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Development of a synthetic compost for mushroom growing based on wheat straw and chicken manure

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Summary

In mushroom growing there is need for a simple formula for the preparation of synthetic compost to complement the existing formulae for the preparation of compost based on horse manure or pig manure. This paper describes how such a formula was developed and investigates the most important factors involved. It has proved possible to prepare a synthetic compost with 1000 kg of chopped wheat straw, 1000 kg of chicken manure, 60 kg of gypsum and over 5000 litres of water. This mixture produces 3300 kg of compost. The composting time is 15 days according to the scheme -3, 0, 4, 7, 11, 12. At filling this compost has a C/N ratio of 18, a nitrogen content of 2.0 % and an ammonia content of 0.4 % corresponding with a pH of 8.6.

Introduction

Mushrooms are heterotrophic organisms and have to be cultivated on compost, i.e. a selective substrate rich in organic matter (Flegg, 1961; Gerrits, 1970a). In Europe straw-bedded horse manure is mostly used as the basic material for the preparation of compost. In the Netherlands about 300 000 tons of compost are used per year (Gerrits, 1974). However, horse manure is not available everywhere. Where it is not available a substitute is needed; several research workers have studied the possibility of using straw for the preparation of synthetic compost. (Demelon et al., 1937; Edwards, 1949; Lambert, 1929; Sinden, 1938, 1946; Stoller, 1943; Waksman & Reneger, 1934). Even an entirely new procedure for the preparation of a substrate for mushroom growing was developed (Huhnke, 1972). Nowadays yields are much higher than those mentioned in these publications. This is a result of rapid development of the mushroom industry and a better understanding of the processes involved. A lot of work has been done on the microbiology and chemistry of composts (Gerrits, 1969; Grabbe & Haider, 1971a, 1971b; Stanek, 1972), but there is hardly any recent information on the production of a synthetic compost with the same high-yielding capacity as a horse manure compost.

In 1964 Overstijns described a formula for synthetic compost for Dutch conditions. For 2500 kg of compost 1000 kg of wheat straw was used to which 25 kg of urea, 100-150 kg of malt sprouts, 60 kg of gypsum, 20 kg of superphosphate and 25 kg of calcium carbonate were added. The composting scheme was -20, -6, 0, 6, 10, 13, 15, 16 (filling). On day -20 and -6 part of the urea and the malt sprouts was given, on day 0 the rest of malt sprouts and the calcium carbonate and on day 6 the gypsum and superphosphate. The amount of water used varied from 3500-4500 litres per ton of straw. This recipe produced a rather bulky synthetic compost; not more than 75 kg compost per m² could be filled.

This paper explains how a higher-yielding synthetic compost can be prepared with mainly straw and chicken manure. First some experiments will be discussed which were carried out at the old experimental station (Exp. 53-104). Later work (from Exp. 253 onward) has been performed at the new experimental station which was opened in 1971 and is much better equipped. Most experiments have been carried out with various amounts of chicken manure and urea, but also some attention has been paid to time of supplementation, watering, inoculation with dried bacteria, addition of town waste compost and spent mushroom compost, use of urine and vinasse (a waste yeast product), nitrogen sources such as calcium ammonium nitrate and calcium cyanamide and the effect of chopping the straw before composting starts.

A practical formula for the preparation of synthetic compost is presented, and some of the important factors in composting are elucidated.

Experimental

Growing procedure

For the preparation of synthetic compost wheat straw was used throughout. The straw was wetted by means of nozzles placed at one side of the straw in a compost shed with a concrete floor sloping to a drain connected to a pit of 10 000 litres capacity. Normally the straw was wetted in the bales but in later experiments it was chopped first. To stimulate heating some nitrogen in the form of urea, malt sprouts or chicken manure was sometimes sprinkled over the straw before it was wetted. After ten days the straw was shaken loose with a machine and at the same time some organic nitrogen and water were again added, after which heaps were made with a diameter of about 2 m and a height of about 1.50 m. This day is called day 0. After several days the compost was turned by means of a composting machine and 60 kg of gypsum per ton

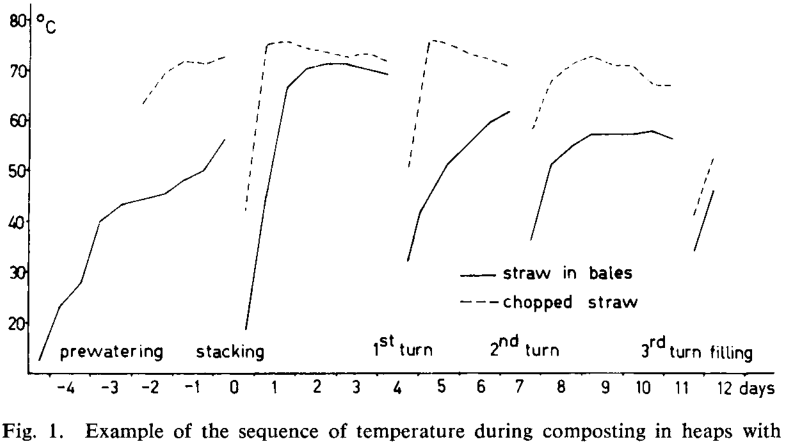

Fig. 1. Example of the sequence of temperature during composting in heaps with normal straw and chopped straw.

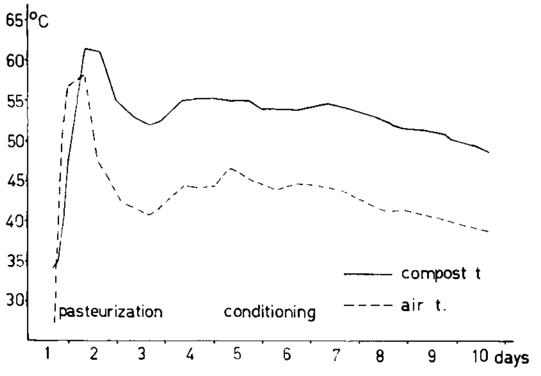

Fig. 2. Example of the sequence of compost and air temperature during peak heating.

of straw were added. Then the compost was turned twice before it was filled into the growing rooms. The turning schedule was: -10, 0, 4, 7, 11, 12 (filling). If the straw was chopped first, the prewetting time could be reduced by one week. In the experimental heaps about 250 kg of straw were used for each treatment yielding 700-800 kg of compost. The sides of the heaps were stacked firmly and the heaps were put into a row. Separation of the individual heaps in the row by means of wood or plastic foil was not necessary. A typical sequence of temperature of normal and chopped straw is given in Fig. 1.

After filling, the compost was peak-heated (i.e. pasteurized and conditioned) for 10 days. A typical sequence of compost and air temperature is given in Fig. 2.

Dependent on the treatment the compost temperature during pasteurization could rise to 60 °C or even to 70 °C. After cooling down to 25 °C the compost was spawned. In all experiments the Sinden A1 strain was used. After a mycelium growth period of 12 days the compost was cased with casing soil consisting of black peat (65 % v/v), white peat (25 %), river sand (5 %) and calcium carbonate (5 %). From casing until the first flush the temperature was decreased to 15 °C. The mushrooms were picked for 5 weeks. After each experiment the houses were steamed for 12 hours at 70 °C before emptying.

Experimental design

In the growing rooms the shelves (5 layers) were divided into experimental plots of 65 × 200 cm, giving 16 plots in one layer. If possible the beds were filled with 100 kg compost per m^2, but in the first experiments the compost was too bulky so that only 80 kg/m^2 could be filled. All yields have been converted to 100 kg of compost per m^2 in order to facilitate comparisons.

In all the experiments factorial designs were used with 8 or 16 compost treatments, for example 2^3 with 8 replicates or 4 × 2 × 2 with 4 or 5 replicates. The layers were considered as blocks and the treatments were randomized in the layers.

Analysis

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 of 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.

The nitrogen and carbon contents at the beginning of composting were calculated from the analysis of the composing materials. For wheat straw 15 % moisture and 0.5 % N was assumed throughout because the batches of straw were not analysed individually. The average composition of the chicken manure was: moisture 38 %, ash 13 %, organic matter 49 %, P_2O_5 2.3 %, C 22.0 %, N 2.4 % (all data as % of fresh weight) and C/N ratio 9.2. The chicken manure originates from broilers, which are kept on wood shavings. It is rather dry so that it can be spread very easily.

Results and discussion

First series of experiments

Some data from the experiments performed between 1964 and 1969 at the old experimental station are listed in Table 1. In the main, different kinds and quantities of organic supplements such as urea, malt sprouts, cotton seed meal, lucerne meal, sugar-beet pulp, molasses and chicken manure were used. The amount of urea varied from 20-40 kg per 1000 kg straw and the organic supplements from 100-180 kg. However, 300-400 kg of chicken manure was used as this material has a higher moisture and ash content. More recent experiments which will be discussed below show that these quantities are too low to get an optimum yield. However it was shown that the materials used can replace each other provided that equal amounts of organic matter and nitrogen are applied per 1000 kg straw.

In Table 1 there are great differences in composting time, in the amount of compost prepared from 1000 kg straw and between the average yields in the experiments. Only two experiments (53 and 57) gave reasonable yields. Because of the long composting time and the large loss of dry matter involved, 100 kg compost per m² could easily be filled in these experiments. Such a compost is very expensive because less than 2000 kg compost can be made from 1000 kg straw.

There is a straight-line relationship between composting time in days (X) and the amount of compost made per 1000 kg straw in 1000 kg (Y). The amount of compost

Table 1. Some data from the older series of experiments.

Exp. No	Composting time (days)	Compost/kg straw (kg) Compost/straw ratio (w/w)	Moisture (%) at filling	Compost (72 %)/ kg straw (kg)	Loss of DM (%)	Yield (kg/m²) in 6 weeks*	Compost chressing (kg/m²)
50	33	2.35	74.5	2.14	45.5	12.4	80
53	44	1.69	70.8	1.76	55.3	15.3	93
57	30	1.93	73.9	1.80	54.5	15.4	100
61	23	2.68	75.0	2.39	39.8	11.8	100
64	25	2.12	72.9	2.05	48.1	10.6	100
75	22	2.50	73.2	2.39	42.4	11.4	100
79	22	2.46	73.6	2.32	41.7	8.8	80
85	22	2.44	74.7	2.20	46.0	9.1	80
89	20	2.11	69.9	2.27	42.7	8.0	75
104	17	2.59	73.8	2.42	44.8	7.7	80

* Not converted into 100 kg compost per m².

is converted to a standard moisture content of 72 %. The regression equation is $Y = -0.023X + 2.78$ ($r = -0.81$). There is also a relationship between composting time (X) and the percentage loss of dry matter (Z). The regression equation is $Z = 0.69X + 27.3$ ($r = 0.85$). These equations hold for a composting time varying from 20-45 days. For each day that the composting time is extended the amount of compost made per 1000 kg straw decreases by 23 kg, whereas the loss of dry matter increases by 0.69 %. In the first 20 days of composting the loss of dry matter must be greater than 0.69 % per day, because usually the real loss of dry matter follows a curve (exponential line). Between day 20 and 45 this curve approximates to a straight line.

As a result of these experiments only 400 kg of chicken manure and 20 kg of urea per 1000 kg straw were used for the preparation of synthetic compost. At the same time the use of superphosphate was discontinued because large quantities of phosphorus are present in chicken manure (20 kg of superphosphate contains 4 kg of phosphorus and 400 kg chicken manure about 10 kg!). Calcium carbonate was omitted from the formula mainly because of results from experiments with horse manure compost (Gerrits, 1970b).

Effect of chicken manure on the amount of compost prepared from 1000 kg of straw
In the experiments carried out from 1971-1973 considerable attention was paid to chicken manure. It is clear that the amount of chicken manure greatly affects the amount of compost made from 1000 kg straw and the amount of water required per 1000 kg straw to get a compost with a certain moisture content. This is shown in Table 2. For each experiment the following details are given: the time of year of composting, the quantities of chicken manure and water used, the quantity of compost prepared per 1000 kg of straw and the moisture content at filling. In addition the losses of dry matter and water during composting are shown together with the amounts of water lost for every kilogramme of dry matter which has been broken down. There is no significant correlation either between the amount of chicken manure per 1000 kg of straw and the loss of dry matter ($r = 0.24$), or between the amount of chicken manure and the loss of water ($r = 0.19$): We can therefore use average figures for loss of dry matter (37 %) and loss of water (55 %) in our calculations. In the table there seems to be an indication that the loss of water depends on the season. In the summer months the loss is greater than in the winter months. The dry matter loss of 37 % holds for a composting time of 22 days. From the data in the first series of experiments the loss of dry matter in 22 days is 42 % but since there is a large time interval between the two series the order of magnitude is rather similar.

The moisture content of the compost has a large effect on the amount of compost prepared from one ton of straw. To find the effect of the amount of chicken manure on the quantity of compost prepared from one ton of straw, all the moisture contents are converted to 72 %. There is a straight-line relationship between the amount of chicken manure (in kg) added per 1000 kg of straw (X) and the amount of compost (converted to a moisture content of 72 %) produced per 1000 kg straw (Y). This relation is plotted in Fig. 3 and the corresponding regression equation is $Y = 1.17X + 2163$ ($r = 0.89$). The amount of water necessary to reach a moisture content of 72 % increases with increasing amounts of chicken manure.

The actual amount of water given was often too small or too large. The difference between the amount of water given and the amount that had to be given to reach 72 % is either substracted from or added to the actual amount given. This 'standardized' water supply in litres (Y) is plotted in Fig. 4 against the amount of chicken manure in

Table 2. Some data from the experiments with chicken manure.

Exp. No	Time of composting	Chicken manure/1000 kg straw (kg)	Water/ 1000 kg straw (l)	Compost/ 1000 kg straw (kg)	Moisture in compost at filling (%)	Loss of DM (%)	Loss of water (%)	Water lost/kg DM decomposed (l)
253	Jan.	400	3840	3365	75.1	29.4	40.6	4.9
		650	3890	3098	73.4	31.8	47.2	5.3
257	Febr.	400	4445	3747	79.2	30.9	38.1	5.3
		600	4890	3417	77.5	36.8	44.9	4.8
		650	4165	3467	76.7	35.4	42.8	4.5
		850	4725	3581	76.5	34.7	46.8	5.4
263	March	400	4619	2603	74.6	41.9	60.1	6.1
279	June	300	4937	2711	75.2	39.0	60.9	7.4
		600	4892	2813	71.8	38.5	61.7	6.6
		900	5075	2961	70.9	41.3	62.4	5.7
		1200	5345	3082	67.4	39.1	65.2	6.0
289	Aug.	500	4400	2797	74.1	42.1	63.9	6.9
295	Sept.	300	4790	2895	77.0	39.9	56.0	6.4
		600	4890	3230	76.4	40.4	53.4	5.5
		900	5010	3372	74.3	40.2	54.8	5.2
		1200	5355	3581	73.3	41.1	56.3	5.1
310	Nov.	300	4823	3278	77.8	35.6	49.8	6.3
		600	4814	3505	76.9	38.4	48.1	4.9
		900	5179	3566	75.8	43.0	52.2	4.6
		1200	5629	4099	75.4	40.5	50.3	4.6
327	Febr.	300	4925	2846	71.7	26.4	60.8	11.0
		600	5146	3015	70.2	28.7	61.9	9.5
		900	5348	3145	69.2	32.2	63.1	8.0
		1200	5633	3461	70.0	34.8	61.4	7.0
343	May	800	5240	3200	71.1	37.9	59.6	5.9
359	Aug.	500	4623	2505	72.1	43.4	63.6	5.9
		1000	5371	3340	69.4	33.8	60.7	6.9
375	Oct.	300	4825	2766	75.1	37.4	57.0	6.6
		600	5213	2931	74.1	41.0	58.4	5.8
		900	5600	3263	72.9	39.7	57.6	5.5
		1200	6050	3655	73.3	40.9	55.7	5.0

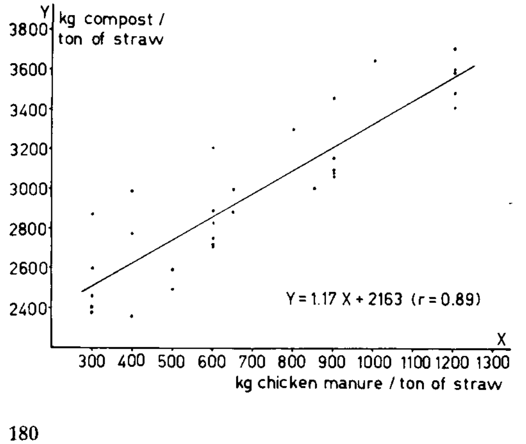

Fig. 3. Relationship between the amount of chicken manure added per 1000 kg straw and the amount of compost prepared per 1000 kg straw (moisture content 72 %).

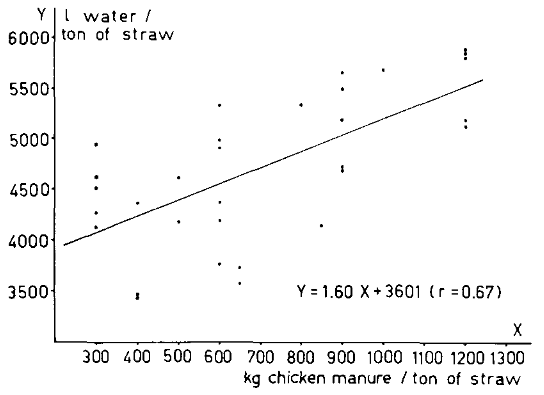

Fig. 4. Relationship between amount of chicken manure added per 1000 kg straw and the amount of water required per 1000 kg straw to obtain a moisture content of 72 % at filling.

kg per 1000 kg of straw (X). There is a straight-line relationship between X and Y. The regression equation is $Y = 1.60X + 3601$ ($r = 0.67$).

For several levels of chicken manure the amount of compost produced and the amount of water required to reach 72 % were calculated from these equations. These are listed in Table 3 together with some data that can be derived from them. The following conclusions can be drawn from this table.

– For an increase of chicken manure of 100 kg per 1000 kg straw the amount of compost increases by 117 kg and an extra 160 litres water have to be given; this is in accordance with results from trials with horse manure compost (Gerrits, 1972).

– At the same time the amount of straw necessary for 1000 kg compost decreases by about 15 kg per 100 kg of chicken manure. Because chicken manure is very cheap and straw expensive or even very expensive this is an important statement for the practical grower.

– For every 100 kg of chicken manure per 1000 kg straw the amount of chicken manure per 1000 kg compost rises by about 25 kg; at a low supplementation rate this is more than 25 kg and at a high rate it is less than 25 kg.

– If the amount of compost produced per 1000 kg of straw and the amount of water required is calculated with the aid of the average loss of dry matter of 37 % and the average loss of water of 55 %, similar data are obtained as those shown in Table 3.

For this calculation the moisture content of the chicken manure should be 40 %; 60 kg gypsum and 20 kg urea (i.e. 80 kg D.M.) should be given.

Table 3. Some data calculated with the aid of the equations in Fig. 3 and 4.

Chicken manure/1000 kg straw (kg)	Chicken manure/ 1000 kg straw (kg DW)	Compost/ 1000 kg straw (kg)	Water/ 1000 kg straw (l)	Straw/ 1000 kg compost (kg)	Chicken manure/1000 kg compost (kg)	Chicken manure/ 1000 kg compost (kg DW)
200	120	2397	3921	417	83	50
400	240	2631	4241	380	152	91
600	360	2865	4561	349	209	125
800	480	3099	4881	323	258	155
1000	600	3333	5201	300	300	180
1200	720	3567	5521	280	336	202

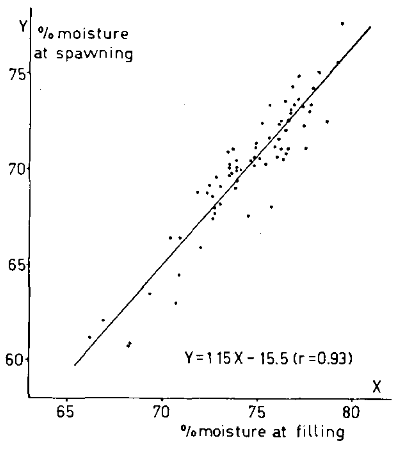

Fig. 5. Relationship between the moisture content of the compost at filling and at spawning.

Loss of water during peak-heating

During peak-heating (pasteurization and conditioning) a lot of water evaporates from the compost and the moisture content decreases. In 72 composts the moisture content at filling and at spawning was determined from 4 or 8 samples per compost (Fig. 5). There exists a linear relationship between the moisture content at filling (X) and the moisture content at spawning and also between X and the decrease of the moisture content during peak-heating (Y′). The regression equations are:

$$Y = 1.15X - 15.5 \ (r = 0.93)$$

$$Y' = -0.15\,X + 15.5 \ (r = -0.32).$$

This means that at 75 % at filling the moisture content decreases by 4.3 %, at 70 % by 5.0 % and at 65 % by 5.8 %. A high moisture content decreases less during peak-heating than a low moisture content. In both cases the amount of water lost per m^2 is the same. This agrees with the data on horse manure compost (Gerrits, 1972). The behaviour of synthetic compost during peak-heating is not essentially different from that of horse manure compost.

Nitrogen, ammonia and C/N ratio

In most experiments the percentages of C and N in the compost at filling were analysed. The C and N contents of the basic materials (straw, chicken manure und urea) are known so that the N content and the C/N ratio of the starting mixture can be calculated. The C/N ratio is calculated from the N content of the dry matter; the ammonia content is not taken into consideration.

Gerrits et al. (1967) have showed that the N content and the C/N ratio during composting converge towards a certain value. In Fig. 6 and 7 this is clearly demonstrated again. The N content and the C/N ratio at the beginning are plotted against the increase or decrease of these values during the composting process. If the N content is under 2.0 % it increases and if it is higher than 2.0 % it decreases. The C/N ratio rises if it is lower than 18.0 at the beginning and decreases if it is higher than 18.0. So the values converge towards a N content of 2.0 % and a C/N ratio of 18.0. The reason

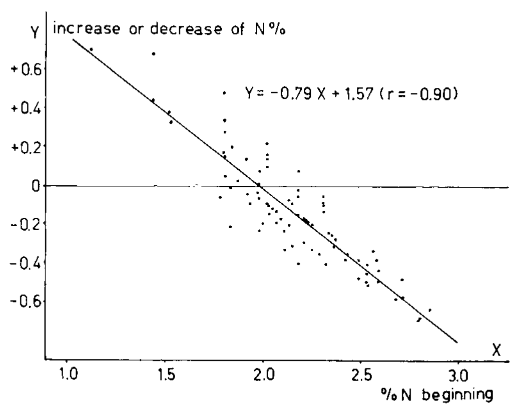

Fig. 6. Relationship between the percentage of N at the beginning of composting and the increase or decrease of the N content during the composting process.

for this is that the more nitrogen is applied the greater is the nitrogen loss. This is clearly shown in Fig. 8 where kg N per 1000 kg straw at the beginning is plotted against kg N lost. Starting with 15 kg, 2 kg is lost and starting with 50 kg, 27 kg, the variation in the amount of N at filling being limited to only 13-23 kg (calculated per 1000 kg of straw). 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 % at filling as it is used throughout is mushroom literature is not a very useful figure to characterize a 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 that 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. 9 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 content than the N content. If only N is determined by the Kjeldahl method it is possible to get an idea of the total N content (inclusive

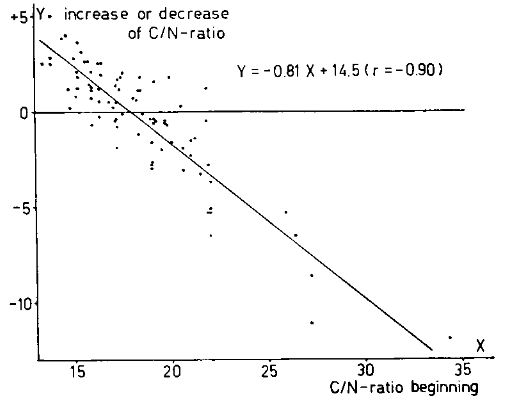

Fig. 7. Relationship between the C/N ratio of the composts at the beginning of composting and the increase or decrease of the C/N ratio during the composting process.

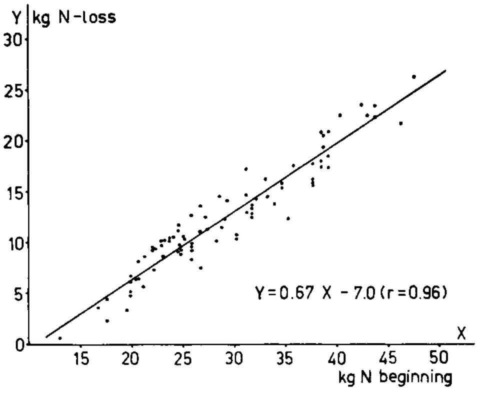

Fig. 8. Relationship between the amount of N present per 1000 kg straw and the loss of N during the composting process.

of NH_4) by applying oxalic or tartaric acid to the compost before the samples are dried to fix the free ammonia.

If urea and chicken manure are added to 1000 kg straw the N content of the starting material can easily be calculated. The more that is added the higher the N content at the beginning will be, and there is a slight increase in the N content at filling. As has been shown the concentration of ammonia will increase as well. To determine exactly the effect of the amount of chicken manure (X_1 in kg) and urea (X_2 in kg) on the NH_4 concentration (Y) and the N content (Z) of the compost at filling multiple regression was applied to 46 sets of data. The regression equations are:

$$Y = 0.000351\ X_1 + 0.00794\ X_2 + 0.011$$

$$Z = 0.000254\ X_1 + 0.0051\ X_2 + 1.73.$$

Both equations are significant at $P<0.01$. From these equations the N and NH_4 contents of the compost at filling can be calculated with various combinations of urea and chicken manure; these values are listed in Table 4.

The pH of the compost increases if the ammonia content increases. If the ammonia

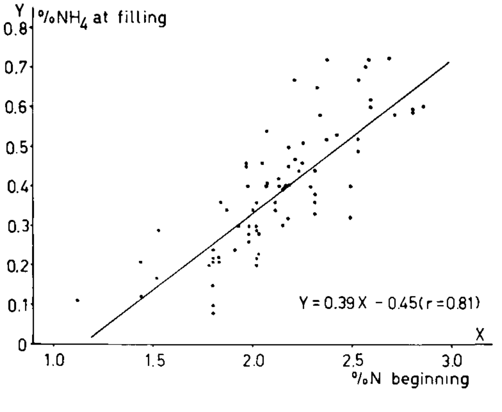

Fig. 9. Relationship between the percentage of N at the beginning of composting and the percentage of NH_4 in the compost at filling.

Table 4. Percentage of nitrogen (Z) and NH_4 (Y) (in brackets) in synthetic compost at filling prepared with various amounts of chicken manure (X_1) and urea (X_2) as derived from the equations: $Y = 0.000351\ X_1 + 0.00794\ X_2 + 0.011$; $Z = 0.000254\ X_1 + 0.0051\ X_2 + 1.73$.

Chicken manure (kg/1000 kg straw)	Urea (kg/1000 kg straw)			
	0	10	20	30
200	1.78 (0.08)	1.83 (0.16)	1.88 (0.24)	1.93 (0.32)
400	1.83 (0.15)	1.88 (0.23)	1.93 (0.31)	1.98 (0.39)
600	1.88 (0.22)	1.93 (0.30)	1.98 (0.38)	2.04 (0.46)
800	1.93 (0.29)	1.98 (0.37)	2.04 (0.45)	2.09 (0.53)
1000	1.98 (0.36)	2.04 (0.44)	2.09 (0.52)	2.14 (0.60)
1200	2.03 (0.43)	2.09 (0.51)	2.14 (0.59)	2.19 (0.67)

content is X and the pH is Y, there exists a linear relationship between these values as calculated from 52 sets of data. The equation is $Y = 0.96\ X + 8.2$ ($r = 0.64$), so that with no ammonia present the pH is 8.2 and with 0.7 % NH_4 the pH is 8.9. After pasteurization nearly all ammonia has disappeared (0.02-0.08 %) and the pH has decreased to about 7.5-7.8 depending on the pH at filling. It should be remarked here that the pH of a compost decreases considerably after sampling and therefore the pH was measured immediately. The higher the pH is, the more the pH decreases. Obviously this has something to do with the loss of ammonia from the compost after sampling.

Chicken manure and malt sprouts

In addition to earlier results two experiments have been carried out to prove whether chicken manure could be used as a compost supplement instead of malt sprouts. For comparison the amount of organic matter in both materials should be the same and therefore 100 kg of malt sprouts must be compared with 200 kg of chicken manure, because of the higher moisture and ash content of the chicken manure. The results of the experiments are given in Table 5. In Experiment 257 there is an increase in yield if 650 kg of chicken manure is used instead of 400 kg. The difference of 2.4 kg/m² is partly caused by a difference in moisture content because the compost with 400 kg was too wet. There is no difference between 650 kg of chicken manure and 400 kg of chicken manure + 100 kg of malt sprouts, which is in accordance with our hypothesis. The highest rate of supplementation (650 kg of chicken manure + 100 kg of malt sprouts) is only slightly better which agrees with later results discussed below.

Table 5. Result of two comparisons between chicken manure and malt sprouts (given in kg per 1000 kg of straw).

	Chicken manure	Malt sprouts	Urea	Yield (kg/m²)
Exp. 257	400	0	20	11.8
	650	0	20	14.2
	400	100	20	14.1
	650	100	20	14.5
Exp. 263	400	0	20	14.0
	0	200	20	14.2

In Experiment 263 there is no difference between the two supplements. The conclusion from these and earlier experiments is that with increasing amounts of organic matter the yield increases up to a certain point, and that there is no difference between malt sprouts and chicken manure. These findings are exactly the same as those obtained for horse manure compost (Gerrits, 1970b). Apparently it is important to add a definite amount of organic matter and nitrogen (i.e. a certain amount of organic matter with a definite C/N ratio) to obtain an optimum result. The nature of the organic matter is less important: whatever is readily available (cotton seed meal, malt sprouts, brewers' grains, lucerne meal, sugar-beet pulp, wheat bran, etc.) can be used.

Quantity of chicken manure

A considerable number of experiments were performed with different amounts of chicken manure per 1000 kg of straw. The effect the chicken manure has on the amount of compost produced from 1000 kg straw and on the nitrogen and ammonia content of the compost has already been discussed. In the experiments 20 kg of urea and 60 kg of gypsum were used throughout. There are indications that gypsum is extremely important especially at higher levels of chicken manure. The results of all the experiments are shown in Fig. 10. Because the level of production was different it was necessary to convert all the yields into percentages of the maximum yield obtained in the experiments in order to be able to compare all data. It is possible to calculate a curved line (parabola) through the points obtained. The regression equation ($P<0.01$) is given in the figure. The best yield (top of the parabola) is obtained with 842 kg chicken manure per 1000 kg straw, but the curve is rather flat so that this amount can vary from 700 up to 1000 kg without influencing the yield by more than 2 %. To get an idea about the effect on yield expressed as kg/m² the yield of 100 % may be fixed at 20 kg/m² as indicated by the supplementary Y-axis in Fig. 10. A yield of 20 kg/m² was quite normal in our later experiments. Overstijns & Bockstaele (1974) obtained almost the

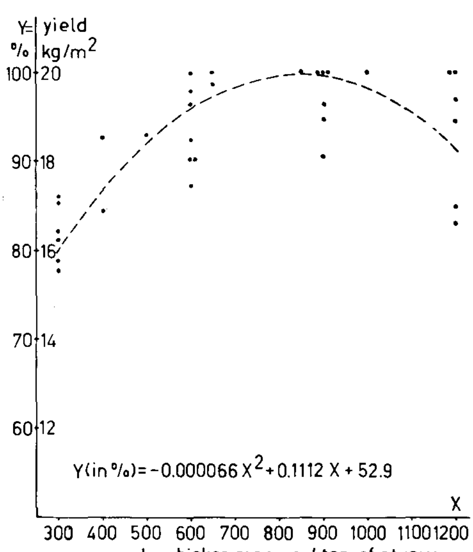

Fig. 10. Relationship between the amount of chicken manure per 1000 kg straw and the percentage yield. For comparison the yield in kg/m² is indicated on a secondary Y-axis, assuming 100 % = 20 kg/m². (20 kg urea per 1000 kg straw were used throughout.)

same results. They used 200, 400 and 600 kg chicken manure per 1000 kg straw, but did not reach a maximum yield even with 600 kg, because they only worked in the rising part of the curve.

Table 4 shows that with 840 kg of chicken manure and 20 kg of urea the N content of the compost at filling will be 2.05 % and the ammonia content 0.45 %. From Fig. 6 it is apparent that a N content of about 2.0 % will not change during composting.

It has now been shown that at this N content the optimum yield is obtained. This means that a compost will be optimum if composting proceeds under uniform conditions from the beginning to the end, with nitrogen concentration neither too low nor too high. It seems that the nitrogen content of synthetic compost (2.0 %) is higher than that of horse manure compost (1.6 %). This is mainly caused by the ash content which is lower in synthetic compost (20 %) than in horse manure compost (33 %). In both cases the N content of the organic matter and the C/N ratio are the same. The C content of the organic matter is about 47 %, so that the C/N ratio can easily be calculated if the ash content is known.

Effect of urea

In practice usually 20-25 kg urea per 1000 kg straw is used during wetting. The ammonia arising from the urea should have a beneficial effect on the softening of the straw (Bels-Koning, 1962). Some combinations of urea and chicken manure have been

Table 6. Survey of yields (kg/m^2) obtained with various amounts of urea per 1000 kg straw at different levels of chicken manure.

Exp. No	Chicken manure (kg/1000 kg straw)	Urea (kg/1000 kg straw)			
		0	10	20	30
253	no malt sprouts added				
	400			11.8	13.3
	650			14.2	13.5
	100 kg malt sprouts/1000 kg straw				
	400			14.1	12.9
	650			14.5	12.1
327	300		18.7	19.5	
	600		22.4	22.3	
	900		23.3	23.4	
	1200		24.7	24.7	
395	300	13.6		19.7	
	600	19.6		21.0	
	900	20.9		18.7	
	1200	20.0		18.7	
359	500	19.8	21.3	22.4	23.3
	1000	22.7*	22.9	22.6*	20.3
375	300	16.8	17.2	17.9	17.7
	600	18.8	19.6	18.2	21.5
	900	21.0	20.1	19.6	20.1
	1200	20.1	19.1	19.1	19.3

* Yield corrected because moisture content at filling was only 67 %.

tried. The results are listed in Table 6. Generally there exists an interaction between the amount of urea and chicken manure. At low quantities of chicken manure urea (even in large amounts) works beneficially, while at high rates of chicken manure the addition of urea depresses yield. Only in Experiments 327 and 375 does this interaction not reach significance; in the other experiments it is significant ($P<0.01$). The most striking conclusion from these data is that it is possible to get an optimum yield with synthetic compost from merely chicken manure in large quantity but no urea at all. This seems to be in contradiction with existing theories about the function of urea (ammonia) during composting. However, with a lot of chicken manure it is also possible to achieve the ammonia level essential for an optimum composting process.

MacCanna (1969) has already pointed to the significance of the ammonia concentration in a compost. With 1000 kg chicken manure and no urea the N content of the compost will be 1.98 % and the NH_4 concentration 0.36 % (Table 4). The same N and NH_4 contents are obtained with 800 kg chicken manure and 10 kg urea, with 600 kg chicken manure and 20 kg urea or with 400 kg chicken manure and 30 kg urea. With these combinations almost the same yield can be obtained. With decreasing amounts of chicken manure and increasing amounts of urea the same N and NH_4 contents can be obtained, but in that case less C sources are available so that yield tends to be affected negatively. This is in accordance with earlier work (Gerrits et al., 1967; Gerrits, 1969; Muller, 1967), but the variation in C sources has to be very great if the effect on yield is to be significant. The optimum combination from Fig. 10 (850 kg of chicken manure and 20 kg of urea) can be replaced by about 1000 kg of chicken manure only. If 1200 kg chicken manure are used the N content will be the same as with 850 kg + 20 kg urea but the structure of the compost becomes too dense, which is unfavourable as will be shown below.

Effect of urine or vinasse

To stimulate heating, liquid nutrients in the form of urine or vinasse were used. Urine (leechings from compost heaps) was collected on a composting plant. Vinasse is a waste product of yeast factories after yeast has been cultivated on molasses. Per 1000 kg straw 3000 litres urine were used (1.5 % dry matter and 0.08 % N) together with 10 kg urea; this solution was compared with 3000 litres water and 20 kg urea at various levels of chicken manure.

In another experiment water and 20 kg urea was compared with vinasse (3.5 % dry matter and 0.13 % N). No urea was added to the vinasse. The results of the two experiments are shown in Table 7. In both experiments there is an interaction ($P<0.01$)

Table 7. Effect of wetting the straw with urine or vinasse at different levels of chicken manure (yield in kg/m^2).

Chicken manure (kg/1000 kg straw)	Exp. 279		Exp. 327	
	water + 20 kg urea/ 1000 kg straw	urine + 10 kg urea/ 1000 kg straw	water + 20 kg urea/ 1000 kg straw	vinasse
300	12.5	14.3	16.7	20.3
600	13.9	14.8	20.3	21.7
900	15.4	15.1	21.5	22.3
1200	13.0	11.7	22.6	20.2

between the use of urine or vinasse and the amount chicken manure. Both liquids stimulate the yield in a poor compost (i.e. with little chicken manure) but depresses yield in a rich compost (i.e. with a lot of chicken manure). At a level of 900 kg chicken manure the influence is nil. In the case of urine about 45 kg extra dry matter was added per 1000 kg straw and in the case of vinasse 100 kg. This amount of organic dry matter has the same function as chicken manure and can partly replace it. It depends on local circumstances which formula will be most advantageous to use.

Calcium ammonium nitrate and calcium cyanamide

Instead of urea, sulphate of ammonia is often used in mushroom growing as a N source during composting. The sulphate ion remaining after micro-organisms have consumed the ammonium ion has to be neutralized by calcium carbonate. Therefore it seems to be more interesting to use nitrate of ammonia from which both the ammonium and the nitrate part can be used by compost micro-organisms to incorporate in their cell proteins. No acid part of the molecule will be left. Calcium cyanamide (granular form) was used because this material is often cited as a source of nitrogen in the preparation of synthetic compost (Sinden, 1946). The results are summarized in Table 8. There are no significant differences between urea and calcium ammonium nitrate. These N sources can be interchanged without harm.

At filling only 5 % of the nitrate was detectable, so that 95 % was used by micro-organisms as a N source for their organic molecules or denitrified in anaerobic parts of the compost heap. The last possibility seems unlikely, because the major part of a compost heap is not really anaerobic. Calcium cyanamide causes an enormous reduction in yield. The material was not tried further. Besides it is not readily available and is an unpleasant material to work with.

Table 8. Comparison between the effect of urea, calcium ammonium nitrate and calcium cyanamide as a N source at different levels of chicken manure (yield in kg/m²).

Exp. No	Chicken manure (kg/1000 kg straw)	Urea (20 kg/1000 kg straw)	Calcium ammonium nitrate (40 kg/1000 kg straw)	Calcium cyanamide (50 kg/1000 kg straw)
253	400	13.9	14.4	-
	650	15.0	15.3	-
310	300	18.1	16.9	-
	600	21.2	18.7	-
	900	19.2	19.3	-
	1200	17.6	18.1	-
343	800	16.5	17.1	9.6

Inoculation with dried bacteria

In Experiment 263 a product was used called Enzobac 3000 containing dried 'mutated and adapted' bacteria. This product should stimulate heating of the compost heaps, decrease composting time and increase yield. Only 200 g per 1000 kg straw were used. Instead of higher temperatures slightly lower temperatures were recorded during composting. The yield is in accordance with this observation (see Table 9). The product cannot be used successfully in a mushroom compost; this agrees with experiences in

Table 9. Effect of inoculation of the straw with Enzobac 3000 (yield in kg/m²).

	Without Enzobac 3000	With Enzobac 3000
400 kg chicken manure/1000 kg straw	14.0	12.5
200 kg malt sprouts/1000 kg straw	14.2	12.6

other fields, such as plants for waste water treatment where the same material was used without success.

Use of spent mushroom compost and town waste compost
From the literature it is known that a great many materials can be used for the preparation of a compost. Block et al. (1958) worked with saw-dust, Delmas & Laborde (1972) with town waste compost and pine bark, Kneebone (1972) with sugar cane bagasse.

It could be interesting to add a compost to straw in order to initiate heating. The temperature should rise more rapidly because more micro-organisms are present. In two experiments the effect on yield was studied of replacing 25 % of the weight of the compost by spent mushroom compost or town waste compost; the materials were mixed in at the very beginning of composting. The results are given in Table 10. In Experiment 253 there is no significant difference in yield with or without spent compost but in Experiment 343 there is a marked reduction in yield if 25 % spent mushroom compost or town waste compost is used. The explanation of this difference could be as follows. In Experiment 343 the straw was chopped and more chicken manure was used than in Experiment 253. Both factors cause a denser structure of the compost. At a high supplementation rate too dense a structure can be one of the limiting factors of production. Spent mushroom compost or town waste compost also cause a denser structure, just as chicken manure. All these factors together make the compost of Experiment 343 much denser than that of Experiment 253, so that the yield decreases considerably. With spent compost the straw in fact starts to heat more quickly, but this is also typical for a dense compost as will be shown below. The conclusion is that spent mushroom compost and town waste compost are not interesting substitutes for fresh mushroom compost under Dutch conditions. If spent mushroom compost were to be used from a poor yielding crop which had a lot of nutrients remaining, or town waste compost containing much more organic matter than ours, the results could perhaps be a little more positive.

Table 10. Effect of spent mushroom compost and town waste compost as a substitute for straw (yield in kg/m²).

Exp. No	Chicken manure (kg/1000 kg straw)	Control	25 % spent compost	25 % town waste compost
253	400	13.9	14.9	–
	650	15.0	15.3	–
343	800	16.5	10.8	11.4

Table 11. Effect of various watering procedures on yield (in kg/m²) at different levels of chicken manure.

	Chicken manure (kg/1000 kg straw)	Watering at day -7	Watering at day -14
Exp. 279	300	13.4	13.3
	600	14.7	14.0
	900	15.3	15.2
	1200	12.4	12.3

Exp. 295	Chicken manure (kg/1000 kg straw)	3000 l/1000 kg in one application + 1200 l after 10 days	3000 l/1000 kg in one application + 1200 l spread over 10 days
	300	10.8	11.4
	600	12.3	12.6
	900	13.0	12.9
	1200	13.7	13.2

Watering of the straw

In Table 1 and Fig. 4 it has already been shown that 1000 kg straw require 4000-5500 litres water depending on the amount of chicken manure used. The season of the year also influences the evaporation and therefore the water requirement. The difference between 7 and 14 days of pre-treatment of the straw was studied in Experiment 279. Table 11 shows that there is no significant difference.

In Experiment 295 one part of the straw was moistened every day after the straw was watered with 3000 litres per 1000 kg. No water was given to the other part for 10 days, but at stacking the same amount of water was given as had been used to keep the straw wet, so the same amount of water was given in total. Table 11 shows that there is no significant difference between the two procedures, so we may conclude that watering procedures can vary considerably without affecting yield provided the moisture content at spawning is the optimum.

Effect of chopping the straw

In earlier experiments on synthetic compost the bales were first stacked three layers high and the straw was watered in the bales. In most cases, the urea and some organic material were spread between the bales to initiate heating, and 3000 litres water were used per 1000 kg straw. The water running off the bales was collected and pumped back until all the water was absorbed by the straw. With this procedure the straw was left in the bales for about 10 days, but the temperature in the straw did not rise very quickly. After the bales were opened up and the straw mixed with chicken manure (and water) the composting process really started. In winter time when the temperature in the bales was only 0-10 °C, live steam was sometimes introduced to raise the temperature above 30 °C in order to start heating. This procedure did not lead to the results expected, perhaps because it is impossible to stimulate micro-organisms artifically by only increasing the temperature. The compost was too bulky and only 80 kg compost per m² could be filled, although the moisture content was sometimes very high (over 75 %). To make the compost more compact an attempt was made in Experiment 310 to chop the straw into pieces of 5-8 cm in length, before watering. To reach

Table 12. Effect of watering the straw in bales in comparison with watering after the straw is chopped at different levels of chicken manure (yield in kg/m²) (Exp. 310).

Chicken manure (kg/1000 kg straw)	Straw in bales	Chopped straw
300	15.8	18.1
600	17.7	21.2
900	20.3	19.2
1200	19.7	17.6

a moisture content of 70 % this chopped straw has to be watered with 4000 litres per 1000 kg.

Because this amount of water is more than the theoretical value, there must be strong evaporation during watering. The chopped straw heats much more quickly than the straw in the bales (Fig. 1). This is a result of the more compact structure with the air:water:dry matter ratio being more favourable for an optimum composting process. Even with a normal moisture content of 70-72 % 100 kg compost per m² can easily be filled. The results are given in Table 12. The yield is converted to 100 kg compost per m² as throughout this study, although only 80 kg per m² was filled with the compost made from unchopped straw. There is an interaction ($P<0.01$) between the amount of chicken manure and the chopping of the straw. With chopped straw 600 kg of chicken manure is the optimum but 900 kg with unchopped straw. The reason for this interaction has to be sought in the structure of the compost. Chopping gives the straw a denser structure and the pieces of straw are opened up mechanically to some degree. This means that less time is needed for biological degradation. The micro-organisms can reach the fibres of cellulose more easily and even at lower levels of chicken manure a good yield is obtained if the straw is chopped. At high levels of chicken manure the structure becomes more dense and this negatively affects yield. If the straw is made still finer (by grinding through a hammer mill), the optimum amount of chicken manure could be even less and composting time shortened. By thinking in this direction we quickly arrive at the process of Huhnke (1972) or the method of rapid composting of Laborde et al. (1972). In these processes a synthetic mixture or horse manure is milled to a very fine texture after which only a short pasteurization is necessary. After Experiment 310 only chopped straw was used in the experiments. The prewetting of the straw was shortened by one week. The composting schedule became -3, 0, 4, 7, 11, 12, i.e. 15 days, a reasonable time for the preparation of a synthetic compost.

Conclusion

From the results obtained in this study a useful method for the preparation of synthetic compost is as follows.

1000 kg wheat straw is chopped into pieces of about 5-8 cm and watered with about 4000 litres water, this water being pumped back until all the water is taken up by the straw. Then the straw is mixed with 1000 kg chicken manure (day 0) and the material turned according to the scheme 0, 4, 7, 11, 12. For every kg of chicken manure 1.5 litres of water has to be added. On day 4, 60 kg of gypsum are given and on day 12 the compost is ready and can be filled. 1000 kg straw give 3300 kg of compost. A compost will be obtained with a C/N ratio of 18, i.e. with an ash content of 20 %, the N content will be 2.0 %. The concentration of NH_4 at filling will be 0.4 % with a pH of about 8.5.

Instead of chicken manure other N-rich organic materials such as malt sprouts, brewers grains, cotton seed meal, lucerne meal, wheat bran or sugar-beet pulp can be used. The amounts of organic matter and nitrogen have to be the same as in the chicken manure. If less chicken manure is used it is possible to apply nitrogen as urea or ammonium nitrate but if the amount of chicken manure becomes too small yield is negatively affected because of a shortage of available carbon sources. It is also possible to use liquids containing organic material such as urine or vinasse to replace part of the chicken manure. The structure of the compost is very important and there should be a definite dry matter:water:air ratio during composting in order to have an optimum heating of the compost. If the straw is very fine less chicken manure can be used and if it is very coarse more chicken manure can be used. The watering procedure is not very important but it is recommended that the moisture content should be as constant as possible during composting; however, the moisture content at filling and spawning will determine the yield.

Use of spent mushroom compost or town waste compost is not recommended, because this decreases yield. No positive effect of adding dried bacteria, which should stimulate heating, could be established.

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