Mushroom Science IX (Part II)
Proceedings of the Ninth International
Scientific Congress on the Cultivation of
Edible Fungi, Taipei, 1974

THE SUPPLEMENTATION OF HORSE MANURE COMPOST AND SYNTHETIC COMPOST WITH CHICKEN MANURE AND OTHER NITROGEN SOURCES

J.P.G. GERRITS

Mushroom Experimental Station
Horst (L), the Netherlands

INTRODUCTION

The history of mushroom research shows a lot of work on the clarification of the role of nitrogen in the compost (reviews by Bohus, 1959; Flegg, 1961 and further MacCanna, 1969; O'Donoghue, 1967; Bech and Rasmussen, 1969). Later on the carbon sources were also taken into consideration to an increasing extent (Gerrits et al., 1967; Hayes and Randle, 1967). Many research workers have analyzed compost (Grabbe, 1972) to look for a relationship between some factor and mushroom yield. This is difficult because a compost is such a complicated chemical and physical system. The C/N ratio of the compost is often used as an important figure to characterize a compost. As the C/N ratio is considered to be the ratio of all the carbon to all the nitrogen in the compost; in fact this representation of the matter is too simple. The total amount of carbon includes all kinds of carbon from readily available to available with great difficulty. The same applies to the nitrogen which is present partly as ammonia, partly as protein and other organic forms and a part may even be fully immobilized for the microorganisms as it is incorporated in complex molecules. For the activity of the microorganisms the total C/N ratio is of much less importance than the amounts of C and N actually available at any given moment and the relative proportions of the available carbon and nitrogen. This can be called "available" C/N ratio as distinct from the "total" C/N ratio. It seems likely that normally there will be a certain relationship between the total and "available" C/N ratio. If there is very little nitrogen (wide C/N ratio) there will be little ammonia and if there is a lot of nitrogen (narrow C/N ratio) there will be a high concentration of ammonia in the compost. Because ammonia is very readily available it will greatly influence the "available" C/N ratio and its concentration will be particularly important for the activity of the microflora.

Together with the amount of water the concentration of ammonia is of primary ecological importance. This statement must be explained as follows. The amount of water, directly important for the microflora, defines together with the structure of the compost pile the amount of air in the pile and the ventilation of the pile.

The oxygen pressure and the total nitrogen content are important for the amount of ammonia that will be set free by the microorganisms. This influences the "available" C/N ratio. So water, oxygen, carbon dioxide and free ammonia ultimately define the activity in the pile. This complex has also been studied by Laborde et al. (1972a, b,) and Tschierpe and Sinden (1962). The production of ammonia increases the pH, while the carbon dioxide produced by the developing microflora in turn neutralizes the pH to some extent. Allison and Kneebone (1962) have already studied the influence of compost pH on mushroom production, but the dependence of the pH on the ammonia content was not mentioned. High temperatures in the pile caused by the microflora growing under optimum conditions have a beneficial effect on the ventilation of the pile and therefore on the oxygen supply of the microorganisms. This influences ammonification and in this way several factors are dependent on each other and influence each other. It is very difficult indeed to describe what is exactly going on in a compost pile. I have paid a lot of attention to the influence of the primary ecological factors water and ammonia, because it is likely that these factors play a deciding role in the composting process and will greatly determine the nature of the microflora and what the quality of the compost will be. In soil microbiology (Parkinson and Waid, 1960; Gray and Parkinson, 1968) the kind of species present is not always important but rather the function of a physiological group as a whole. Within such a group with a special function the kind of species can vary. In this paper primarily the influence of some ecological factors on mushroom production has been studied. It is likely that differences in the composition of the microflora could have been found depending on the treatment of the composts, but we did not study it.

Two composts with quite a different microflora could produce the same yield, whereas two composts with the same microflora could give different yields. This is so, because bacteria, actinomycetes and fungi can in part have the same physiological behaviour (e.g. cellulolytic activity) whereas the same microorganisms can react differently under different (e.g. aerobic or anaerobic) conditions. In my opinion mushroom yield depends more on the nature of the ecological factors (e.g. water and ammonia) than on the species of microorganisms developing in the compost under definite conditions. The ecological factors will determine the composition and the ultimate result of the activity of the microflora as a whole. If the influence of the ecological factors is known it could be significant to study the composition of the compost microflora under several conditions. For this work these conditions would have to be well defined. In this paper chicken manure and urea are added to fresh horse manure in various quantities to find the optimum amount to be added to the compost. To get an idea about the "available" C/N ratio, ammonia was determined in most of the composts. In previous work (Gerrits, 1970) it has already been shown that several organic N-sources can be used in the compost and interchanged without adverse effects. In this paper this will be proved by one more example. The results will be discussed and compared with similar work on synthetic compost published recently (Gerrits, 1974).

MATERIALS AND METHODS

The compost was prepared according to the scheme -3, 0, 4, 7, 8. On day -3 the fresh horse manure was wetted with an amount of water dependent on the moisture content of the fresh manure and if urea was used it was added at this time. The quantity of water added was derived from previous work (Gerrits, 1972).

The amount of chicken manure greatly affects the amount of compost produced from one ton of horse manure and also the amount of water required to achieve a certain moisture content. In this work (Gerrits, 1972) this is only checked for 100 kg of chicken manure per ton of horse manure. As a rule for each 100 kg of chicken manure about 150 l of water have to be added. The amount of compost that can be prepared from one ton of horse manure increases by 150 kg for every 100 kg of chicken manure added. There is a difference between the addition of supplements per ton of fresh manure and per ton of compost. In our experiments 100 kg of chicken manure per ton of horse manure equalled 85 kg of chicken manure per ton of compost, because 1 ton of horse manure with 100 kg of chicken manure on average produced 1185 kg of compost. On day 0 chicken manure or other organic material was added, on day 4 25 kg of gypsum per ton was given, on day 7 there was another turning and on day 8 the trays or shelves were filled with exactly 100 kg of compost per m^2. Generally there was a 10 day peak-heating period and the mycelium growth lasted for 12 days. The mushrooms were harvested for 5 weeks and all the yields in this paper are expressed as kg cut mushrooms picked in 5 weeks per m^2 and per 100 kg of compost.

The average composition of the chicken manure was: 38% moisture, 13% ash, 49% organic matter, 2.3% P_2O_5, 22.0% C, 2.4% N and the C/N ratio was 9.2. The chicken manure came from broilers held for 7 weeks in the pen on wood shavings. The pH was 8.4 and 30-60% of the nitrogen was present as NH_4. The fresh horse manure was supplied by the Compost Enterprise of the CNC (Cooperative Dutch Mushroom Growers Association) at Ottersum. The average moisture content of the different batches of fresh horse manure (10-20 determinations per batch making 250 determinations in total) was 63.5% varying from 58-68%.

The average standard deviation per batch was 4% ranging from 2-10% according to the homogeneity of the manure. The average density was 375 kg/m^3 with a considerable variation from about 200-500 kg/m^3 for light or heavy manure respectively. All the supplements were given per ton of fresh manure independent of the variation in moisture content. The reason that the variation in moisture content was not taken into consideration was argued in previous work (Gerrits, 1972), where the necessity of eliminating all possible sources of variation was pointed out. A very wet manure can in fact be very poor if it is wet through rainfall and not through urine of the horses. In fact the addition of dry matter of chicken manure per ton of dry matter of horse manure varied from 15-21% with an average of 16.8% according to the variation in moisture content of the two types of manure.

The experiments were carried out either in experimental plots in shelves of 1.3 m^2 in growing houses of 120 m^2 or in trays of 0.27 m^2 in growing houses of 25 m^2 both treated as a one-zone system. In the houses there were 5 layers with 16 plots or 18 trays in one layer. In most of the experiments factorial designs were used such as a 2^4 or a 4x2x2 or a 2x3x3 layout with 4 or 5 replicates. The layers were considered as blocks and the treatments were randomized in the layers.

In fresh samples of compost ammonia was distilled off in the presence of magnesia (MgO) to determine the ammonia content of the compost. This ammonia is expressed as % NH_4 in the dry matter. In dried, finely-ground samples (0.5 mm mesh) ash was determined by burning at 600°C, carbon by burning the samples and weighing the CO_2, and nitrogen according to the Kjeldahl method.

RESULTS

Various kinds of organic matter

In recent decades a good deal of attention has been paid to the supplementation of mushroom compost with organic materials such as malt sprouts, brewers' grains, cotton seed meal, alfalfa meal, wheat bran and sugar beer pulp. In earlier studies (Gerrits, 1970; 1974) it was shown that all these materials have exactly the same effect when added to a compost. They can even be replaced by chicken manure, a much cheaper material, especially if it is supplied fresh. However, the amount of chicken manure added should contain exactly the same amount of organic matter and nitrogen as the other materials, in other words it is necessary to add a certain amount of readily available organic matter with a definite C/N ratio.

In an additional experiment (269) five organic materials were compared to prove this once more. To all composts 3.5 kg of urea and 25 kg of gypsum were added. The results are shown in Table 1. The supplemented composts gave a slightly better yield than the control, but there is no difference between the organic materials used.

Table 1. Comparison of five organic materials added per ton of fresh horse manure (Exp. 269).

Supplement	Yield (kg/m^2)
No supplement	12.7
Chicken manure (100 kg/ton)	14.1
Malt sprouts (50 kg/ton)	13.3
Cotton seed meal (50 kg/ton)	13.8
Wheat bran (50 kg/ton)	13.5
Sugar beet pulp + urea (50 + 3 kg/ton)	13.0

This equivalence of chicken manure and the other organic materials does not mean that these materials are fully identical, but only that they have the same effect on yield if they are added to a compost and are composted together with the horse manure. So many substances are broken down and built up again during composting that at the end of composting it makes no difference for the mushroom what kind of available material was added as long as the total quantity is the same. It is unlikely that these materials also have identical effects in a non-composted substrate like the Till-substrate (Huhnke et al., 1967).

Quantity of chicken manure

An important question already raised in previous work (Gerrits, 1970) is how much chicken manure has to be added to a ton of fresh horse manure to get an optimum yield? This question is very difficult to answer for individual shipments of horse manure but on average one can get an idea after performing a series of experiments with various kinds of horse manure as is shown in Table 2. Quantities of 0, 50, 100 and 150 kg of chicken manure were added to the different kinds of horse manure. The results of the experiments 86-94 were already mentioned in previous work (Gerrits, 1970).

In the experiments 86, 88 and 90 various combinations of malt sprouts, cotton seed meal, sugar beet pulp and chicken manure were given, but because no difference exists between the four materials all the organic matter is converted as if only chicken manure was given. In experiments 121 and 124 0, 60, 120 and 180 kg of chicken manure was added instead of 0, 50, 100 and 150 kg because in the two experiments the chicken manure was a little wetter than normal. The average moisture content of the chicken manure in these experiments was 38%. There is a great variation in the amount of chicken manure which is optimum; 50 kg was optimum in 5 experiments, 100 kg in 3 experiments and 150 kg in two experiments. On average the optimum quantity of chicken manure is 100 kg per ton of fresh horse manure but with 50 kg or 150 kg the yield is only slightly reduced. In these experiments the amount of water in the compost was not sufficiently increased with increasing amounts of chicken manure and therefore the moisture content of the composts with a lot of chicken manure was lower than with little chicken manure as is shown in the last line of Table 2.

Table 2. Effect of various quantities of chicken manure added per ton of horse manure on yield (in kg/m²).

Exp.	Chicken manure (kg/ton)			
	0	50	100	150
86	8.9	11.6	14.0	12.6
88	10.0	10.5	12.6	15.4
90	10.7	13.0	11.6	8.8
93	12.4	14.1	15.4	14.6
94	12.7	15.1	16.9	16.6
109	13.7	16.2	18.2	20.2
121+	18.8	20.4	18.5++	16.8
124+	12.2	14.7	13.2	13.4
233	17.6	19.1	18.0	15.4
234	16.9	18.8	18.1	17.8
Mean	13.4	15.4	15.7	15.2
g/kg DM	517	569	560	539
% Moisture (filling)	74.1	72.9	72.0	71.8

+ In these experiments 0, 60, 120 and 180 kg of chicken manure were used.

++ Yield corrected because the compost was too dry giving rise to a strongly decreased yield.

Calculated as grams of mushrooms per kg dry matter at filling 50 kg of chicken manure is optimum, but there is hardly any difference with 100 kg. For this reason 100 kg of chicken manure per ton of horse manure was used in Dutch practice because it is advantageous to use as much chicken manure as possible because the material is much cheaper than horse manure and therefore the price of the compost decreases.

In later experiments increasing quantities of water were used with increasing quantities of chicken manure (about 1.5 l of water per kg of chicken manure) in order to get composts with equal moisture contents at filling. The conversion of yield per m^2 into yield per kg dry matter in order to give a correction for a variation in moisture content can only be done successfully if the moisture content is in the optimum area (69-73%) because at a higher or lower moisture content not only the yield per m^2 decreases but also the yield per kg dry matter (Gerrits, 1972).

Effect of urea

Several years ago the effect of 3.5 kg urea per ton of compost on yield was studied in three experiments. In these experiments 14 kg of cotton seed meal and 10 kg of malt sprouts were added corresponding with 50 kg of chicken manure. Also the effect of gypsum was studied in these experiments, but this will not be discussed here because the results of gypsum have already been published (Gerrits, 1970). The results with urea are given in Table 3 in kg/m^2.

Table 3. Effect of urea on yield in three experiments.

Gypsum (kg/ton)	Urea (kg/ton)	Yield (kg/m^2) Exp. 76	Exp. 77	Exp. 78
0	0	10.4	6.4	13.1
25	0	12.7	6.5	14.7
0	3.5	11.8	6.2	11.2
25	3.5	14.1	8.1	14.2
Urea effect		+ 1.4**	+ 0.7⁻	- 1.2**

\- = Effect not significant
** = Effect significant at the 1% level.

In the experiments 76, 77 and 78 we found an increase, no significant effect and a decrease of the yield respectively after addition of 3.5 kg of urea per ton. Studying the sequence of temperature during composting in these experiments more carefully it was shown that there is an increase in yield if the temperature during composting rises after the addition of the urea, that there is no influence on yield if addition of urea does not change the temperature and that there is a decrease in yield if the temperature decreases after the addition of 3.5 kg of urea.

This points to the significance of a definite concentration of ammonia in the compost heap during the composting process. If too little ammonia is present it is beneficial if the ammonia level is increased by the addition of urea; if the ammonia level is nearly satisfactory, there is no effect of urea and if the ammonia level is already too high, addition of more ammonia added as urea is disadvantageous. (Urea is immediately split into ammonia and carbon dioxide if it is added to a compost).

This idea had to stay as a theory because the ammonia concentration in the compost was not determined at that time. If the idea is right then there has to be a difference between the addition of urea in the presence of little or a lot of chicken manure. At high levels of chicken manure it must be harmful and with no chicken manure added to the compost it must be favourable.

Table 4. Comparison of the effect of urea and calcium ammonium nitrate (Exp. 304).

Chicken manure (kg/ton)	Urea (kg/ton)	Calcium ammonium nitrate (kg/ton)	Yield (kg/m^2)
0	0	0	18.0
100	0	0	20.6
0	3.5	0	19.5
100	3.5	0	21.2
0	0	7	19.5
100	0	7	22.2

Effect of calcium ammonium nitrate

In exp. 304 3.5 kg of urea was replaced by 7 kg of calcium ammonium nitrate, so that the same amount of nitrogen per ton of compost was added. Ammonium sulphate has already been used in other work (Bech and Rasmussen 1969). The advantage of calcium ammonium nitrate over ammonium sulphate is that in the former both the ammonium and the nitrate part of the molecule can be used by the thermophilic microflora as a N source, while in the latter only the ammonium ion is used. The sulphate ion has to be neutralized by calcium carbonate (Bech and Rasmussen, 1969; Gerrits, 1970). At filling hardly any nitrate was present in the compost so either it has been used by the microflora or denitrified in anaerobic parts of the compost heap. The last possibility is not very likely because a compost heap is not a strong anaerobic environment. Table 4 shows that both urea and calcium ammonium nitrate increase the yield by about 1.5 kg/m^2 in the presence or absence of chicken manure.

There is no significant difference between the effect of urea and calcium ammonium nitrate so that both N sources can be used in compost preparation.

Combinations of chicken manure and urea

Eleven experiments were carried out with various combinations of urea and chicken manure. Sometimes large differences in the rate of supplementation were used. The results of these experiments are given in Table 5. This table shows the N content at filling, the percentage NH_4 and the pH at filling and at spawning, the yield expressed in kg/m^2 and as grams per kg dry matter at filling in order to eliminate the influence of the moisture content of the compost. Some interesting relationships can be derived from the data in Table 5.

Through the addition of chicken manure (X_1) and urea (X_2) the NH_4 content (Y), the N content (Z) and also the pH of the compost at filling increases. The relationship between the amount of nitrogen (X_1 or X_2) added and the increase of Y and Z at filling were calculated with the aid of multiple regression. The equations obtained are:

$$Y = 0.00212\ X_1 + 0.0592\ X_2 + 0.217 \quad (1)$$

$$Z = 0.000812\ X_1 + 0.01035\ X_2 + 1.56 \quad (2)$$

The increase of the NH_4 concentration of the compost after the addition of both chicken manure and urea are significant at the 1% level. The increase of the N content after addition of chicken manure is significant at the 1% level as well and the increase after addition of urea is not significant. To visualize the influence of various quantities of chicken manure and urea on the N and NH_4 content of the compost at filling some data derived from the equations (1) and (2) are listed in Table 6. The average N content of the compost without supplements is 1.56% and the ammonia content is 0.22%. However these values vary from horse manure to horse manure as is shown by the data in Table 5.

Table 5. Results of the experiments with combinations of chicken manure and urea.

Exp.	Chicken manure (kg/ton)	Urea (kg/ton)	% N	% NH_4 (filling)	% NH_4 (spawning)	pH (filling)	pH (spawning)	Yield (kg/m²)	Yield (g/kg DM)
237	0	3.5	–	0.39	0.10	7.8	7.4	17.0	641
	100	3.5	–	0.60	0.18	8.1	7.5	19.4	639
245	0	0	·	–	0.02	8.2	7.3	12.4	512
	0	3.5	–	–	0.03	8.1	7.1	13.0	518
	100	0	–	–	0.03	8.3	7.1	16.1	590
	100	3.5	–	–	0.08	8.4	7.1	15.6	598
269	0	3.5	1.46	0.39	–	7.9	7.3	12.7	457
	100	3.5	1.49	0.60	–	8.1	7.4	14.1	445
304	0	0	–	0.23	0.02	8.6	7.6	18.0	717
	0	3.5	–	0.42	0.06	8.6	7.6	19.5	771
	100	0	–	0.42	0.04	8.7	7.7	20.6	755
	100	3.5	–	0.56	0.13	8.6	7.7	21.2	771
325	0	0	1.65	0.14	–	8.1	–	19.4	752
	0	3.5	1.58	0.42	–	8.5	–	22.8	854
	100	0	1.55	0.45	–	8.6	–	23.6	891
	100	3.5	1.61	0.54	–	8.5	–	22.9	792
334	0	0	1.54	0.17	–	8.0	7.4	13.4	491
	0	3.5	1.68	0.40	–	8.0	7.4	18.1	678
	100	0	1.64	0.36	–	8.4	7.5	18.0	684
	100	3.5	1.67	0.56	–	8.5	7.6	18.9	724
293	0	3.5	1.52	0.47	0.04	8.6	7.2	12.0	443
	75	3.5	1.53	0.66	0.03	8.6	7.3	12.6	463
	150	3.5	1.64	0.78	0.16	8.7	7.6	10.4	370
	225	3.5	1.84	0.94	0.22	8.8	8.0	5.6	207
338/339	0	3.5	1.58	0.46	0.17	8.1	7.3	17.6	690
	75	3.5	1.54	0.72	0.50	8.5	8.0	19.2	725
	150	3.5	1.68	1.04	0.56	8.6	8.1	15.5	562
	225	3.5	1.70	1.12	0.54	8.8	8.1	5.9	210
283/284	0	0	–	0.22	0.04	8.1	7.5	8.8	365
	0	3.5	–	0.55	0.38	8.3	8.0	10.4	419
	100	0	–	0.40	0.22	8.5	8.1	10.0	358
	100	3.5	-	0.73	0.52	8.5	8.1	9.2	336
	200	0	–	0.60	0.42	8.5	8.2	8.1	295
	200	3.5	–	0.97	0.58	8.6	8.4	2.5	90
	300	0	–	0.76	0.38	8.8	8.3	1.0	34
	300	3.5		1.05	0.76	8.7	8.4	0.1	3
299/300	0	0	1.76	0.26	0.04	8.4	7.8	5.7	219
	0	3.5	1.73	0.63	0.30	8.4	7.9	6.8	278
	0	7	1.78	0.95	0.41	8.7	8.2	7.8	311
	100	0	1.77	0.60	0.14	8.7	8.1	5.6	216
	100	3.5	1.83	0.83	0.41	8.8	8.0	6.0	227
	100	7	2.03	0.87	0.55	8.9	8.4	4.1	164
	200	0	1.87	0.91	0.45	8.9	8.5	1.7	64
	200	3.5	1.90	1.02	0.72	8.7	8.6	0.2	8
	200	7	2.06	1.39	0.80	8.9	8.5	0.2	8
315/316	0	0	1.57	0.06	0.03	7.7	7.6	10.4	441
	0	3.5	1.50	0.32	0.06	8.2	7.3	12.8	538
	0	7	1.58	0.43	0.16	8.2	7.4	13.0	558
	100	0	1.69	0.26	0.04	8.3	7.5	13.8	559
	100	3.5	1.65	0.34	0.07	8.3	7.3	15.6	607
	100	7	1.43	0.58	0.30	8.4	8.0	15.9	614
	200	0	1.58	0.50	0.20	8.6	8.0	16.4	646
	200	3.5	1.64	0.51	0.15	8.6	7.9	16.5	627
	200	7	1.76	0.53	0.28	8.4	8.0	15.2	503

Table 6. Percentage of nitrogen (Z) and NH_4 (Y) (in brackets) in the compost at filling prepared with various amounts of chicken manure (X_1) and urea (X_2) as derived from the equations:

$$Y = 0.00212\,X_1 + 0.0592\,X_2 + 0.217$$
$$Z = 0.000812\,X_1 + 0.01035\,X_2 + 1.56$$

Chicken manure	Urea (kg/ton)		
(kg/ton)	0	3.5	7
0	1.56(0.22)	1.60(0.43)	1.63(0.63)
100	1.63(0.43)	1.67(0.64)	1.70(0.84)
200	1.70(0.64)	1.74(0.85)	1.78(1.05)
300	1.78(0.85)	1.81(1.06)	1.85(1.26)

The effect of 100 kg of chicken manure and 3.5 kg of urea per ton of horse manure on the nitrogen and ammonia content is about the same, although theoretically the effect of 3.5 kg of urea should be slightly less.

Gerrits et al., (1967) have already shown that the N content and the C/N ratio during composting converge towards a definite value. Recently (Gerrits, 1974) this was clearly demonstrated again for synthetic compost. In Fig. 1 the N content at the beginning of composting is plotted against the increase or decrease of this value during the composting process. If the initial N content is lower than 1.5% it increases and if it is higher it decreases. At a N content of 1.5% the percentage of N stays at the same level. The ammonia content at filling is not taken into account in Fig. 1. The reason for the increase or decrease of the N content is that the more nitrogen is added the more is lost. In Fig. 2 the amount of nitrogen per ton of horse manure at the beginning of composting is plotted against the nitrogen lost. The points with the straight line indicate the loss if the ammonia N at filling is included in the calculation and the circles with the dotted line if ammonia N at filling is excluded from the calculation. The increasing difference between the lines indicates that the more initial N is present the more N stays as ammonia and is not incorporated in microbes. Starting with 5 kg 1 kg is lost and starting with 15 kg 7.5 kg, the variation in the amount of N at filling being limited to only 4-7.5 kg (calculated per ton of fresh horse manure).

If nitrogen in the compost is determined the samples are mostly dried before they are analyzed. During this drying process most of the ammonia disappears. This means that the N percentage at filling as it is used throughout in mushroom literature is not a very useful figure to characterize a

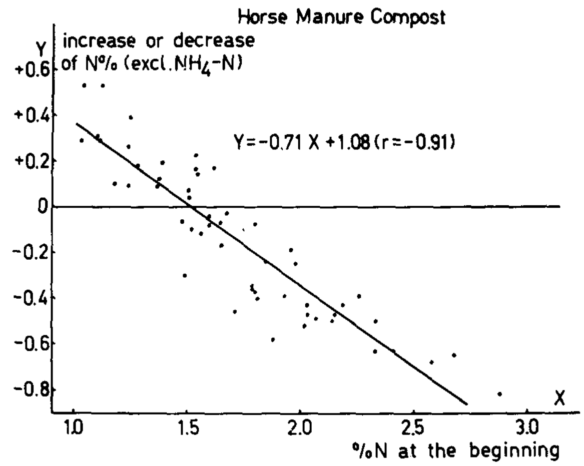

Fig. 1. Relationship between the percentage of N at the beginning of composting and the increase or decrease of the N content during the composting process (The ammonia-N at both stages is excluded from the calculation).

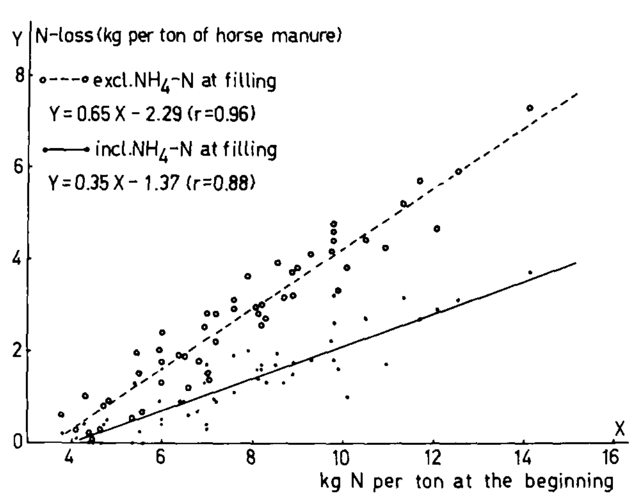

Fig. 2. Relationship between the amount of N present at the beginning (kg per ton of fresh horse manure plus supplements) and the loss of N during the composting process (points and straight line: including ammonia – N at filling; circles and dotted line: excluding ammonia at filling).

compost. This is also the reason why it is very difficult or impossible to find a relationship between the N% and the yield (Gerrits et al., 1967). However the more nitrogen is given during composting the more ammonia is left in the compost at filling.

This was found by determining the ammonia concentration in a large number of fresh compost samples.

In Fig. 3 it is shown that there is a straight-line relationship between the N content of the starting material and the concentration of NH_4 at filling. It will be shown below that the ammonia content is very important for the quality of the compost and that it is even more important to know the NH_4% than the N%. If only N is determined by the Kjeldahl method it is possible to get an idea of the total N% (including NH_4) by applying oxalic or tartaric acid to the compost before the samples are dried, to fix the free ammonia. This is illustrated in Table 7. The nitrogen contents determined after drying with oxalic acid are higher than without oxalic acid. The difference is approximately equal to the amount of NH_4-N except at higher concentrations of NH_4-N. Perhaps more oxalic acid should be added at high ammonia levels to fix all the ammonia. Dureau and Delmas (1962) also recognized this problem.

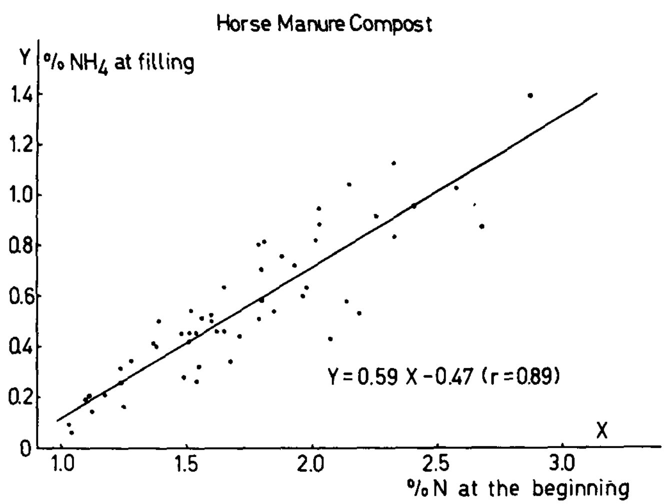

Fig. 3. Relationship between the percentage of N at the beginning of composting and the percentage of NH_4 in the compost at filling.

Table 7. Effect of the addition of oxalic acid to the compost samples before drying on the nitrogen content.

Exp.	Chicken manure	Urea	NH_4-N	N- oxalic acid	N+ oxalic acid
334	0	0	0.14	1.54	1.63
	0	3.5	0.31	1.68	1.88
	100	0	0.28	1.64	1.83
	100	3.5	0.44	1.67	1.96
336	0	0	0.14	1.49	1.66
	0	3.5	0.32	1.67	1.79
	100	0	0.37	1.70	1.78
	100	3.5	0.53	1.78	1.80

During peak-heating the ammonia is lost by ventilation or incorporated in cell proteins of the microflora. Fig. 4 shows how the ammonia content at spawning depends on the ammonia content at filling after a 9-10 days peak-heating period. If the ammonia content at filling is low it will soon disappear, but if a lot of ammonia is present at filling a relatively large amount will be left behind.

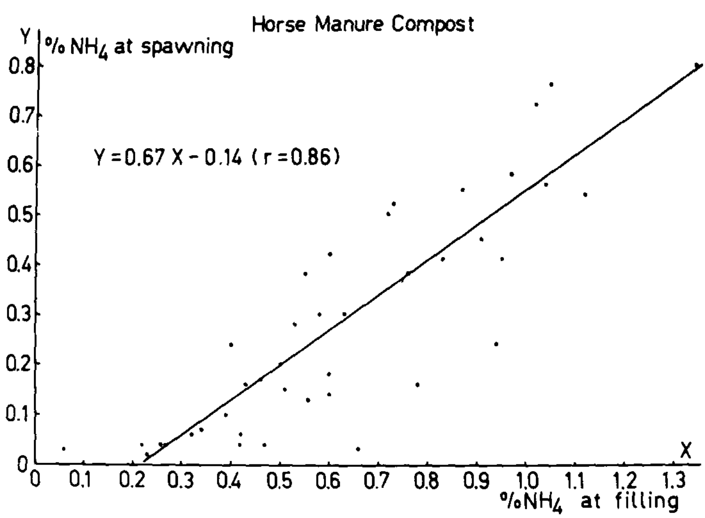

Fig. 4. Relationship between the percentage NH_4 at filling and at spawning.

The pH of the compost decreases during peak-heating as is already generally known (Allison and Kneebone, 1962). Table 5 shows the decrease of the pH during this process. On average the pH falls by 0.6-0.7 units, whether the value at filling is low or high. The fall of the pH shows great variation. The ammonia content of the compost has a large effect on the pH (O'Donoghue,1967). In Fig. 5 the data from table 5 on pH and ammonia content at filling and at spawning are plotted.

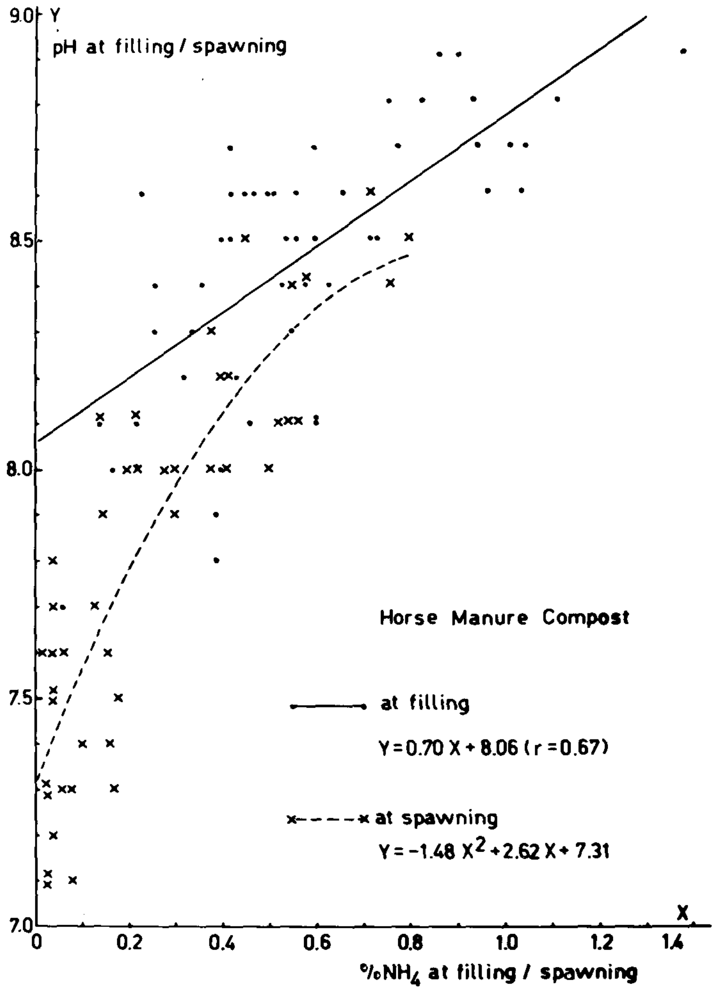

Fig. 5. Relationship between the percentage NH_4 and the pH at filling (points and straight line) and at spawning (crosses and dotted line).

There is a straight-line relationship, significant at the 1% level, between the ammonia content and the pH at filling. A significant curvilinearity in the regression could not be established. However there was a curvilinearity in the regression significant at the 5% level between the ammonia content and the pH at spawning. It should be remarked here that it is difficult to determine the real pH of a compost. There is a great variation between various composts (Table 5). The questions concerning the determination of the pH of a compost will be studied in detail in the near future.

The hypothesis was put forward above that the addition of urea should be beneficial in a poor manure (little NH_4) and harmful in a rich manure (much NH_4). Table 5 shows that this holds for most experiments. In Exp. 315/316 e.g. a poor horse manure was used and in Exp. 283/284 a rather rich one. In both experiments there is an interaction significant at the 1% level between the addition of urea and chicken manure. This shows that an optimum yield can be obtained both with urea or chicken manure. If the data of Table 5 are studied more carefully it proves that the optimum yield is mostly achieved at a certain ammonia content at filling. Therefore

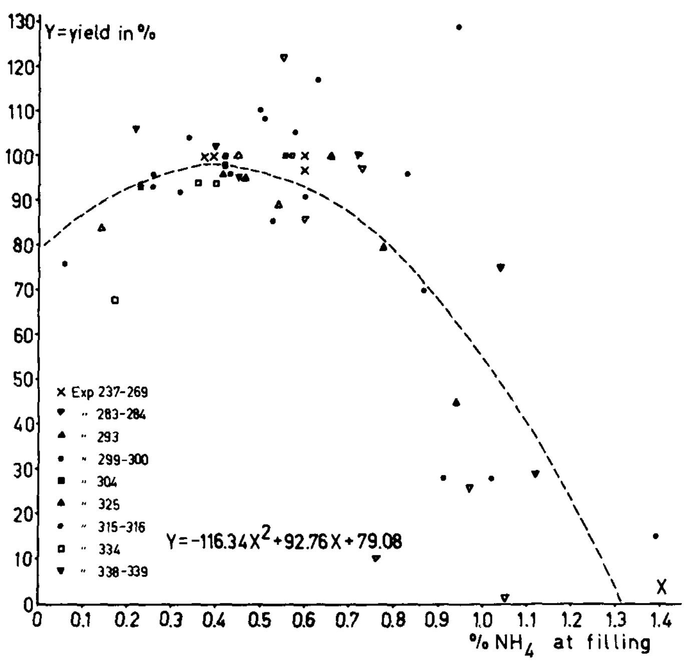

Fig. 6. Relationship between the NH_4-content of the compost at filling and the percentage yield.

an attempt was made to find a relationship between the ammonia content at filling and the yield using all data of Table 5. First of all the variation in the moisture content at filling was eliminated by converting all yields to a standard moisture content of 71%. This is the moisture content found to be optimum (Gerrits, 1972). Because the level of production in the experiments shown in Table 5 varies considerably all yields were converted into percentages. In Fig. 6 the ammonia content at filling is plotted against the percentage yield. A highly significant (1% level) curvilinear relationship (parabola) could be established between the ammonia content and the yield, the optimum NH_4 concentration at filling (top of the parabola) being 0.40%.

Table 6 shows that in an average horse manure the level of 0.40% NH_4 at filling will be obtained if 100 kg of chicken manure or 3.5 kg of urea is added per ton of horse manure. If the horse manure is poorer or richer, more or less of the supplements are required. Chicken manure is much cheaper than urea and more compost can be obtained per ton of horse manure if chicken manure is added. For the preparation of compost therefore only chicken manure is necessary. On the large Dutch compost enterprise in Ottersum the addition of urea has been discontinued from 1973 onwards. It has been the experience of practical growers that peak-heating is now easier and that they can get rid of their ammonia more quickly. The duration of peak-heating in relation to the ammonia level in the compost will be studied further in the near future.

DISCUSSION

The most important conclusion of this study is that a horse manure compost has to be supplemented with nitrogen until the ammonia content at filling is 0.4%. This can either be done with organic nitrogen sources such as cotton seed meal or chicken manure or with urea, ammonium sulphate or calcium ammonium nitrate. This holds for a composting time of 1-2 weeks, a pasteurization time of 10 days and the use of gypsum i.e. normal Dutch conditions. It is striking that the optimum results are obtained if the ammonia content is 0.4%, because at this level the nitrogen content in the compost remains constantly at 1.5% from the beginning until the end of composting. If the nitrogen content is constant all the time there will be an equilibrium between the production and fixation of ammonia by the microflora. The conditions in the pile are constant from the beginning until the end of the composting process as far as nitrogen and ammonia are concerned. The "available" C/N ratio will be constant as well.

The same situation was found in synthetic compost. Here the optimum ammonia content at filling is also 0.4%, but the nitrogen content is then

2.0%. In synthetic compost however, the nitrogen content from the beginning to the end of composting is constant at the value of 2.0%. The main reason that this N content in synthetic compost is higher than in horse manure compost is the lower ash content (more organic matter) of the synthetic compost. The N content of the organic matter or the total C/N ratio is the same in both cases, about 18-20. The pH at filling is 8.3-8.5 and at spawning about 7.5. If composts are made from mixtures of various manures or organic materials (Ross, 1969; Schisler, 1974) this can be a useful guide-line in finding the right proportion between the substituting materials.

Also the dependence of the nitrogen lost during composting on the initial amount of nitrogen present is the same for both types of compost. For synthetic compost, the data expressed per ton of straw (Gerrits, 1974), seem to be three times that of horse manure compost, because one ton of straw produces over three tons of compost. The importance attached in this work to the nitrogen and ammonia content seems to be in contradiction with earlier statements about the role of readily available carbohydrates (Gerrits et al., 1967). Here we have seen that the nitrogen content (determined in the dry matter by the Kjeldahl method after the samples have been dried) is only slightly increased if more nitrogen is added to the compost, so that it is very difficult to find a relationship between the total N and the yield. On the contrary, the ammonia content is strongly influenced by the amount of nitrogen that is added to the compost. The function of the addition of readily available carbohydrates is to influence the C/N ratio i.e. to increase the "available" C/N ratio, so that the free ammonia can be fixed more easily.

In both horse manure and chicken manure there is a lot of ammonia and readily available carbohydrates present. The point is to achieve the optimum ratio i.e. an ammonia content at filling of 0.4%, because at this value the mushroom yield is optimum if the compost is pasteurized for about 10 days. In fact the ammonia content of a compost gives a good indication of the "available" C/N ratio in the compost. According to our experience the ammonia content in an unsupplemented horse manure compost is always less than 0.4%. Provided enough readily available carbohydrates are already present in a manure which is not too light, it is only necessary to add nitrogen. This can be done either by urea, calcium ammonium nitrate or chicken manure. With chicken manure both nitrogen and carbon are given, so that with this supplement no lack of readily available carbohydrates can occur even in a light manure. Moreover, with chicken manure not only can the desired C/N ratio be reached, but also more compost can be obtained from a ton of horse manure. This is very important in the Netherlands where horse manure is much more expensive than chicken manure.

If in synthetic compost little chicken manure is added to the straw (less than 400 kg per ton) whereas a lot of urea is used, it is possible to obtain the desired ammonia content of 0.4% but the yield will not be as good as with a lot of chicken manure and little or no urea and this is really caused by a lack of available carbohydrates.

The advantage of chicken manure and other organic materials like cotton seed meal as compost additives is that nitrogen is added without the danger of quickly disturbing the C/N ratio, because carbohydrates are added as well. As long as nitrogen is added as one of the organic materials well-known in mushroom growing there is no reason to be concerned about available carbohydrates, but their function remains essential.

In producing synthetic compost, straw can be considered as an extremely poor horse manure, that is a horse manure with no urine and no droppings at all. If this lack of droppings is offset with chicken manure it is possible to obtain exactly the same results with synthetic as with horse manure compost (Gerrits, 1974).

A good **synthetic compost** can be made from the following ingredients:

1000 kg of wheat straw, 1000 kg of chicken manure, 60 kg of gypsum and water. In an average horse manure 100 kg of chicken manure has to be added for an optimum result. The difference in supplementation rate between a light and a heavy horse manure will be studied separately. In particular the moisture and the N content of the fresh manure will be taken into account.

It is again emphasized here that gypsum is used in all experiments. There are already strong experimental indications that the addition of gypsum is of tremendous importance especially if larger amounts of chicken manure or heavy horse manures are used. This confirms the experience of mushroom growers from the distant past.

SUMMARY

Experiments on the addition of various amounts of chicken manure and urea (or calcium ammonium nitrate) have confirmed that horse manure is very variable. Sometimes almost no chicken manure is needed, whereas in other loads 200 kg of chicken manure per ton of fresh horse manure is optimum. Under Dutch conditions the average optimum supply of chicken manure is 100 kg per ton of fresh horse manure. The ammonia content and the pH at filling give a good indication of the amount of nitrogen supplied to the compost. With a 10 day pasteurization, practised in the Netherlands, optimum results are obtained with an ammonia content of

0.4% and a pH of about 8.3. Chicken manure, urea and calcium ammonium nitrate can replace each other. If enough chicken manure is added no other source of nitrogen is necessary. The results are compared with the results obtained from work on synthetic compost published recently. With horse manure compost and synthetic compost the same results are obtained as far as the optimum ammonia concentration and the pH are concerned.

RÉSUMÉ

Des expériences sur l'addition des quantités diverses de fumier de poulet et d'urée (ou d'ammonitrate) ont prouvé que le fumier de cheval est très variable. Parfois presque aucun fumier de poulet est nécessaire mais dans d'autres parties l'emploi de 200 kg de fumier de poulet est optimal. Dans des conditions hollandaises l'addition optimale est en moyenne de 100 kg par tonne de fumier de cheval. Le taux d'ammoniaque et le pH au moment du remplissage donnent une bonne indication de la quantité d'azote ajoutée au compost.

Avec une pasteurisation de 10 jours pratiquée aux Pays Bas, des résultats optimaux ont été obtenus avec un taux d'ammoniaque de 0,4% et un pH de 8,3 environ.

Le fumier de poulet peut être replacé par l'urée et l'ammonitrate. Quand on a ajouté assez de fumier de poulet aucune autre source d'azote n'est nécessaire. On compare les résultats aux résultats obtenus dans les recherches avec du compost synthétique, publiés récemment. Avec le fumier de cheval et le compost synthétique nous avons obtenu des résultats identiques en ce qui concerne la concentration d'ammoniaque et le pH.

ZUSAMMENFASSUNG

Versuche mit Zusätzen unterschiedlicher Mengen Hühnermistes und Harnstoffes (oder Kalkammonsalpeter) haben bestätigt, dass Pferdemist sehr variabel ist. Manchmal wird fast kein Hühnerdung benötigt während in anderen Fällen Mengen von 200 kg Hühnerdung per Tonne frischen Pferdemistes optimal sind. Unter holländischen Bedingungen beträgt der optimale Zusatz an Hühnerdung im Durchschnitt 100 kg per Tonne frischen Pferdemistes. Der Ammoniumgehalt und der pH-Wert beim Füllen sind gute Indikatoren für die dem Kompost zugesetzte Menge Stickstoff. Bei einer Pasteurisierungszeit von 10 Tagen, wie sie in den Niederlanden praktiziert wird, werden optimale Ergebnisse mit einem Ammonium-Gehalt von 0,4% und einem pH-Wert von etwa 8,3 erzielt. Hühnermist, Harnstoff und Kalkammonsalpeter können einander ersetzen. Wenn genügend Hühnerdung zugefügt wurde ist keine andere Stickstoffquelle mehr erforderlich. Die Ergebnisse werden mit den Ergebnissen verglichen, die kürzlich

veröffentlichte Arbeiten mit synthetischem Kompost erbrachten. Mit Pferdemist-Kompost und synthetischem Kompost wurden, soweit es das Optimum der Ammonium Konzentration und den pH-Wert betrifft, die selben Ergebnisse erzielt.

BIBLIOGRAPHY

Allison, W.H. and L.R. Kneebone. 1962. Influence of compost pH and casing soil pH on mushroom production. Mushroom Science 5: 81-90.

Bech, K. and C. Riber Rasmussen. 1969. Further investigations on organic and inorganic supplementation of mushroom compost. Mushroom Science 7: 329-342.

Bohus, G. 1959. Investigations concerning the life processes of the cultivated mushroom. Mushroom Science 4: 86-131.

Dureau, P. et J. Delmas. 1962. Essais de méthode d'analyse pour les composts à champignon de couche. Mushroom Science 5: 39-45.

Flegg, P.B. 1961. Mushroom composts and composting. A review of the literature. Glasshouse Crops Res. Inst., Littlehampton, England, Report 1960: 125-134.

Gerrits, J.P.G., F.M. Muller and H.C. Bels-Koning. 1967. Changes in compost constituents during composting, pasteurization and cropping. Mushroom Science 6: 225-243.

Gerrits, J.P.G. 1970. Inorganic and organic supplementation of mushroom compost. Mushroom Grow. Ass. Bull. 251: 489-508.

Gerrits, J.P.G. 1972. The influence of water in mushroom compost. Mushroom Science 8: 43-57.

Gerrits, J.P.G. 1974. Development of a synthetic compost for mushroom growing based on wheat straw and chicken manure. Neth. Journal Agr. Sci. 22: 175-194.

Grabbe, K. 1972. Vergleichende Untersuchungen zur Spezifität von kompostiertem und nicht kompostiertem Champignonkultursubstrat. Mushroom Science 8: 533-552.

Gray, T.R.G. and D. Parkinson. 1968. The ecology of soil bacteria. Liverpool University Press.

Hayes, W.A. and Ph. E. Randle. 1968. The use of water soluble carbohydrates and methyl bromide in the preparation of mushroom composts. Mushroom Growers Ass. Bull. 218: 81-102.

Huhnke, W., G. Lemke and R. von Sengbusch. 1967. Die III. Phase der Entwicklung des Champignon-Anbauverfahrens auf nicht kompostiertem sterilem Nährsubstrat. Gartenbauwissenschaft 32: 485-502.

Laborde, J., J. Delmas, J.L. Lamau, et J. Berthaud. 1972. La préparation express des substrats (P.E.S.) pour la culture du champignon de couche. Mushroom Science 8: 675-706.

Laborde, J., J.J. Pastol, et M. Dandaleix. 1972. Application de l'analyse par chromatographie en phase gazeuse à l'étude de la fermentation des substrats destinés à la culture du champignon de couche. Mushroom Science 8: 813-829.

MacCanna, C. 1969. Nitrogen supplementation of composts. Mushroom Science 7: 295-307.

O'Donoghue, D.C. 1967. Relationship between some compost factors and their effects on the yield of *Agaricus*. Mushroom Science 6: 245-254.

Parkinson, D. and J.S. Waid. 1960. The ecology of soil fungi. Liverpool University Press.

Ross, R.C. 1969. Experiments on the use of farm waste-products in mushroom composting. Mushroom Science 7: 365-371.

Schisler, L.C. 1974. Possible substitutes for corn cobs in mushroom composts. Mushroom News 22 (5): 6-16.

Tschierpe, H.J. and J.W. Sinden. 1962. Studies on the composition of horse manure compost from beginning of Phase II through mushroom cropping as related to CO_2 evolution. Mushroom Science 5: 61-80.