirable as the temperature tends to fall below 40°C.

(6) Aeration of liquefied night-soil leads to loss of nitrogen as ammonia. Attempts to macerate night-soil by intermittent aeration also leads to considerable loss of nitrogen.

(7) Pot-culture experiments with ragi (*Eleusine coracana*) and barley have shown that, when considered on an equivalent nitrogen basis, the compost prepared out of liquefied night-soil and refuse is at least as efficient as farm-yard manure.

The authors' thanks are due to the Mysore Compost Committee for kindly providing the necessary facilities for some of the field experiments.

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*PUBLISHED MONTHLY*

## **THE INDIAN MEDICAL GAZETTE**

**A Record of Medicine, Surgery, Public  
Health and Medical News, Indian and  
European, with special reference  
to Diseases of Tropical  
Countries.**

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