THE SIGNIFICANCE OF ANIMAL MANURE AS A SOURCE OF NITROGEN IN SOILS

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ABSTRACT

The nitrogen in manure may be considered to be present in three fractions, differing in plant availability: a readily available mineral fraction, an easily decomposable organic fraction which becomes available in the first year after application, and an organic fraction relatively resistant to microbial decomposition, becoming available in subsequent years. An attempt has been made to quantify each of these fractions chemically and to express their availability in terms of equivalent amounts of fertilizer-N ("efficiency index"). Thus, size and efficiency of each of the fractions being known, the efficiency of the total N content of any manure can be calculated. Calculated first-year efficiency indices for different types of manure are in fair agreement with those from field experiments. Under Dutch climatic conditions, repeated equal spring applications of a certain manure will ultimately lead to a state of equilibrium in the soil, at which the annual nitrogen supply to the crop corresponds to about 75 kg fertilizer-N per 100 kg manure-N applied annually.

The work reported shows promise for the possibility of calculating the efficiency of manure-N on a chemical basis, which would eliminate the need for costly experiments.

In areas of intensive animal husbandry huge amounts of manure are being produced. This paper deals with the question to what extent the continual and heavy dressings of manure in these regions will meet or even exceed the nitrogen requirement of the crops.

APPROACH TO THE PROBLEM

On the basis of plant availability, the nitrogen in manure may be considered to be present in a number of more or less homogeneous fractions. If we could quantify these fractions by chemical analysis, and if, in addition, we could express their availability as a figure, the nitrogen effect of each batch of manure could be calculated regardless of its origin or treatment.

Characterization of the Nitrogen Fractions

Part of the total nitrogen (N_t) may be present in a mineral form, mainly as NH_4-N. Together with the nitrogen in rapidly decomposing compounds like urea it is considered to be equally plant available as that in mineral fertilizer. We designate this fraction by N_m.

The nitrogen in the organic matter of the manure is thought to consist of an easily decomposable fraction and a fraction that is more resistant to biological degradation. We call them N_e and N_r, respectively. To distinguish between both we introduce, rather arbitrarily, a one-year limit. That is to say, the nitrogen released from the organic matter in the first year after application of the manure is called easily available, the rest is referred to as residual nitrogen.

So, in our "thought model" three fractions are involved: N_m, N_e and N_r.

Chemical Determination of the Fractions

The mineral fraction N_m can be determined by well-known chemical procedures. Results of analysis may vary from, for instance, 10% of N_t in farmyard manure (FYM) to more then 90% in liquid manure, depending of course on the presence of organic substances in the waste but also on kind and age of animals, method and duration of storage, and treatment.

Accepted chemical methods to determine N_e or N_r are lacking, as far as we know. But there are methods to determine the corresponding fractions of the organic matter (OM_e and OM_r) as will be shown below. By making an assumption as to their nitrogen content, N_e and N_r can be calculated from those OM-values.

The decomposition of the organic matter in FYM is demonstrated in Fig. 1. The data have been derived from literature, some of them pertaining to fallow soils, others to cropped ones (Kolenbrander, 1974). In spite of the diverse origin, the experimental results show a similar behaviour. From the broken line, which refers to field experiments only, it can be seen that after application, 50% of the total organic matter (OM_t) had been decomposed after one year, 63% after two and 68% after three years. In our terminology OM_e and OM_r both constitute 50% of OM_t. Similar curves have been constructed for other organic materials, some of which are presented in Fig. 1 as well. Kolenbrander (1974) obtained in this way OM_r-values for chopped fresh plant material, straw, and different peats of 20, 30, and 90%, respectively.

During our investigations we noticed that these values correlate well with data obtained by acid hydrolysis. The broken line in Fig. 2 calculated from Springer and Lehner (1952), shows the OM_r-values for different organic materials together with their contents of non-hydrolyzable organic matter (OM_{nh}) which were obtained by extracting the materials with alcohol and ether and hydrolyzing the residue with dilute hydrochloric acid and then with sulphuric acid. We followed a greatly simplified procedure: 1 gram of dry, finely ground material was treated with 10 ml of 80% sulphuric acid at room temperature over half an hour, followed by half an hour of refluxing after dilution with water to 400 ml. The fraction of organic matter not hydrolyzed was determined as loss on ignition of the residue. This procedure is a modification of that used to estimate the degree of decomposition of peat products (e.g. Benelux Economische Unie, 1970). So we obtained values for OM_{nh} which, when plotted against the OM_r-data of Kolenbrander (1974), suggest the relationship represented by the solid line in Fig. 2. In mathematical formulation: $OM_r = 1.58\ OM_{nh} - 24$. We leave out of consideration whether or not the line will turn towards the origin in the range of low OM_{nh}-values.

After having shown that OM_{nh} is an adequate characteristic for OM_r, we now come back to the size of N_r and N_e. Since to our knowledge N_r has not been determined in experiments, we need to make an assumption. Though disputable, we assume that for animal manure the nitrogen content of OM_e equals that of OM_r and, if so, it naturally equals the nitrogen content of OM_t. The nitrogen in the organic matter can be determined as the difference between N_t and N_m. All information necessary to calculate N_r and N_e is then available.

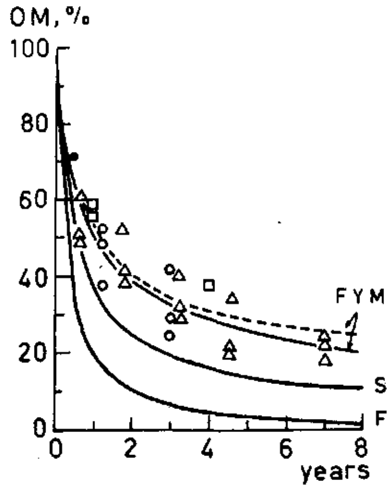

Fig. 1. Decomposition rate of different types of organic matter F = chopped fresh plant material; S = straw; FYM = farmyard manure (broken line for field experiments only, the lower curve for all experiment

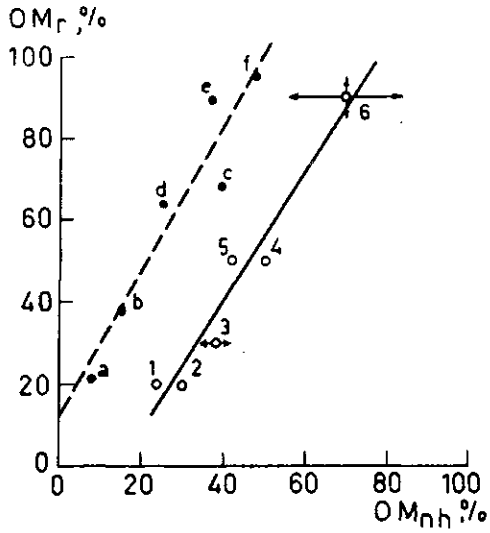

Fig. 2. Relation between residual organic matter, one year after application in field experiments (OM_r), and the non-hydrolyzable fraction of the organic matter (OM_{nh})

Method Springer and Lehner:
a. chopped fresh plant material
b. rye straw
c. coniferous forest litter
d. beech litter
e. ground peat moss
f. ground decomposed moss peat

Modified Benelux procedure for peat:
1. dried and ground grass
2. dried and ground lucerne
3. straw and straw compost
4. farmyard manure
5. cattle slurry
6. different peats

Size of the Fractions

From Fig. 2 it can be seen that the OM_{nh}-values for FYM and cattle slurry are 50 and 42%, respectively with 46% as an average. The corresponding OM_r-value is 49. The analytical data are means of widely varying values for a few dozen samples. More data concerning OM_{nh}, N_m and the calculated values for OM_r, OM_e, N_r and N_e are reported in Table 1. In some cases the figures refer to only a very

Table 1. Contents of different organic matter and nitrogen fractions in manures, expressed as percentages of OM_t and N_t, respectively.

	N_m	OM_{nh}	OM_r	OM_e	N_r	N_e
FYM	10	46	49	51	44	46
Cattle slurry	50	46	49	51	25	25
Poultry slurry	54	34	30	70	14	32
Pig slurry	51	35	31	69	15	34
Liquid manure	94	46	49	51	3	3

few samples.

As could be expected, the slurries show higher N_m-contents than the solid material, whereas liquid manure shows the highest percentage. The fractions N_r and N_e are about the same in cattle waste, but not in the two other types.

Availability of the Three Nitrogen Fractions

In comparing the effect of nitrogen in manure with that in fertilizer it is customary in the Netherlands to use the 'efficiency index' (e.i.). An e.i. of x% means that the effect of x kg fertilizer-N (applied in the spring) equals that of 100 kg manure-N.

As has been said before, N_m is equally available to the plant as fertilizer-N. Its e.i. therefore ought to be 100. However, it often has been observed that during or shortly after application some 20% of this fraction volatilizes. Therefore the e.i. is fixed at 80. It will be clear that this figure is only valid for a spring application of the manure.

N_e, though called easily available, is only effective as far as it is released before the end of the growing period of the crops. In constructing Fig. 3, valid under conditions in the Netherlands, it has

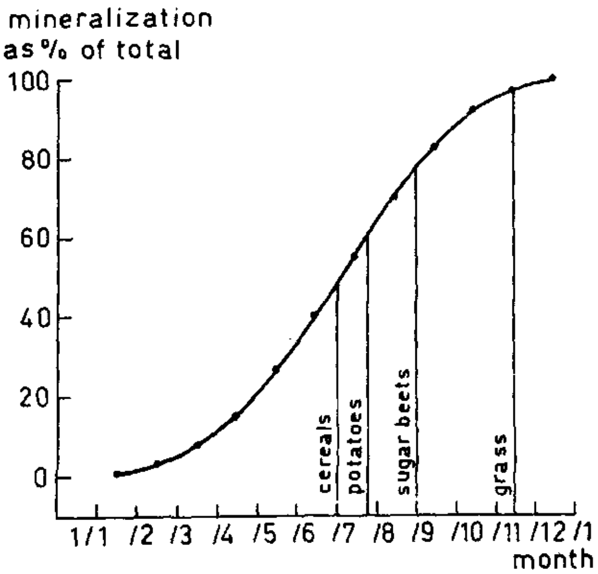

Fig. 3. Mineralization as a percentage of total mineralization on the basis of mean monthly 24-hour temperature in °C.
Monthly mean sum over a year showing 24-hour temperature of the air: 112.1 °C = 100%.

been assumed that mineralization is proportional to the average monthly day-temperature, the year-sum of these averages having been put at 100%. It is also indicated at which points in time the N-uptake by the crops ends. As is shown, cereals can pick up 50% of N_e at the utmost, potatoes and beets about 70%, whereas permanent grassland may utilize N_e for more than 90%. Since fertilizer-N, applied before or in the beginning of the growing season, can be utilized for 100%, the e.i. of N_e lies between 50 and 90%. Under Dutch conditions the manure is often preferably given to root crops, in which case the effect of N_e can be expressed as an e.i. of 70%. If used for all crops in a rotation which includes as many cereals as root crops, the e.i. of N_e will be closer to 60%.

N_r naturally can only show any effect on crop growth in the second and later years after application. According to Fig. 3, 60% of the yearly mineralized portion will be effective, assuming again as many cereals as root crops in the rotation. The question remains which portion of N_r is mineralized annually.

Fig. 4 in which the upper curve of Fig. 1 has been copied, gives us the key to the solution. In the second year after application a percentage a_2 of the organic matter will decompose, in the third year a_3, in the n-th year a_n. If dressings of the same size are repeated year after year, as is to be expected in regions of intensive annual husbandry, the total mineralization of residual organic matter in the n-th year after the beginning of this manuring regime will be $a_2 + a_3 + \ldots\ldots\ldots + a_n$. Assuming that all of the organic matter in manure is decomposable, a steady state will ultimately be reached, in which the total mineralization of residual organic matter amounts to OM_r, which for FYM amounts to 50% of the annually applied quantity of fresh organic matter. It will be clear that in this situation each year an amount of N_r, originating from OM_r, will be released. The e.i. of this nitrogen is 60%.

Of course it takes time before the equilibrium level is reached. From Fig. 1 we calculated Fig. 5, in which the genesis of the final situation is represented. After the start of a certain manuring regime it will take about 5 years before 40% of the final amount that will be released annually by the residual organic matter, is mineralized, and it will take 20 years and about 40-50 years to attain 70 and 90%, respectively.

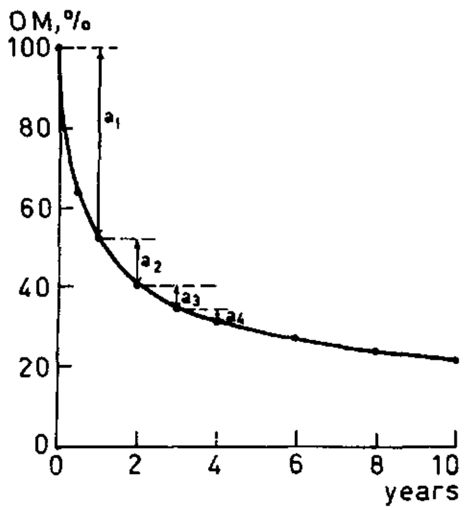

Fig. 4. Decomposition of organic matter in farmyard manure under field conditions as in Fig. 1.
a_1 = decomposition in the first year, a_2 in the second year, etc.

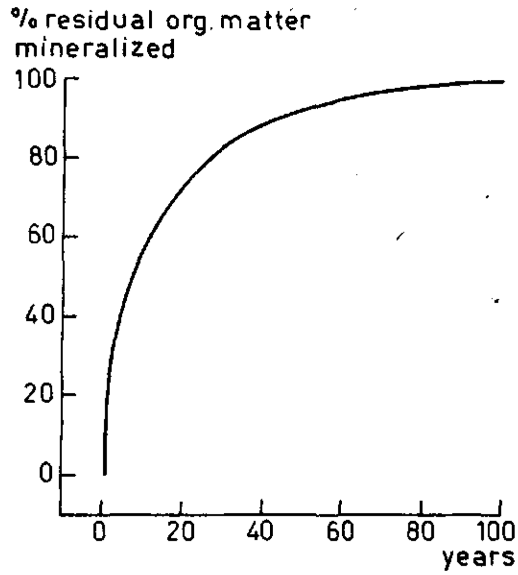

Fig. 5. Rate of mineralization of residual organic matter as a percentage of annual supply of residual organic matter.

The Integral Effect of the Three Fractions

The e.i. of N_m has been taken to be 80%, that of N_e 70% (if there is a preference for application to root crops) and that of the yearly mineralized portion of N_r 60%. In the situation of repeated dressings this portion will finally add up to an amount corresponding to N_r.

In taking N_m, N_e and N_r as percentages of the total nitrogen in the manure, the integrated first-year effect of 100 kg N of a single manure dressing will correspond to that of $0.8 \times N_m + 0.7 \times N_e$ kg fertilizer-N. Naturally there is no effect of N_r in this first year. Annually repeated dressings of the same magnitude should, according to the explanation given before, lead to an annual effect corresponding to $0.8 \times N_m + 0.7 \times N_e + 0.6 \times N_r$ kg fertilizer-N. However, in this calculation that part of the nitrogen is left out of consideration which is mineralized after harvest; this may remain during winter and therefore show an after-effect. On the basis of data of Van der Paauw and Ris (1963) this after-effect equals roughly that of 10% of the same amount of freshly applied fertilizer-N, so its e.i. is fixed at 10%. It stands to reason that the size of this effect depends on climate conditions. The e.i. of 10% is valid for the moderate, marine climate of the Netherlands. Since on the average 30% of N_e mineralizes after crop harvest, the after-effect of this component will correspond to that of $0.1 \times 0.3 \times N_e$ kg fertilizer-N. For N_r, of which 40% mineralizes late in the season, it is calculated at $0.1 \times 0.4 \times N_r$ kg fertilizer-N.

The integral annual nitrogen effect of manure, expressed as an e.i., therefore is (under the climatic and crop planning conditions of the Netherlands):

in the first year of application of a single dressing

$$0.8 \times N_m + 0.7 \times N_e$$

in the long run, with repeated dressings of the same magnitude

$$0.8 \times N_m + 0.73 \times N_e + 0.64 \times N_r$$

The nitrogen in pig slurry, as an example, contains N_m-, N_e- and N_r-fractions of 51, 34 and 15%, respectively. The effect of a single dressing of 100 kg N in this manure will correspond to that of $0.8 \times 51 + 0.7 \times 34 = 65$ kg fertilizer-N in the first year. Continuous use of the slurry leads to a final situation, in which the nitrogen supply to the crops corresponds to $0.8 \times 51 + 0.73 \times 34 + 0.64 \times 15 = 75$ kg fertilizer-N per 100 kg manure-N.

Let us assume that the manure of 50 pigs, which is estimated at 80 tons containing 560 kg total N, is continuously applied to one and the same ha. Then ultimately this soil will supply an amount of nitrogen corresponding to $0.75 \times 560 = 420$ kg fertilizer-N. That quantity would be far too great for many crops. About 364 kg of those 420 originate from the last fresh dressing (65% of 560 kg), the remaining 56 kg N from earlier ones. As soon as the manuring is stopped, the supply will drop to 56 kg N per year, naturally in addition to residual nitrogen from other sources. In later years the subsequent release will of course decrease gradually.

As a consequence of the differences in composition of manures there is considerable variation in efficiency indices, at least with respect to the first year; The materials, having a relatively large N_m-fraction, will show a high e.i. in the first year and a small after-effect. The opposite can be expected of manures with a relatively low N_m-content. Fresh FYM of cattle has, according to our calculation model, in the year of application an e.i. of $0.8 \times 10 + 0.7 \times 46 = 40\%$, whereas liquid manure of the same animals has an e.i. of $0.8 \times 94 + 0.7 \times 3 = 77\%$. The nitrogen effect of continuously repeated dressings of both types of manure will finally lead to e.i.'s of 70% and 80%, respectively. Thus it can be concluded that, when different manures are applied on the basis of equal amounts of nitrogen, their short-term effects will vary considerably with varying N_m-contents, but much less so if manuring has been practised already for a long period of time. In that situation the fresh dressing and the residues of earlier ones together will deliver an almost equal amount of N to the crops regardless of the kind of manure. The richness of the soil will be higher where the manures with the low N_m-contents have been used.

DISCUSSION

It is tempting to claim that the model, presented in this paper can be used for the calculation of the first-year and after-effect of nitrogen in manure irrespective of its origin, treatment and storage. The only thing to be done is to determine N_m and OM_{nh} (as percentages of N_t and OM_t, respectively) and then N_e and N_r can be calculated. The e.i. of the manure-N follows from the equations given. No further experimental work seems to be needed to give a decisive answer to the question of the nitrogen effect of any kinds of animal manure. Wishful thinking could lead to acceptance of the model as applicable even to other organic manures.

However, there are weak points in our argumentation. The fact that the relation between OM_r and OM_{nh} (Fig. 2) has been established only for cattle manure and quite different organic materials but not for wastes from other animals, we consider to be of minor importance. For if the relation for strongly different materials is as close as is shown, there is hardly any doubt about its relevance to all types of animal manure.

Decidedly the weakest point is the assumption that the nitrogen content of the easily decomposable part of the organic matter in animal waste equals that of the more resistant part. An assumption of this nature had to be made since no values for N_r or N_e are available. Perhaps a thorough investigation of literature would yet yield suitable data. If not, it seems desirable to set up experiments to obtain such information. Of course a different assumption could have been made, for instance, that the nitrogen content of the resistant fraction (OM_r) equals that of the non-hydrolyzable fraction (OM_{nh}). Since, however, the latter according to our experience varies with the method of hydrolysis, we do not have much confidence in that supposition. As a matter of fact, we based our choice on the fair agreement existing between the so calculated and the experimentally established efficiency indices of at least some types of manure. We will demonstrate this below.

The model is certainly not simply applicable to organic materials that induce microbiological fixation of nitrogen during their decay if this takes place during the growing season. Such fixation has been observed for straw shortly after it was ploughed down, but might also occur in some manures particularly those which were mixed with a considerable amount of easily decomposable litter or bedding material with a high C/N ratio. Under these circumstances the e.i. of N_m and N_e will be lower than our model suggests. A solution for this problem could possibly be found by introducing the C/N ratio in some way into the model.

A last point is the use of Fig. 4, in which the mineralization of nitrogen is said to be proportional to the averaged monthly temperature. This assumption naturally is disputable.

There is therefore more than one reason pleading for an experimental confirmation of the predictions calculated on the basis of the model. Relevant data in terms of efficiency indices or comparable figures have been published in reviews by Kolenbrander and De la Lande Cremer (1967) and by Cooke (1972).

The first authors presented the data in Table 2, all referring to the first-year effect.

Probably the best founded value in this table is the figure of 40% for fresh farmyard manure applied in spring to arable crops. Calculated on the basis of the data of Table 1 the e.i. in the first year is $0.8 \times N_m + 0.7 \times N_e = 40\%$, which thus is in full agreement with the experimental result. For liquid manure, cattle slurry and poultry manure the calculated e.i.'s are 77, 57 and 66%, respectively, which values show a satisfactory agreement with the experimental results as well, at least if compared with the figures for spring application to arable crops. If the materials are applied before the winter, part of the nitrogen, particularly of the fraction N_m, will leach, so lower e.i.'s will be found. The lower effects on grassland arise as a consequence of volatilization since the manure cannot be ploughed down.

Table 2. Efficiency indices of nitrogen in manure (%)

Type of manure	Time of application	Arable land	Permanent grassland
Liquid manure	Spring	80	70
	Autumn	40	35
Slurry of cattle	Spring	50	35
	Autumn	25	20
Farmyard manure	Spring	40	20
	Autumn	20	10
Poultry manure	Spring	65	40
	Autumn	35	20

So the deviations from the calculated values are more or less well understood.

Cooke (1972) estimates the first-year effect of 25 tons of farmyard manure (containing about 150 kg N) at 40 kg fertilizer-N, which means an e.i. of 27%. If this can be considered as an average for autumn and spring application, it agrees reasonably well with the Dutch data. For poultry manure, used in spring, an e.i. of 50% is mentioned, which seems a little low. Since it was applied to grassland, part of the nitrogen may have volatilized. With regard to kiln-dried poultry manure, Cooke reports e.i.'s of between 53 and 100%, depending on the crop it was used for. Without knowing anything about N_m and OM_{nh}, it is hard to say whether these e.i.'s could have been expected on the basis of our model. In slurries, the nitrogen is said to be half or more of the value of fertilizer-N, at least if applied late, say March. This is again within the limits of the calculated expectations.

Only few data have been reported on the size of the after-effect. Kolenbrander and De la Lande Cremer (1967) report a second-year effect of farmyard manure of 10%, which means that 100 kg N in this manure has the same effect in the second year as 10 kg fertilizer-N applied in the spring of the second year. In Britain, organic nitrogen fertilizers other than blood, are assumed to have half of their original value after one crop has been taken and one quarter after two crops (Cooke, 1972).

According to our model, the second-year effect when related to the first-year effect, will strongly depend on the amount of N_m. If this amount is high, the after-effect is probably relatively low. So the British rule of thumb seems to be too broad a generalization. According to Fig. 1 50% of the organic matter in FYM is mineralized in the first year and another 13% in the second year. The first-year effect is $0.8 \times N_m + 0.7 \times N_e$ = 40%, the second-year effect is thus calculated at $13/50 \times 0.6 \times N_e$ (not 0.7 since this only holds for root crops), that is 7%. This is in rough agreement with the e.i. of 10% mentioned in the Dutch review, but somewhat less so with the British finding, according to which the e.i. in the second year sould be half of the first-year e.i. of 27% mentioned earlier.

Summarizing it may be stated that there is evidence pointing to the usefulness of the model presented, particularly for the calculation of the first-year effect. In order to provide a better picture of the degree of agreement between calculated and experimental results, specifically with regard to the after-effect, a more thorough investigation of literature would be necessary. However, it appears doubtful that suitable experimental results will be found.

Acknowldegement

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