

Processes and Balance of Organic Matter Turnover and Transformation  
of Mineral Compounds during Decomposition of Biogenic Material  
in the Presence of Soil Material

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# 1. Introduction

## 1.1. Formulation of the Research Question

The task of this thesis is to elucidate the process of composting biogenous material in the presence of mineral soil material.

Composting of biological material generally means a full or a partial mineralization of organic compounds of mixed plant material by producing  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{NH}_3$ , or  $\text{NO}_3$ , sulphates and carbonates of Ca, Mg and K, oxides of Fe and Mn, and phosphates. Some of these mineralization products are get lost from the composting biomass as gaseous compounds ( $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{NH}_3$ ), some as solutes with the drainage water ( $\text{NO}_3^-$ ,  $\text{SO}_4^-$ ,  $\text{K}^-$  and Mg hydrogen-carbonates), and some remain as precipitated or adsorbed compounds ( $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ , phosphates, sesquioxides) in the final compost product.

A small metabolic sideway of all composting processes, even under strongly oxidative conditions, leads within the decaying biological masses to the formation of fulvic and humic substances. These are able either to mummify decaying organic tissues — the formation of ``mor`` or german ``moder`` particles — or to become strongly precipitated as humates on the surface of clay particles (mull-formation). In both cases these relatively stable or even inert byproducts create the dark, blackish grey colour of all composts.

The relation between mineralization of organic bio-substance and the formation of dark stable by-products can approximately be demonstrated by means of the usual process of biomass composting without additional soil material under a shelter with return of the mineral solutes to the compost heaps. The resulting compost is looked at as ``fully ripe``, that means showing only very little microbial activity.

## 1.2. Earth Compost

There are principally two aims and two ways of composting: The classical farm yard compost produced for hundred of years consists of a mixture of soil material and biogenic plant and animal borne residues. Loamy soil material was often used without any addition of lime as a possible accelerator of decay, but sandy soil material became often mixed with limy loamy admixtures.

The aim of this composting process was mainly to initiate a very rapid composting process, resulting less in an accumulation of humus in the remaining soil material but in a ``fertilized`` soil material enriched with basic cations and precipitates of carbonates and phosphates of the mineralised biogenic material. After finishing this process of enrichment the soil material was spread out or used for special borders in the garden or in the field — often in exchange against exhausted soil material. Till now this type of soil material fertilisation is still in use in China where it for example serves as a mean for remote the faeces from public latrines. The processes of earth composting are similar to those which run in the field, where harvest residues or farm manure are under ploughed — apart from the different ratios of organic matter and soil material.

Because most of the soil microorganisms destructing organic amendments are more or less sessile ones, settling on the surface of form stable mineral soil particles, a repetition of mechanical mixing of the compost heap initiates a strong promotion of the decaying process by bringing the sessile microflora in new contact with fresh organic residues. Therefore, it is possible to mineralise even meat products and wool waste.

Since the load capacity of the added soil material and its adsorbing minerals is often large enough to use the same soil material for the same repetitions of the composting process without an exchange against exhausted soil, the transportation processes become minimized.

Temperatures during the fermentation process will not increase. It is a ``cold`` biological combustion process. Earlier experiences with this process have shown that the amount of organic residues at the final stage of fermentation is much lower than in the process of biomass composting described below. The reason for this depends on the fact that, only macromolecular substances resulting from the by-process ``humification`` become adsorbed by the clay particles and no other organic bodies like plant tissue detritus are needed for the precipitation of humates, which incrust and preserve these bodies by mummification. Therefore, one may comprehend the process of earth composting as a *cold* (no temperature increase), *catalytic* (presence of sessile microflora on humate adsorbing mineral particles), *combustive composting process*.

The hygienisation of the organic additives, especially the decomposition of animal and plant borne parasites is ruled by the same conditions that exist in traditionally ploughed fields.

Earth compost heaps are more easily to manage as biomass heaps because the troubles with smell, swarming insects, rats, cats, birds and effluents are avoided by the controlling effect of the soil inter-layers or the fully admixed soil additives.

### 1.3. Biomass Compost

In biomass composting the process of fermentation proceeds without any addition of soil mineral masses and only the mineral remnants of the biogenous material, which are determined by ignition, are involved in the process. These remnants consist of plant ash, deposited in side the plant by ionar or molecular uptake of nutrients from the soil, of colloidal substances adhering to the plant surface which originate from dust deposition or rain splash borne suspension, and of soil material associated with the roots of weeds and stubbles extracted from garden soils. A quantitative example for composting process gives the following overview:

	Parts of organic substance	Parts of ignition residues
Original material grass, leaf litter, small hedge twigs	925	75
``Ripe`` Compost	25 (stable)	75
Mineralised organic substance	900	
mineralised : stable = 36		

At the end of the mineralization a ``ripe`` compost can show up to 75 weight percent of accumulated mineral substance and 25 % of the stabilised organic residuals, thoroughly mixed with the mineral remnants compared with the earth composting process, the biomass composting, when it is run as a block process with a big mass of biogenic substance starting the fermentation at the same time, shows a rapid temperature increase up to 70 °C, lasting for some days, which is looked at as an important factor for the hygienisation.

The method of biomass composting originated in the intention of gardeners to produce a material which contains a high amount of stabilized organic substance (humus) in order to improve or to maintain the physical properties of the garden soils or substrate amended with this material. The main condition for its application in the field is that if the compost product is ``ripe``, that means it should not cause any disadvantages to the soil, for example fixation of mineral N compounds or hygienic impacts.

Unlike the earth composting, the aim of biomass composting is not to obtain a quick and nearly complete mineralization of the biogenic material in the bulk mass of the heap but to produce a material rich in humus and lowered in its mineralization capacity after mixing with the soil in the field. The total process of mineralising the biogenic material is thus divided into two phases: the preliminary phase in the compost heap in order to produce a stabilized and hygienized ``ripe``

humus, and the second phase - after adding to the soil - a finally full mineralization at reduced rates.

A direct addition of plant residues without any previous composting to the field soil would be possible - that means earth composting in the field or field composting - but it often causes a delay in growing plant cultures by the problems of microbial adjusting. The biomass composting outside the field shortens this phase

From a microbiological point of view the process of biomass composting differs markedly from earth composting. There are no fixed points for a permanent sessile microflora existing. During the fermentation of pure biogenic masses the volume of the residues is permanently shrinking accompanied by the formation of mucilage which grades from the particles surface into their interior parts. Stable places for the settlement of microorganisms - in the earth compost process offered by mineral particles - are thus rare because shape and size of the particles are permanently changing. In addition the fermentation process is according to the sliming not in all parts an oxic one. Reductive dyoxic compartments are always intermixed.

Dissolved low molecular huminic substances cannot - opposite to earth composting - be absorbed by mineral particles (mull formation). They are infiltrating plant tissue debris, consisting of celluloses and proteins, thus ``tanning`` or ``mummifying`` them (moder or mor formation) and at the same time clogging the accumulating and precipitating mineral compounds. This incrustation process leads to the aspired reduction of their mineralization.

#### **1.4.Recent Status**

Surprising is the fact that, now for about 15 years the described method of biomass composting is the predominantly recommended for the recycling of biogenic residues of households, gardens and village or town green areas. This refers to smallest family composters (decentralised composting) as well as to large compost plants for whole districts (central composting).

There are three crucial ecological points connected with biomass composting:

1. The environmental effects of compost heaps, smell, allergens, flies, rats, etc.
2. The loss of organic compounds by gaseous exhalations including  $\text{NH}_3$  and  $\text{N}_2\text{O}$ -losses and leachates including  $\text{NO}_3$ , K and other soluble nutrients, leachates that affect the underlying soil and often need an additional expensive cleaning process.
3. The point of ``ripeness`` at which the composting process has to be interrupted. Focusing on wastes from households, gardens and parks of urban areas, they are mostly characterized by low C:N ratios. But they need along time for getting a degree of microbial stabilisation which allows storing, transporting, and spreading out without a negative atmospheric impact. The small table in the foregoing chapter reflects the composting of such ripe compost, which has lost more than 90 % of its organic substance.

In this case the relation between pre-composting turnover in the heap and the subsequent low rate of mineralization in the soil has become replaced in an ecologically very ineffective manner. In addition this is accompanied by high useless and even hazardous effluxes of gases and effluents. Why not instead of this problematical way of composting the earth composting with its simple control?

The main argument for biomass composting against earth composting is the low weight of material which has to be transported. Composting and compost distribution seems always to be a transport problem.

But how much of argumentation is connected with ignorance about the process balances. If we consider the addition of soil material to the composting process as the addition of a catalyst and a

loadable nutrient reservoir, which can remain for a large number of repetition of composting at the same composting place, the conditions for comparison are fundamentally changed.

To bring new arguments into this methodical discussion the following studies would concentrate on the investigations concerning earth composting because this technique seems to be neglected in an unjustified manner.

## **1.5.Literature**

The literature concerning composting processes and the techniques in their systematics of terms is mostly not in accordance with the definitions given above or with the functions which the composting products should fulfil as they are

- 1- Substrates for plant growth,
- 2- Fertilise the soil,
- 3- Ameliorate soil physical structure,
- 4- Volatilize soil in their microbial activity,
- 5- Protect soil against erosion,
- 6- Control of weeds and diseases.

### **1.5.1. Compost and Composting Process Definition**

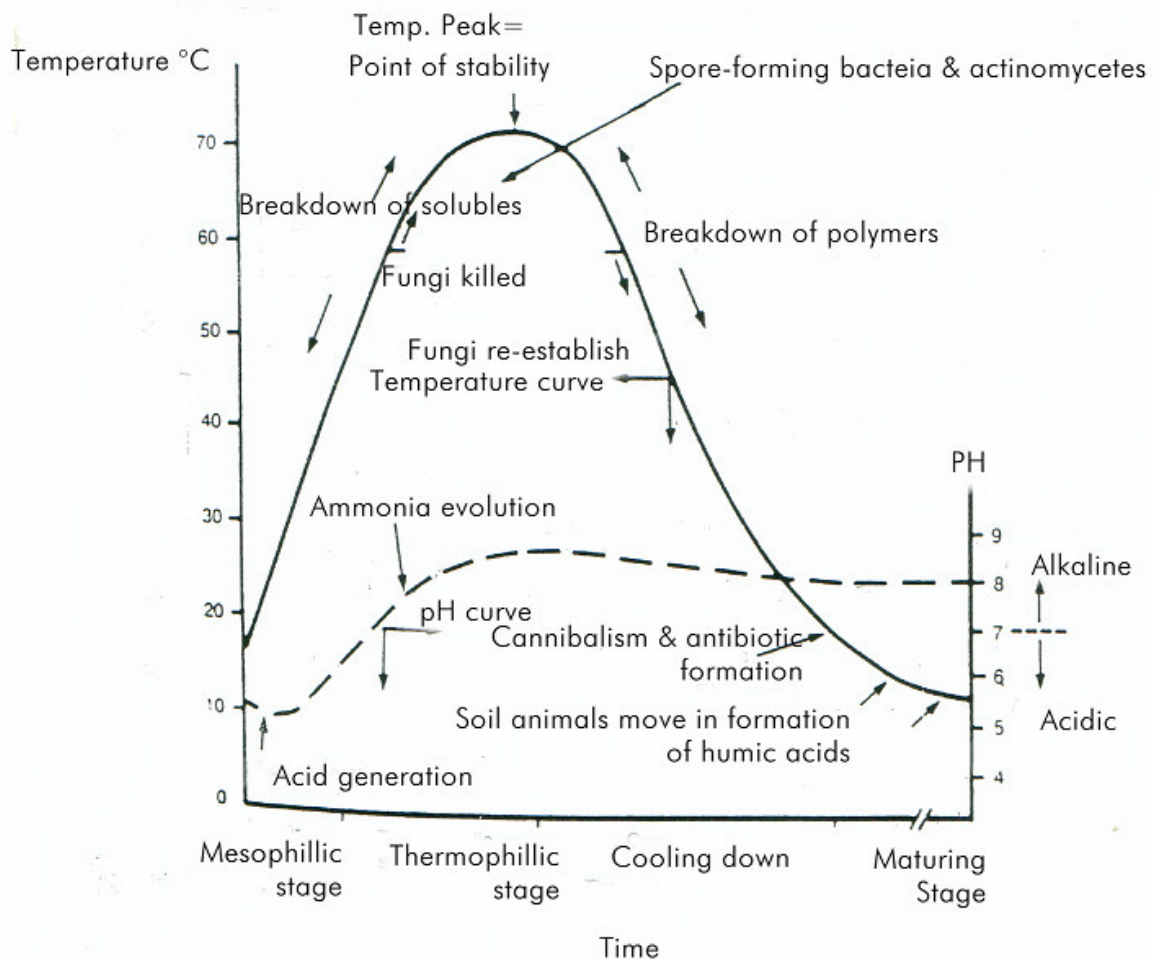
Most of compost literature is directed towards biomass composting. The treatment of organic wastes before applying them to the soil can be aerobic (composting) or anaerobic (fermentation, biogas digestion) which changes their composition (Kirchman and Witter 1992), microbial stability and, therefore, the proportion of C mineralised after their addition to soil (Berndt and Kirchman 1989).

Composting is the most widely used treatment of organic wastes, which is very well developed for city refuse. It is defined as a biological process of aerobic decomposition which degrades labile organic matter to carbon dioxide, water vapour, ammonia, inorganic nutrients and a stable organic material (compost) containing humus-like substance (Sensei 1989).

The composting process is mainly performed by micro-organisms such as bacteria, fungi, actinomycetes, but during later stages animals like mites, insects and worms may also contribute. Heat is produced due to the metabolism of decomposing organisms, but when heat production exceeds heat losses the temperature will start to rise.

The temperature course is used to describe the different phases of composting process; an initial mesophilic phase (25-45 °C), a thermophilic phase (45-70 °C), a second mesophilic phase and a cooling phase when the compost approaches the ambient temperature, figure 1. During these phases, a considerable amount of the dry mass is lost, mainly as carbon dioxide (Eklind 1998).





**Figure 1: Temperature and pH variations in a compost heap (source: Gray and Biddlestone 1981)**

### 1.5.2. The Historical Development of Composting

Application of organic residues on agricultural lands has been practiced for increasing soil fertility and crop production from time immemorial. Composting is known as the oldest and most natural way to recycle organic wastes. Farmers and gardeners for many centuries have practiced composting in some of its primitive forms. Night-soil, vegetable matter, animal manure, refuse, etc. were placed in piles and pits located in some convenient places and allowed to decompose as conditions would permit until the material was ready for the soil or the farmers were ready to apply it to the land. This process involved little or no control, required long periods in the pile to provide a good humus, might or might not conserve maximum nitrogen, and certainly did not provide sanitary treatment (Gotaas 1956).

The first important advance in the practice of composting was known as Indore process, named after the locality in which it was developed, (Howard and Wad 1931). This process when first developed used only animal manure, but later it involved stacking on open ground alternate layers of readily putrescible materials, such as Night-soil, animal manure, sewage sludge, and garbage and relatively stable organic matter such as straw, leaves, municipal refuse, and types of stable wastes. The composting stacks were aerobic for a short period after piling and after each turn, and were anaerobic during most of the composting period.

In 1935 intensive studies on problems of composting of faeces and wastes in rural areas were carried out in Northern China by Scott (1952).

During the period 1926-1941 Waksman et. al. (1939) carried out fundamental research on aerobic decomposition of vegetable residues and stable manure.

From 1950-1952, Golueke and Gotaas (1954) conducted research on some of the basic aspects of composting mixed municipal refuse containing garbage, both with and without addition of sewage sludge.

During the period that the early composting practices were being refined in India, China and elsewhere, other investigators, notably in Europe, were devoting considerable efforts to mechanise the composting process particularly for use as a method for the treatment and sanitary disposal of the garbage and refuse from cities.

The mechanized and the enclosing processes are primarily designed for cities but they are also valuable in rural and village composting.

One of the most widely used processes was developed by Beccari (1920), Italy. Initial anaerobic fermentation is followed by a final aerobic stage. It was later modified as Verdier process.

Bordas (1931) further modified the Beccari process, his aim being to eliminate the anaerobic stage.

A silo-type multiple-grade digester for producing compost under aerobic conditions, using rotary ploughs and forced air for aeration, was patented by Earp-Thomas of Haulton, N.J. (1939). An essential feature of the process is the use of special bacterial cultures supplied by Earp-Thomas.

A variation of the digester-type enclosed cell, consisting of a double-walled silo with multiple floors, was recently designed by the Ralph W.Kiker company of Lansing, Mich., a special inoculum is reported to be involved in this process.

The Frazer process (Eweson 1953), patented in the USA in 1949, used an enclosed fully mechanised aerobic digester.

Snell (1954) has carried out experimental studies on composting in a silo-type digester using mechanized stirring.

The first Dano process developed in Denmark is usually referred to a composting process, but it is essentially a refuse-separating and grinding operation, the product of which can be composted by any recognized procedures.

The Dano Corporation (1955) has developed a mechanized silo-type digester, known as the Bio-stabilizer, which has been in operation on a pilot-plant scale, composting about 20 tons of refuse per day.

The VAM processing procedure, utilized in the Netherlands since 1932 by N.V.Vailafoer Maatschappij (VAM), a non-profit utility company formed by the Government for the disposal of a city refuse, is essentially an adaptation of the Indore process for composting large quantities of municipal refuse, which contains little garbage or readily putrescible food materials.

Stovroff and his associates of the compost corporation of America (Stovroff 1954) have carried out extensive pilot-plant operations, and have studied the economics of composting municipal and industrial refuse from larger communities to produce fertilizers.

The plant planned for aeration in Oakland, California, as a private enterprise, is designed to compost 300 tons of mixed garbage and refuse, the operation is entirely aerobic, using the windrowed-pile method, and is in effect, a modern mechanisation of the basic indoor technique.

Another plant is in Baden-Baden, Germany. This plant has mechanized materials-handling equipments.

In London, the Borough of Southwark has composted market refuse, stable manure and garbage since 1906 (Martin 1949).

Various parts of Africa use different modification of the Indore procedure (Vuren 1949).

One of the experiments with mechanising earth composting has been performed in Regensburg (Germany) by Dr. Issels, who used the soil material washed from sugar beets in the sugar factory for mixing and composting of biogenic town wastes.

## **1.6.Objectives**

The main objectives of the experiments of this thesis are:

- To study the general conditions, phenomena and effects of earth composting.
- To evaluate the effect of different quantitative mixtures of soil material and organic matter on the velocity of turnover and mineralization of the biogenic substance.
- To make a balance of the process of mineralization products and to ascertain the pathways of mineralization products like gaseous losses or adsorption by soil mineral particles.
- To monitor the fate of organic byproducts of composting like fulvic and huminic acids and their sorption on clay particles as humates.

## **1.7.Experimental Design**

Considerations concerning the technical applicability in practice and the experimental practicability led to the conclusion to use a soil material which is widely spread in Middle Europe, which contains enough clay for sorption (10-15 %), simple to handle within creating a finely crumbled substance by sieving and easily mixable with organic residues. Such material is loess or material from loess derived soils. Because there was no detailed knowledge available about the possibly promoting effect of lime on the velocity of organic decomposition it seemed advisable to start with an original calcareous loess material referring to the traditional techniques.

Regarding the biogenic test substance and with respect to the intention to repeat the experiment with the same soil material for several times it seemed necessary to store a bigger volume of this biogenic test substance. The best manner to achieve that is by air-drying. Additionally, the experimental design to conduct the experiments in small composting cages required a material with a good miscibility. This led to the decision to gather grass from a short cut lawn and to make hay of it.

The mixing ratios of soil material and hay should comprehend different composting conditions. One of them should simulate the situation on arable fields, where the remnants of cultivated plants or an intercrop are mixed with the soil by tillage. Reduced tillage with an admixture to the upper 5 cm of the soil can here cause soil:biogenic substance dry matter ratios between 50 and 75. Therefore, it is advisable to choose such a large ratio.

On the other hand, a practicable minimum rate must allow an economic composting inside of bulk-masses. A weight ratio of 10:1 means volumetrically a mixture of about 6 volume parts of soil material and of 4 to 6 volume parts of grass hay, not being compressed but only softly condensed. Looking on the technical problems of mixing and the large volume losses of the bulk-mass during mineralization this mixing ratio seems to lie at the lower limit of what one can call ``earth composting`` - specially under considering the demand of a good contact between the sessile microflora and the biomass.

## 2. Materials and Methods

### 2.1. Components of the Experiment

#### 2.1.1. Standard Grass Material

The grass was mawn at a lawn belonging to the university clinic complex, Göttingen, on a loess derived luvisol, air dried in the field to hay and stored in a shelter for repeated experiments. The analysis of the dry matter is given in table (1):

**Table 1: Chemical composition of the grass, % dry matter**

	%		%		
Na <sub>2</sub> O	0.173	Ct	44.270	Ct:Nt	15.64
K <sub>2</sub> O	1.580	Nt	2.830	Nt:St	11.0
MgO	0.367	St	0.257	Ignition loss (IL)	91.5
CaO	1.080			IL:Ct	2.1
P <sub>2</sub> O <sub>5</sub>	0.862				
Ignition residue	8.524				

#### 2.1.2. Standard Loam Material

Calcareous material was dug out from the calcareous subsoil (Cr-horizon) of a gley-chnozem developed in a more than 3 m parcel of Wuermian (Weichselian) Loess of the youngest phases of the last glaciation period. This calcareous material had been chosen because the general old opinion is that, lime is one of the promoting factors in earth composting.

The soil material was air dried, crushed by a breaker, sieved at an aggregate size less than 5 mm and stored for repeated experiments. Analytical data are given in table (2).

**Table 2: Composition of the loam, % dry matter, mg, grain size composition of loess, % material free of lime**

2000-630µm	630-200µm	200-63µm	Sand Σ	63-36µm	36-20µm	20-6µm	6-2µm	Silt Σ	Clay < 2µm
0.83	0.83	2.80	4.46	29.13	25.13	19.78	4.90	78.94	16.60

Chemical components:

CaCO <sub>3</sub> , %	12.73	CEC, mmol IE/kg	92.8
C org, %	0.08	Na <sup>+</sup> , mmol IE/kg	3.5
Nt %	0.0165	K <sup>+</sup> , mmol IE/kg	2.7
Corg / Nt	4.54	Mg <sup>++</sup> , mmol IE/kg	2.3
Gypsum, %	0.015	Ca <sup>++</sup> , mmol IE/kg	84.3
		NO <sub>3</sub> -N, mg/100g	5.427
		NH <sub>4</sub> -N, mg/100g	0.04

### 2.2. Procedure

#### 2.2.1. Reaction Vessels

The grass/loam composting reactions were studied by use of cube formed 150 litre cages, consisting of an iron frame 50 x 50 cm bottom measure and 60 cm high and iron lattice walls of 50 mm mesh width. These air open containers were put together in a block system, which protects them against influence of different water input and output by a plastic cover. To avoid losses of soil material, the cages were coated internally by a Nylon-net with 100 µm pore diameter.

### 2.2.2. Variable Mixtures

The reaction vessels were filled with 6 different mixtures of standard loam and standard grass of the following ratios of dry matter weight:

- 1) 10    2) 16    3) 21    4) 32    5) 44    6) 54

The last variable had been chosen because it nearly reflects the situation of arable land, which has got the harvest remnants incorporated by shallow ploughing. The first mixture ratio represents the technical minimum of mixing for the earth composting system.

After filling in both materials, the mixture was wetted with tap water up to field capacity, and incubated under a shelter that controlled wetting due to precipitation but at the same time exposed them to the changing atmospherically temperature conditions of the different seasons (averages January +1°C, July 18°C).

### 2.2.3. Repetition

After different incubation time intervals the addition of grass to the ``composted`` mixture was repeated. Table 3 lists up the data of different actions. Phases 1 and 2 are preliminary experimental phases and were not considered here.

The main composting phases were 3 & 4 lasting 2.5 months, 5 & 6 lasting 4 months and 8 & 9 lasting about 1.5 months. Table 4 comprehends the amounts of dry matter involved in the composting process.

**Table 3: Data for the different manipulations of composting**

Addition of grass	Addition No	Mixing (only)	Homogenisation and sampling	Sampling No. (letter)	days of incubation			
12.08.93	1							
04.11.93	2							
17.09.99	3				74	211	360	446
			30.11.99	a	24			
24.12.99	4				113			
			15.04.00	b				
		10.06.00			97			
21.07.00	5				52	149		
			11.09.00	c				
		23.10.00			86			
			06.12.00	d				

**Table 4: Mixture components loam and grass in kg dry matter per composting vessel**

kg loam initial admixture (12.08.93)*	ratio loam:grass = treatment	Grass repeated admixture kg					Total
		12.08.93 No. 1	04.11.93 No. 2	17.09.99 No. 3	24.12.99 No. 4	21.07.00 No. 5	
79	10	4,78	2,17	7,90	7,90	7,90	30,66
75	16	4,35	2,17	4,70	4,70	4,70	20,62
80	21	3,48	2,17	3,81	3,81	3,81	17,08
73	32	2,17	2,17	2,27	2,27	2,27	11,16
96	44	1,96	2,17	2,18	2,18	2,18	10,67
88	54	1,73	2,17	1,63	1,63	1,63	8,79

\* calculated for addition No. 3, 4, 5 (17.09.99 – 21.07.00)

## **2.3. Mixing and Sampling**

Mixing combined with sampling of compost material was performed in the following way: The reaction vessels were emptied. The compost material (CM) was sieved in air-dry condition through 1.1 cm sieve. The sieve was selected after Atterberg-2-system-scale and for an optimal separation of the preserved grass remnants. The compost was separated into:

Fraction 1 (F1): > 1.1 cm diameter mainly grass residues with some adhering loess.

Fraction 2 (F2): < 1.1 cm diameter mainly loess material and brownish grass detritus.

The substance passed the 1.1 cm sieve (Fraction F2) was washed on a 2mm sieve. The 2 mm sieve Atterberg scale is commonly used for the separation of fine earth. In this case it was opted to separate the structure-less swollen moder aggregates of low density from the adhering silt. The passing material separated into a swimming (float) and a settling components (sediment). The swimming part (float) was combined with the material remaining on the sieve and called fraction 2a. The sediment forms the fraction 2b. Therefore, fraction F2 was separated into:

Fraction 2a (F2a): FLOAT mostly organic grass borne fine residues = moder, mor.

Fraction 2b (F2b): SEDIMENT, mostly loess minerals and organo-mineralic aggregates.

### **2.3.1. Sampling Without Mixing**

From each reaction vessel three samples were taken by using an auger of 50 cm length and 3.5 cm in diameter. Fractionation was done in the same way as described above. The samples were stored at room temperature for later analysis.

## **2.4. Chemical Analysis**

The following analyses were carried out on ground 105 °C dried samples:

### **2.4.1. Ash (Ignition Remnant)**

600 °C for 6 hours (CM, F1, F2a, F2b).

### **2.4.2. Total Carbon (Ct)**

Dry combustion, gas chromatography, heat conductivity detector.

### **2.4.3. Total Nitrogen (Nt)**

Dry combustion, gas chromatography, heat conductivity detector, System Carlo Erba ANA 1400 (CM, F1, F2, F2a, F2b).

### **2.4.4. CaCO<sub>3</sub>**

Gas volumetric CO<sub>2</sub> determination after HCl addition by Scheibler apparatus (loess, F2).

### **2.4.5. Nmin**

NO<sub>3</sub> dissolved plus NH<sub>4</sub> adsorbed: Extraction by 0.2 N CaCl<sub>2</sub> and 0.2 N KCl, respectively. Steam distillation after Bremner and Keeney (1966):

### **2.4.6. Total Sulphur (St)**

Total S is estimated by a method described by Brumsack (1981) using C/S Analysator (Eltra CS 500). 500 mg of fine ground sample are used for measurement.

S is measured at 750 °C (FeS, S org) and at 1550 °C (CaSO<sub>4</sub>). SO<sub>4</sub> content is determined by the difference between total S and S (loess, grass, F1).

#### 2.4.7. Total Phosphorus (Pt)

Pt is determined by using the digestion method described by Olsen and Dean (1965).

##### **Reagents:**

- Perchloric acid (HClO<sub>4</sub>), 60 %
- Ammonium paramolybdate-vanadate: Dissolve 25 g of ammonium paramolybdate {(NH<sub>4</sub>)<sub>6</sub>Mo<sub>7</sub>O<sub>24</sub>·4H<sub>2</sub>O} in 400 ml of distilled water. Dissolve 1.25 g of ammonium metavanadate (NH<sub>4</sub>VO<sub>3</sub>) in 300 ml of boiling distilled water. Cool the solution, and add 250 ml of concentrated nitric acid (HNO<sub>3</sub>). Cool the solution to room temperature. Pour the ammonium paramolybdate solution into the NH<sub>4</sub>VO<sub>3</sub>-HNO<sub>3</sub> solution, and dilute to 1 litre with distilled water.
- Standard phosphate solution: Dissolve 0.4393 g of oven-dry potassium dihydrogen phosphate (KH<sub>2</sub>PO<sub>4</sub>) in distilled water, and dilute the solution to 1 litre. One millilitre of this solution contains 100 µg of P. Prepare solutions containing 10 µg of P/ml by diluting suitable aliquots of the solution with distilled water.
- Sodium hydrogen sulphite (NaHSO<sub>3</sub>) solution: Dissolve 5.2 g of reagent grade NaHSO<sub>3</sub> in 100 ml of 1.0 N sulphuric acid (H<sub>2</sub>SO<sub>4</sub>). Prepare the solution weekly and stopper the flask.

##### **Procedure:**

2.0 g of finely ground material (0.5 mm) are mixed with 30 ml 60 % HClO<sub>4</sub> in a 250-ml volumetric or Erlenmeyer flask. The mixture is digested at a temperature a few degrees below the boiling point on a hot plate in a hood until the dark colour due to organic matter disappears, then continued heating at the boiling temperature 20 minutes longer. At this stage, heavy white fumes of HClO<sub>4</sub> appear, and the insoluble material became like white sand. The total digestion usually requires about 40 minutes. The mixture is cooled and distilled water is added to obtain a volume to 250 ml, mixed and allowed to settle before taking the aliquots.

The aliquot is pipetted into 50-ml volumetric flask. 10 ml of the vanadomolybdate reagent is added and the solution is diluted to 50 ml with distilled water.

After 10 minutes the optical density is measured at wave length from 400 to 490 nm. The reagent blank is prepared and its optical density is subtracted from that of the sample (loess, grass, F2).

#### 2.4.8. Capacity for Exchangeable Cations (CEC)

MEHLICH method uses Ba as exchanging ion and Triethanolamine as buffer (pH 8.1) with respect to the carbonate content of the samples. The following analyses are carried out with grumbled soil material.

10 g of loess or compost material are filled in plastic tubes. 250 ml of exchange solution are added from above by tube pumping. The outflow is analysed for K, Mg and Na by atomic absorption analysis (AAS). In a second run the Ba adsorbed by the soil material in the leaching tube is exchanged by CaCl<sub>2</sub> solution added in the same way as before by a tube pump. Ba is also determined by AAS. Ca is calculated by difference:

Ba (total exchange capacity) minus the sum of exchanged K, Mg Na.

This is useful because in the presence of CaCO<sub>3</sub> often more Ca is dissolved than exchangeable Ca (loess, F2).

## **2.5. Physical Analysis**

### **2.5.1. Water Holding Capacity (WHC)**

A paste of compost material is put into a sieve. After runoff of surplus water the weight is determined. Weighing is repeated after oven drying (F2a).

### **2.5.2. Grain Size Analysis**

The grain size analysis consists of sieving and sedimentation analysis. Since the loess material used here contains very little humus, only  $\text{CaCO}_3$  and iron oxides had to be destroyed.

$\text{CaCO}_3$  is destroyed by HCl addition,  $\text{FeOOH}$  by reduction with Sodiumdithionite/Citrate mixture. This seems to be sufficient for comparison between the standard loess material and its final reaction products.

The fraction  $> 20 \mu\text{m}$  in diameter were separated by sieve analysis, the smaller fractions by repeated sedimentation analysis at  $25 \text{ }^\circ\text{C}$  following Atterberg, that means sampling all fractions for mineralogical analysis.



## 3. RESULTS

### 3.1. Turnover of Organic Matter

#### 3.1.1. Structural Changes during Earth Composting

This chapter deals with destruction of added grass by tracing the turnover of its organic compounds. All figures considered here are related to the organic substance added, determined by ignition loss or elemental analysis. The amounts are given in g/vessel.

Table 5 is related to tables 3 and 4 and it presents the amounts of organic substance in added grass and compost fractions (g/vessel) at the 4 sampling dates.

Sampling b and d were determined after winter period and incubation in a glass house with controlled temperatures at about 17 °C, sampling a and c after a summer/autumn period under field conditions. The difference between the two groups depends on the accumulation of remnants of previous grass additions.

The tables demonstrate that the decay of grass clearly detectable by its histological structures (fraction F1) consists at a first step in the formation of smaller particles, which consist predominantly of organic material and can easily be separated from the mineralogical soil compounds by its low density by means of water suspension. This is the moder or mor fraction (F2a).

The second step consists in the formation of organo-mineral complexes, which can only be separated by chemical or biochemical methods and is referred to ``mull`` (F2b).

The evaluation of data in table 5 showed that F2a represents only an intermediate or transition fraction, which has to be considered as a flow equilibrium fraction. It increases and shrinks again with the magnitude of grass input, remnants of the preceding sampling date and the duration of incubation.

Therefore, it seems suitable to combine fractions F1 and F2a in table 5 for two reasons:

- 1) In course of auger sampling (sampling a and c) no separation between F1 and F2a was done.
- 2) The increase and decrease of F1 between the sampling data and between the mixture variants is often accompanied by a reverse swelling and shrinking of the moder fraction F2a. Thus it is useful to operate with the sum of these two fractions.

The data in table 5 in the columns 2 to 8 are determined by ignition loss, the data in column 9 by combustion of total C and multiplication by 1.724.

Table 6 gives a basis for calculation of the C-balance in the system. It picks out the situation at the end of the experiment after 446 days of reaction and 3 additions of grass. With respect to the fact that the composition of the organic matter in the fractions is changing during the transformation process the balance was based on the organic bound C.

It also shows that the gaseous losses occurring during the transformation of grass to mull humus have accounted to about 59 % in average - except treatment 10, where the high amounts of grass was added, seemed to lower the mineralization rate by delay of grass decomposition

Gaseous losses are one of the fates of C transfer. The other one consists in the formation of mull humus where the average percentage is found to be about 17 (table 6).

Table 5: Amounts of organic substance in form of added grass and compost fractions (g dry matter/vessel) at the four sampling data A-D (compare table 3)

1	2	3	4	5	6	7	8	9
	organic substance total added			remnants total at sampling date				Mull humus at sampling date
	no.	no.	sum	F1+F2a+F2b	F1	F2a	F1+F2a	F2b

**Sampling a (30<sup>th</sup> Nov 1999) 74 days after addition no. 3**

treatment	1+2	3	$\Sigma$				
10	6957	7900	14857	3508	2552	2552	956
16	6521	4700	11221	2361	1733	1733	628
21	5652	3810	9462	2795	2209	2209	586
32	4348	2270	6618	1446	956	956	490
44	4130	2180	6310	1781	1311	1311	470
54	3904	1630	5534	1513	1129	1129	384

**Sampling b (15 April 2000) 113 days after addition no. 4  
211 days after addition no. 3**

treatment	1+2+3	4	$\Sigma$				
10	14857	7900	22757	5704	1953	2550	4503
16	11221	4700	15921	5406	1735	2529	4264
21	9462	3810	13272	3354	1425	655	2080
32	6618	2270	8888	2454	584	1236	1820
44	6310	2180	8490	2775	971	1208	2179
54	5534	1630	7164	1920	87	1401	1488

**Sampling c (11 Sept 2000) 52 days after addition no. 5  
262 days after addition no. 4  
360 days after addition no. 3**

treatment	1+2+3+4	5	$\Sigma$				
10	22757	7900	30657	8541	5741	5741	2800
16	15921	4700	20621	6737	4488	4488	2249
21	13272	3810	17082	5646	3845	3845	1801
32	8888	2270	11158	3711	2657	2657	1054
44	8490	2180	10670	3579	2627	2627	952
54	7164	1630	8794	2754	2215	2215	539

**Sampling d (6 Dec 2000) 138 days after addition no. 5  
348 days after addition no. 4  
446 days after addition no. 3**

treatment	1+2+3+4	5	$\Sigma$				
10	22757	7900	30657	13558	4572	5062	9634
16	15921	4700	20621	6610	2125	1965	4090
21	13272	3810	17082	6475	2417	1897	4314
32	8888	2270	11158	3769	1458	497	1955
44	8490	2180	10670	3742	1305	770	2075
54	7164	1630	8794	2819	534	1467	2001

**Table 6: C-balance at the end of the experiment (Sampling D)**

Loam:Grass mixing ratio (=treatment)		10	16	21	32	44	54
C-added by grass (total) g/kg loam		161	121	99	67	50	44
		C		%			
1	Added by grass	100	100	100	100	100	100
2	Gaseous losses	45,5	60,2	56,0	58,4	59,6	59,6
3	Mull fraction F2b	17,0	16,3	15,9	21,6	17,8	12,4
4	Sum 2+3	62,5	76,5	71,9	80,0	77,4	72,0
5	Remnants F1+F2a	37,5	23,5	28,1	20,0	22,6	28,0

If we add the C of gaseous losses (row 2) and C of mull humus formation (row 3) we earn an average (row 4) of about 73 % total losses of grass C. It has to be stated that, surprisingly the percentage of C in gaseous losses, mull formation and remnants of grass and moder are roughly independent on the amount of admixed grass—except the variant with the highest amounts of admixed grass and possibly a mechanical factor causing decomposition delay.

Depending on this fact it is necessary to point out that the experiments in the phase of sampling a to c were done without any mixing between the date of grass addition and the sampling date, the omission has the function reduce the rate of decay. An exception was made in the last stage of composting where a mixing after 94 days of reaction was done (table 3).

Consequently the grass leaves remained in their original contact with mineral particles or better: aggregates, which they had got immediately after their admixture to the loam. If we regard the theory that the decay of plants tissues is caused by microorganisms which settle on the surface of mineral grains or aggregates, every grass leave—independent of the admixed mass—has the same chance of getting into contact with a certain number of those microorganisms colonies. The resulting moder particles would then mainly consist of the short pieces of grass leaves, separated by microbial perforation holes.

The next section of this chapter about nitrogen turnover will show that during the transition from grass to moder up to three quarter of the organic carbon is getting lost contrary to nitrogen which shows gaseous losses.

Table 7 gives the data expressed in the same way as in table 6 but now for all of the sampling data; the given percentages are related to the total amounts of grass added till the corresponding sampling date.

**Table 7: Percentages of gaseous losses, mull formation and remnants of organic C related to the preceding total C addition by grass, average values of all variants**

Sampling date	Gaseous losses	Mull humus formation F2b	Remnants F1+F2a
a	71	9	20*
b	65	9	25
c	63	12	26
d	57	17	20

\*the additions 1 and 2 were done 6 years before.

The data given in table 7 show independency between the preceding reaction time and the masses of admixed grass. The percentage of remnants (F1+F2a) is nearly the same, whereas the mull humus-C percentage increases with the proceeding composting process. This leads to the calculated decrease of gaseous losses percentage.

The fact that even after widely varying reaction times of composting the percentage of remnants is nearly the same leads to the conclusion that there must be a state of decay at which no further transformation occurs. Transformation could only be enhanced by mechanical mixing of the

composting mixture which facilitates new contact between microorganism colonies and fresh hay leaves parts.

Therefore, table 7 elucidates again the above mentioned theory for explanation and seems to make it conclusive

### 3.1.2. Mull Humus Formation

As written earlier, the fraction F2b could not be separated from the mineral components of the loess loam added to the compost by mechanical methods. It is referred to ‘mull humus’ or in the following text simply ‘humus’. It has to be interpreted as dark organic compounds, which are precipitated on the mineral grain surfaces. They seem to be mainly products of the chemical decomposition of grass (F1) and moder (F2a) down to colloidal molecular size like fulvates or humates. This humification seems to represent the predominant sideway of mineralization.

On the contrary, the other fractions, F1 and F2a, which have to be interpreted as transition or intermediate fractions, the amount of this humus increases permanently with the preceding process of grass admixture and composting. This is shown by table 8, which is based on organic C x 1.724.

**Table 8: Mull humus, g/kg loam (Corg x 1.724)**

Sampling date	a	b	c	d
Loam:grass				
10	11,5	16,0	33,8	47,4
16	8,5	15,4	30,3	34,0
20	7,4	14,5	22,6	27,1
32	6,8	8,8	14,6	25,2
44	5,0	6,4	10,2	15,3
54	4,4	5,0	6,2	9,5

A comparison of the data given in the above table can be done in a vertical direction, the comparison of mixing variants at the different sampling dates and a horizontal view, the increase of humus by time.

Figure 2 gives an impression of the time dependence of humus accumulation in the six different mixing variants. The main question in this connection: is this accumulation process a process with a final termination or not? From soil genetic studies the process of humate accumulation seems to be a restricted one, the restriction being given by the amount of adsorption or precipitation sites. The clay minerals are the main points of humate fixation, and earlier calculations have shown that for example in the Chernozems the thickness of the humate mantle around the clay minerals is about 5 nm, corresponding with a clay dependent humus content of those soils of 2.0 to 5.0 %.

In our case the curves don't show the begin of a saturation section, even in the variant with the lowest loam:grass ratio where the humus content related to loam has reached about 4.7 % at its maximum. Considering the fact that the added loam has 16.6 % clay and the natural Chernozems with comparable clay contents show equilibrium humus content of about 4 % at maximum, it had to be expected that especially the curve of the treatment ‘‘10’’ would show the begin of a decrease of the accumulation rate.

Considering the circumstances of this experiment it has to be stated that again figure 2 doesn't represent a true function of time dependent humus accumulation. It only shows a progress of humus contents from sampling date to sampling date and it has already been pointed out that there are different time lapses in the general run.

Experiments which follow the aim to find reliable functions have to be conducted in another way: Repeated mixing with exact controlling of time and humus fraction analysis in shorter intervals. The statistical analysis of the vertical columns in table 8 will give a comparison of the different

variants of the experiment. As shown in figure 2 the variants curves are splaying with increasing grass addition.

Figure 3 (5a to 5d) presents statistical analyses for this phenomenon. For the calculation of the regressions the initial Corg-content of the loam was not taken into consideration. The reason for this was given by the fact that otherwise the y-axis transects were negative, especially for A and C. This can be explained by the possibility that the originally lower humus content of the loess has a markedly other composition than the newly formed humus. The slope of the functions humus content versus the amount of totally added grass carbon increases from sampling date a to d in the following way:

a	0.1208
b	0.1749
c	0.2394
d	0.2888

Since between the 5c and 5d there was no further addition of grass, the increase of slope between the corresponding functions is only due to time factor and indicates that at 5c the final equilibrium of decay has not been reached.

The well known humus accumulation formulas based on the function between annual (bi-, tri-) addition of a certain amount of organic substance (a) with a certain quantity, characterized by its specific mineralization rate (100-q), and the resulting equilibrium humus content (s). These formulas  $s = f(a, q)$  have an exponential character. They mainly start at a point where the adsorption sites of the soil for humus, the clay, are more or less saturated by humates and do not bind further humates.

In our case we are still in the initial phase of this process and this doesn't give a successful further statistical evaluation at the reached stage. The increase of humus splays as indicated by the increasing slopes of the functions in figure 3 lead to the supposition that the exponential flattering of the accumulation curves is just in its beginning.

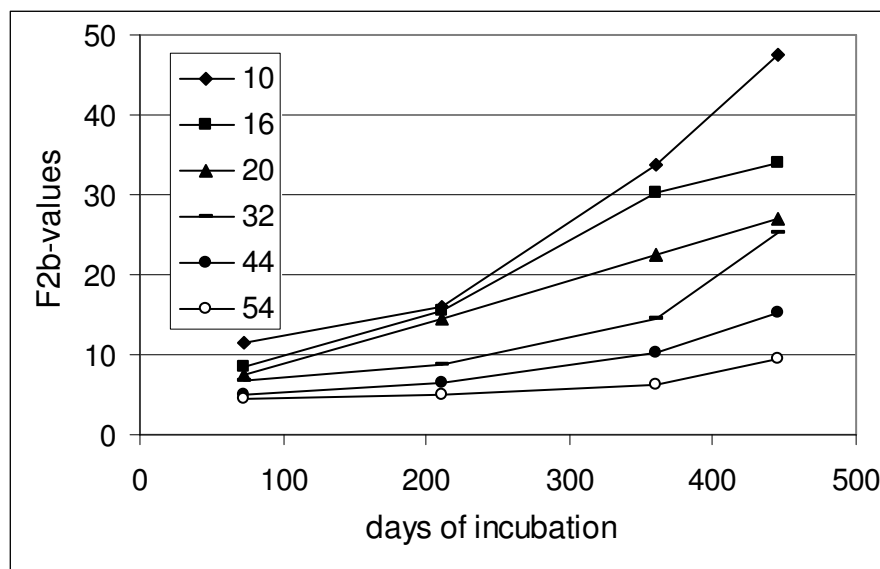
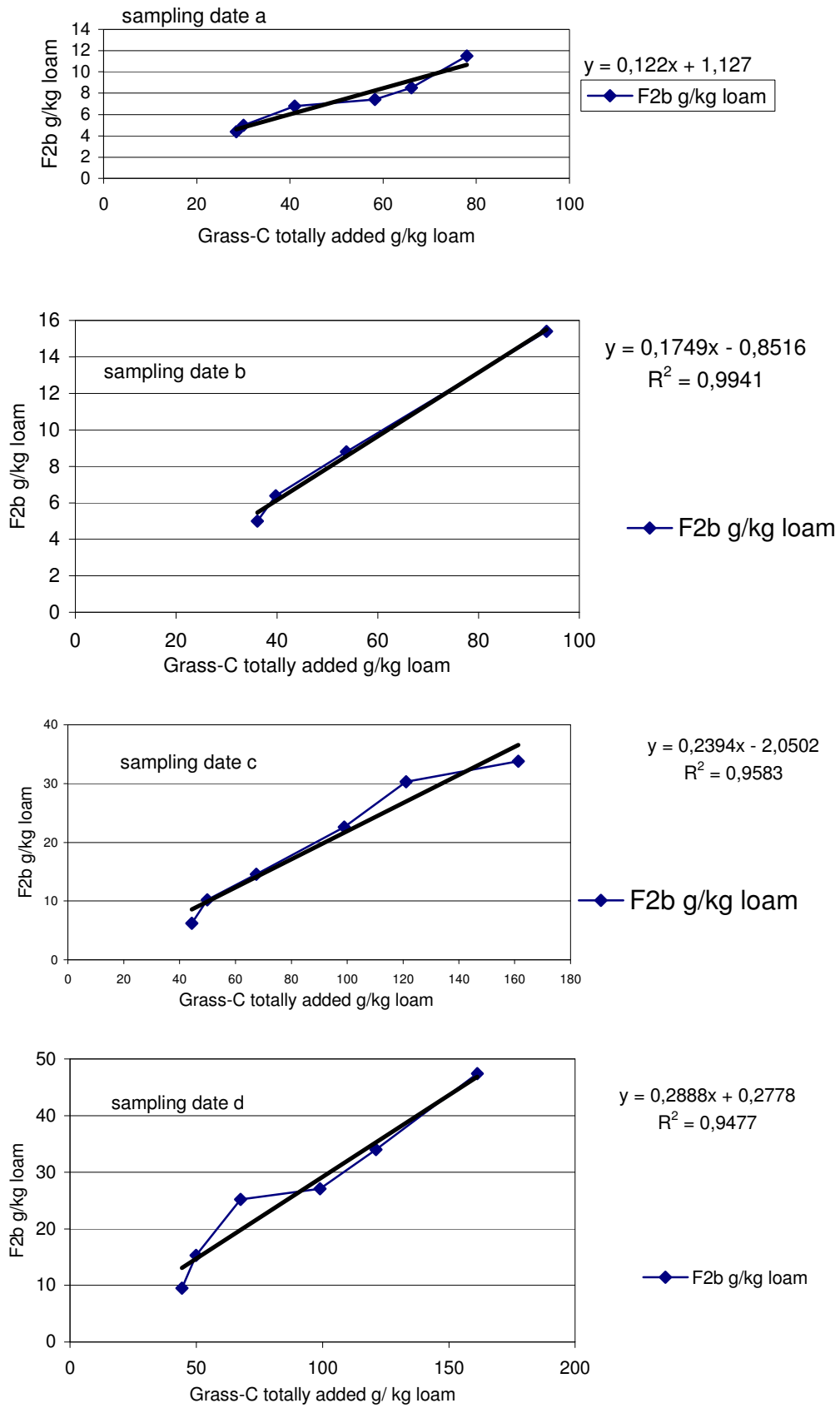


Figure 2: F2b g/kg loam as a function of days of incubation in different mixing variants



**Figure 3: Humus amount versus grass-C totally added g/kg loam**

### 3.2. Turnover and Balance of Nitrogen

Table 9 gives information about the C- and N-contents of grass (F1), moder (F2a) and mull fractions (F2b).

**Table 9: Ignition loss (organic substance), Corg and Norg in the fraction F1 (grass)**

	fraction	% Sample dry matter				% IL		% IL		C/N
		Ignition remnants (ash)	Ignition loss IL	Corg	Norg	C	IL:C	N	IL:N	
Grass	F1	8.5	91.5	44.27	2.83	48.4	2.067	3.11	32.3	15.6
Moder	F2a	29.2	70.8	39.54	2.44	55.9	1.791	3.45	29.0	16.2
						calculated				
Mull	F2b					58.0	1.724	5.8	17	9.9

Table 9 shows that the transformation of grass into moder leads to an increase of ash, which remains embedded in the organic moder substance. From the above data the loss of grass organic matter during the transformation process into moder is about three quarter (77.5 %) of the grass organic matter. These losses are attributed not only to the gaseous losses into the atmosphere but also to a less degree to the formation of mull humus.

The transformation of grass organic substance into fractions F2a and F2b is accompanied by increase of the C-content of organic matter, well known as humification process: the C-content increases from 48.4 % OM (cellulose 44.4 %) to 55.9 and 58.0 % OM in the fractions F2a and F2b, respectively.

What is the fate of the organic bound nitrogen of the added grass? Table 9 shows that during the transition of grass to moder indicated by C/N ratio, the loss of N is a little bit greater than the loss of C but we can not recognize whether this loss is due to gaseous losses or to mull humus formation, which is relatively enriched showing a C/N ratio of 9.9. The answer is given in table 10.

Table 10 gives a balance of the N totally added in the compost-experiment. At the end of the total time of composting, 446 days, about 25% of the N added by loam and successfully by grass is still present in the form of grass remnants and moder.

There is no clear dependency of this percentage on the amount of grass added. The main sink for the N being transformed by the decay of grass and moder is the mull humus, which retains about 50 % of the N totally added. Four of the mixing variants, 10; 16; 20 with the highest amount of grass added, and 54; with the smallest amount show the same percentages, independent on the loam:grass ratio. This is an important fact.

It is not clear why the variants 32 and 44 show such a strong reduction of the N remnants in F1 and F2a fractions (19 and 21 %), accompanied by a high percentage of N storage in the F2b fraction (67 and 58 %) and a very high amount of mineralized N as well as in the adsorbed  $\text{NH}_4\text{-N}$  as in the  $\text{NO}_3\text{-N}$  fraction dissolved in the compost solution. Probably this fact reflects a very good mixture of grass and loam at the grass addition data 4 and 5. This suggestion could be supported by the findings in connection with the organic matter and C-turnover. It has been pointed out that these two variants show no or nearly no gaseous losses of N.

The N liberated as  $\text{NH}_3/\text{NH}_4^+$  during the decay of grass remnants and moder becomes only intermediately adsorbed by the three layered clay minerals. The subsequent nitrification transforms it into  $\text{NO}_3\text{-anions}$ . Even the  $\text{NH}_4$  adsorbed in the loess loam in its primary stage becomes reduced by this process at about 96.4 percent in average.

The nitrate-N becomes stored by dissolution in the pore solution of the compost. The experimental conditions had been arranged in a way that no seepage water could leave the reaction

vessels. The water content was always kept below field capacity and the compost was protected against evaporation by plastic foil.

**Table 10: Nitrogen balance sheet. Ref. Table 5, 6th of Dec. 2000, end of the experimental phase. Dim.: g\*kg<sup>-1</sup> loess loam**

N-addition from begin			N in fractions					N-loss % total N
Grass	Loam	Total	F1	F2a	F2b	NH <sub>4</sub> -N exch.	NO <sub>3</sub> -N	
10.49	0.165	10.651	1.65	2.05	5.05	0.09	0.42	13.1
7.87	0.163	8.036	0.85	0.95	3.82	0.08	0.43	23.7
6.06	0.164	6.224	0.91	0.83	2.98	0.06	0.32	18.1
4.39	0.179	4.569	0.60	0.25	3.06	0.06	0.73	0
3.24	0.165	3.410	0.42	0.28	1.97	0.05	0.67	0.6
2.88	0.165	3.045	0.18	0.54	1.30	0.04	0.46	17.2
			% N added					
	100		34.7		47.4	4.83		13.1
	100		22.5		47.5	6.3		23.7
	100		28.0		47.9	6.1		18.0
	100		18.6		67.0	14.4		0
	100		20.5		57.8	21.1		0.6
	100		23.6		42.7	16.4		17.2

The estimation of the pore water NO<sub>3</sub>-N concentration in the saturation state corresponding to field capacity reveals for e.g. in variant 1 a concentration of 1963 mg nitrate N per litre. This corresponds to about 140 meq nitrate per litre or 10 mS\*cm<sup>-1</sup>. This is a salt concentration which in the scale of conductivity in the US Agricultural Handbook No.60, allows only salt tolerant crops yields satisfactorily.

If we consider variant 4 with its high amount of nitrate the value increase to 3411 meq/litre, corresponding to 243 meq/litre or 18 mS\*cm<sup>-1</sup>, a soil solution which allows only yields of few species of very salt tolerant plants.

The given values are related to field capacity conditions. Since the water content was kept below this water holding capacity, the nitrate impact on plant and microbial life must be considered as much severe. The potential acidification of the compost by NH<sub>4</sub><sup>+</sup>-oxidation to NO<sub>3</sub><sup>-</sup> is prohibited by the high content of CaCO<sub>3</sub> of the loess loam which leads to the formation of Ca(NO<sub>3</sub>)<sub>2</sub>.

The losses of N, expressed as percent of total N added (table 10), is exclusively to be attributed to gaseous losses, because no leaching of N was allowed by the experimental conditions. Gaseous losses may consist of liberated NH<sub>4</sub>, a process which is promoted by alkaline conditions and by losses of denitrification products like N<sub>2</sub> and N<sub>2</sub>O. The later is also produced during the nitrification process. Dealing with the percentages of N-loss we can not find again any correlation with the amount of grass added. Interesting is the fact that the variants 32 and 44, which represent the highest rates of grass and moder decay and of nitrification, show losses of N tend to be zero. This has been explained by a very good distribution of grass in the loess loam during mixing. If we add the percentages of nitrate-N and N-loss, the sums are 17, 28, 23, 16, 21 and 32 % which show no dependency on the amount of totally added grass or the intermediate remnants in the fractions F1 and F2a.

Considering the fact that denitrification in its intensity is depending on the oxygen deficiency e.g. by water logging, high amounts of organic substance competing for the rate of O<sub>2</sub>-diffusion and a high nitrate concentration the explanation seems only to be: because the experiments were conducted under well aerated conditions only nest like accumulations of grass and moder are able to consume air oxygen at rates which minimise it at a degree that nitrate becomes the competing oxidising agent under the formation of denitrification gases.



Therefore, the result of this chapter dealing with nitrogen balance of the experiment is that related to the organic substance added, the losses of N are markedly lower than those of C. The reason for this is that the mull humus formed during the process of decay plays an important role in the sink of N.

Surprising is the fact that during earth composting the pore volume is another sink for the nitrate formed by oxidation of the N liberated during the transformation process. This is one of the advantages of earth composting compared with biomass compostation where water storing aggregates are lacking and the nitrate formed becomes leached.

On the other hand the storage of nitrate in the pore water restricts the repeated use of the same loess loam in composting in an unexpected way: while other liberated elements are able to become adsorbed by the mineral mass of the loam, the nitrate-N can only be stored in a dissolved form. Our experiment shows with respect to the high nitrate concentrations the loess material seems to be exhausted forbidding a continuation of the repeated process of admixture.

### 3.3. Transformation of Dominant and Chemical Nutritional Elements

The contents of ash (ignition remnants) and its components in the grass added, given in the following arrangement, show only small differences in their percentage of dry matter compared with the average analyses of grass samples produced under low input conditions (ref. Faustzahlen für Landwirtschaft und Gartenbau, 1993).

	added grass	average contents
Na <sub>2</sub> O	0.17	--
K <sub>2</sub> O	1.58	1.7-1.9
MgO	0.37	0.1-0.4
CaO	1.08	0.4-1.0
P <sub>2</sub> O <sub>5</sub>	0.86	0.4-0.5
S	0.26	0.1-0.3

Besides these elements the main component of the grass ash is silicic acid and some iron and manganese.

During the process of organic substance turnover by composting these elements become set free. The rate of liberation depends on the character of the elements.

**Mg and Ca** are set free corresponding to the amount of organic substances which are mineralized to CO<sub>2</sub> and NH<sub>4</sub>. What happens with the Mg and Ca having been organically bound in those percentages of the added grass, which become transformed into mull humus?

It has to be supposed that Mg and Ca during this process also became liberated for adsorption to the newly formed organic adsorbentia.

So it seems justified, to add the amounts of Mg and Ca in the rows 2 and 3 of the tables 11 and 12, corresponding to Corg mineralized and Corg transferred into humus as the Mg and Ca amounts set free by composting.

These amounts can become precipitated as carbonates or adsorbed as cations, a small part also dissolved in solution equilibrium with carbonates and adsorbed ions in the pore water, or as cations of the newly formed nitrates and sulphates in the soil solution.

The use of calcareous loess material certainly restricts the adsorption by the loam component of the compost. Only the newly formed organic humus can be taken into account, because it has specific adsorption ability for earth alkaline cations.

Ca and Mg are relatively stable plant tissue components, which show only a negligible leaching. On the contrary by proceeding decay and mineralization of the organic plant material these

components show — together with the plant ash dominating  $\text{SiO}_4$  — often an increase with an embedding in the resulting humificated aggregates of the moder.

**Na and K** are cations very rapidly leached from plant tissues and their disintegration products e.g. the moder humus. Therefore it is necessary to take the whole sum of Na and K added to the loam by the whole mass of grass of the five admixtures as the totally liberated Na and K (row 1).

The fate of the Na consists in its dissolution or — by drying out in its precipitation — in the soil solution as hydrogen carbonate, chloride or nitrate. K contrarily has the chance to become adsorbed and fixed in the three layered expanding clay minerals. The simple adsorption at immediately exchangeable adsorption sites on the surfaces of the clay minerals is in our case impeded by the high concentration of Ca in the soil solution caused by the carbonate content of the loess. But in some of our grass addition variants the concentrations of the added K are high enough to allow adsorption corresponding to GAPON equation.

Not negatively affected but probably even promoted by the Ca-concentrations of the solution is the K-fixation inside the clay minerals. This is expected to be the main reason for K-sink in the system.

**P:** To measure for the P set free by mineralization and mull humus formation it seems to be allowed to use the transfer of C on these pathways. It can be supposed that the fractions F1 and F2a keep their P in organic bounding. The problem is, whether the organic substance which become converted into mull humus-F2b-fraction take their P with them forming organic phosphates or whether the P becomes liberated and newly fixed by organic binding. Therefore it seems more reliable to use the row 2 as a measure for P liberation.

It has to be assumed that the liberated P under the calcareous milieu conditions becomes rapidly transfused in hydroxyl apatite.

**S:** In the case of S the assumption is allowed that the amount of S set free in form of sulphate corresponding with Corg mineralized to atmospheric  $\text{CO}_2$ .

Looking on the Corg:Norg ratio (15.6), the Norg:Sorg ratio (11.0) and the Corg:Sorg ratio (172) of the grass and following their changes on the way from grass via moder to mull humus it seems to be allowed to use the same assumption about the percentage of redistribution as have been made with nitrogen.

Since there are no gaseous losses with sulphur, the percentages of nitrogen lost by gaseous exhalation, can in the case of sulphur added to the amount accumulated in the soil solution or precipitated as gypsum.

## Results of Tables 11 and 12

**S:** Let us consider first that element which can only be stored in the dissolved form in the pore solution, the S.

The solubility of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) is about  $2.3 \cdot \text{g} \cdot \text{l}^{-1}$ . The pore water of 1 kg of soil at field capacity accounts to about 214 ml and 492 mg of gypsum can be dissolved in it. This corresponds to about 92 mg S. If we look on table 11.6, S-balance, row 2, we find that the amount of S liberated corresponding to gaseous C-losses is in all variants of the experiment higher than the saturation concentration. That means that gypsum has become precipitated and that gypsum is the main reason for S-sink.

The process of gypsum formation consumes mainly Ca for precipitation, because the Ca-salt of the sulphuric acid has the lowest solubility compared to Na, K and Mg.

Looking on table 12.6, S-balance, row 2, the  $\text{meq}\cdot\text{kg}^{-1}$  of newly formed sulphate accounts from 10 to 27. Compared to Ca-balance, table 12.4, row 4, the sulphate formation alone consumes about 30 to 36 % of the Ca liberated by mineralization and humus formation.

**P:** Ca is also consumed by P that has been mineralized. A comparison of table 12.5, P-balance, row 2 and Ca-balance, table 12.4, row 4, shows that the formation of Ca-phosphate consumes another 67-79 % of the liberated Ca.

**Ca:** The formation of gypsum and formation of phosphates together consume 100 % and theoretical even more of the calcium liberated (99-106 %). That means there is no necessity for carbonate precipitation or adsorption of surplus Ca.

**K:** The original cation exchange capacity of 1 kg of the loess loam was 92.8.

The sum of the equivalents of totally added Na, totally added K and Mg liberated, row 4 are : 196, 153, 117, 86, 58 and 49 corresponding to the lower and higher loam:grass mixing variants, respectively.

This sum in the first 3 variants is higher, in the second 3 variants lower than the original exchange capacity. But the exchange capacity becomes increased by the mull humus formation. If one calculates a specific exchange capacity of about 3000  $\text{meq}$  per kg humus, then the exchange capacity would increase in the different variants at about 236, 253, 174, 169, 139 and 121  $\text{meq}\cdot\text{kg}^{-1}\cdot\text{loam}$ .

This additional humus based cation-exchange capacity has a specific adsorption for bivalent cations and discriminates monovalent ones. The means the mineralized Mg finds preference in adsorption whereas Na and K are removed. K has the opportunity to become adsorbed and fixed in the interlayers of the clay minerals widened by Ca-ions.

The K-fixation capacity or more exactly to say the exchangeable binding of K at specific sites with high GAPON coefficients depends on the degree of exhaustion can not be predicted without a more detailed analysis. Experience with some Chernozems of the Hildesheim region allow to assume that the smectites and vermiculites of the loess are in one case able to take up the high amounts of K.

**Nitrate, Na, Mg:** The formation of nitric acid also needs cations for neutralisation. The  $\text{meq}\cdot\text{kg}^{-1}$  soil are in the sequence of the variants 7, 7, 5, 12, 11 and 7. The neutralisation could easily be done by the above given amounts of Na (variants 1-3) or additionally (variants 4-6) by Mg.

**Table 11: Balances of dominant chemical and nutrient elements at the end of the composting process after 5 admixtures of grass, values in mg\*kg<sup>-1</sup> loam**

**11.1 Na-balance**

Loam:grass dry matter mixing ratio	10	16	21	32	44	54
1 Na-added by grass (total)	475	357	275	199	147	131
2 Na-liberated by gaseous C loss	212	211	161	113	86	76
3 Na-liberated by humus formation	79	57	46	42	26	16
4 $\Sigma$ 2+3	291	268	207	155	112	92
5 Difference 1-4	184	89	68	44	35	39

**11.2 K-balance**

1 K-added by grass (total)	4856	3652	2813	2032	1504	1334
2 K-liberated by gaseous C loss	2171	2158	1643	1159	883	777
3 K-liberated by humus formation	811	584	466	429	264	162
4 $\Sigma$ 2+3	2982	2742	2109	1588	1147	939
5 Difference 1-4	1876	910	704	444	357	395

**11.3 Mg-balance**

1 Mg-added by grass (total)	820	616	475	343	254	225
2 Mg-liberated by gaseous C loss	366	364	277	196	149	131
3 Mg-liberated by humus formation	137	99	79	72	45	27
4 $\Sigma$ 2+3	503	463	359	268	194	158
5 Difference 1-4	317	153	119	75	60	67

**11.4 Ca-balance**

1 Ca-added by grass (total)	2859	2149	1655	1196	885	785
2 Ca-liberated by gaseous C loss	1278	1270	967	682	520	457
3 Ca-liberated by humus formation	477	343	275	252	155	95
4 $\Sigma$ 2+3	1755	1613	1142	934	675	552
5 Difference 1-4	1104	536	513	262	210	233

**11.5 P-balance**

1 P-added by grass (total)	1393	1047	807	583	431	383
2 P-liberated by gaseous C loss	631	627	477	337	257	226
3 P-by humus formation	236	170	136	125	76	47
4 $\Sigma$ 2+3	867	797	613	462	333	273
5 Difference 1-4	526	250	194	121	98	110

**11.6 S-balance**

1 S-added by grass (total)	952	716	551	398	295	261
2 S-liberated by gaseous C loss	433	431	328	231	176	155
3 S-in humus	162	117	93	85	53	32
4 $\Sigma$ 2+3	595	548	421	316	229	187
5 Difference 1-4	357	168	130	82	66	74

**Table 12: Balances of dominant chemical and nutrient elements at the end of the composting process after 5 admixtures of grass, Values in mval.kg<sup>-1</sup> loam**

**12.1 Na-balance**

Loam:grass dry matter mixing ratio	10	16	21	32	44	54
1 Na-added by grass (total)	21	16	12	9	6	6
2 Na-liberated by gaseous C loss	9	9	7	5	4	3
3 Na-liberated by humus formation	3	2	2	2	1	1
4 $\Sigma$ 2+3	12	11	9	7	5	4
5 Difference 1-4	9	5	3	2	1	2

**12.2 K-balance**

1 K-added by grass (total)	124	93	72	52	38	34
2 K-liberated by gaseous C loss	56	55	42	30	23	20
3 K-liberated by humus formation	21	15	12	11	7	4
4 $\Sigma$ 2+3	77	70	54	41	30	24
5 Difference 1-4	47	23	18	11	8	10

**12.3 Mg-balance**

1 Mg-added by grass (total)	67	51	39	28	21	19
2 Mg-liberated by gaseous C loss	30	30	23	16	12	11
3 Mg-liberated by humus formation	11	8	6	6	4	2
4 $\Sigma$ 2+3	41	38	29	22	16	13
5 Difference 1-4	26	13	10	6	5	6

**12.4 Ca-balance**

1 Ca-added by grass (total)	143	107	83	60	44	39
2 Ca-liberated by gaseous C loss	64	63	48	34	26	23
3 Ca-liberated by humus formation	24	17	14	13	8	5
4 $\Sigma$ 2+3	88	80	62	47	34	28
5 Difference 1-4	55	27	21	13	10	11

**12.5 P-balance**

1 P-added by grass (total)	135	101	78	56	42	37
2 P-liberated by gaseous C loss	61	60	46	33	25	22
3 P-liberated by humus formation	23	16	13	12	7	5
4 $\Sigma$ 2+3	84	76	59	44	32	27
5 Difference 1-4	51	25	19	12	10	10

**12.6 S-balance**

1 S-added by grass (total)	59	45	34	24	18	16
2 S-liberated by gaseous C loss	27	27	20	14	11	10
3 S-in humus	10	7	6	5	3	2
4 $\Sigma$ 2+3	37	34	26	19	14	12
5 Difference 1-4	22	9	8	5	4	4

## 4. Discussion

### 4.1. Decomposition of Organic Matter during Composting and the Influencing Factors

It is well known that when plant materials are incorporated into a soil they decompose rapidly and release a considerable portion of their carbon and nitrogen within few days. After a short period of decomposition, they became part of soil organic matter (OM). During composting the amount and proportion of OM change dramatically. Approximately 50 % of the added organic matter becomes fully mineralised, mostly due to the degradation of easily degradable compounds such as proteins, cellulose and hemi-cellulose, which are utilised by microorganisms as C and N sources. The residual OM contains newly formed macromolecules along with non-degradable OM jointly forming the humic-like substance (HS), the most stable fraction of the mature compost (Chefatez et al. 1998).

Organic matter is decomposed for the most part of the soil micro-flora (Martin 1985), although slight decomposition occurs even under biotic or photochemical conditions (Wurzer, 1981; Scharpenseel et al. 1984). The conversion of substrate carbon into cell carbon is called assimilation. The different members of the micro-flora are not equally efficient in performing this process. In general, filamentous fungi and actinomycetes are the most efficient, followed by aerobic bacteria and finally by anaerobic bacteria which utilize carbohydrates very inefficiently, leaving incompletely oxidized products (Martin 1985). The percentages of metabolised carbon ranges from 30-40 percent, 5-10 and 2-5 percent, respectively, for the above mentioned groups (Alexander 1977). In aerobic soil, there is a great diversity of decomposers, consisting of fungi, actinomycetes and a wide range of bacteria, whereas under anaerobic conditions decomposition is accomplished by facultative and obligatory anaerobic bacteria. Organic material amendments can vary considerably in both physical and chemical properties and therefore they may have different effects on the composting process. The amount of organic material used also affects carbon and nitrogen turnover. It was found that small amounts of organic materials decompose more rapidly in soil than large quantities (Broadbent and Bartholomew 1948; Van Schreven 1964; Clark 1968). This was supported in some but not all of the experiments with  $^{14}\text{C}$  labelled plant material done by Sauerbeck (1968); Hallam and Bartholomew (1953), since the proportion of added plant C decomposing in a given time was substantially independent of the rate of the addition (Jenkinson 1977). Other tracer experiments conducted in the laboratory (Broadbent 1948, Hallam and Broadbent 1953) showed that green manuring results in a net loss of organic matter from mineral soils, losses were greater with small additions than with small additions. While other studies (Pink et al. 1950; Pink and Allison 1951; Winsor and Pallard 1956) found that the addition of crop residues increased the amount of organic matter in soil, the increase being proportional to the amount of residue added. However, carbon additions of up to 2 percent (i.e. approximately 100 tons of dry plant matter per hectare to a depth of 20 cm; an application far in excess of that normally found in nature) the proportion of carbon decomposed was little affected by the amount added (Jenkinson 1971; Oberländer 1973). The percentage of carbon released when plant material was incubated with soil, above that from the control (soil alone), has always been independent of the quantity added if the carbon addition did not exceed 1.5 % of the dry weight of the soil and if decomposition was allowed to continue for at least 3 to 6 months.

Earlier work on the decomposition of labelled ryegrass tops in soil under field conditions showed that the proportion of inorganic C retained was the same whether 0.3 or 0.6 percent ryegrass were added to the soil (Jenkinson 1965).

The decomposition of added organic material depends heavily on its chemical composition. Plants generally contain the same classes of compounds, but the proportions of each, which de-

pend upon the species and maturity, may influence the degree and rate of decomposition (Kononova 1966). High plant lignin content was correlated with slow decomposition (Barghoorn 1952) whereas cellulose decomposes more rapidly (Flaig 1964).

The C/N ratio is often used to characterize the composition of the material with respect to process effects. Microorganisms receive their energy by breaking down energy-rich C bonds of substrates and use N to build up amino acids and proteins. Thus carbon and nitrogen are the major nutrient substance for the soil micro-flora. Protein rich substrates are metabolised faster than substrates with low nitrogen content (Martin 1985). As the carbon contents of most crop plants range around 40 percent of the dry weight, their nitrogen contents can be compared by their C:N ratio (Alexander 1977).

Temperature is also an important factor regulating decomposition of the organic matter. Decomposition is accelerated by increasing temperatures. Maximum rates of decay have been measured at temperatures ranging from 30 to 40 °C (Martin 1985).

Air is another important factor. As aerobic bacteria are more efficient than anaerobic ones, decomposition slows down when the oxygen supply becomes insufficient. Also the nature of the experimental method and apparatus affect the data obtained from organic matter decomposition.

The quantity and type of clay in a soil have a bearing effect upon carbon mineralization because clays adsorb many organic substrates, extra-cellular carbohydrate splitting enzymes produced by micro-organisms, and even bacterial cells. Clays have marked carbon-retaining capacity, and decomposition is suppressed in their presence. Furthermore, the addition of certain clays to culture media inoculated with soil enrichments retards the degradation of a variety of substrates (Alexander, 1977).

Sand and silt influence also decomposition. They may serve as mechanical barriers to microbial movement to particulate organic nutrients or prevent contact between the potentially active cells or their enzymes and a substrate deposited at a microsite shielded non-carbonaceous particles (Ou and Alexander, 1974).

## **4.2.Nitrogen and Carbon Turnover**

It is well known when plant materials are incorporated into a soil (composting) they decompose rapidly and release a considerable portion of their nitrogen within few days. Gaseous N losses during composting occur mainly as NH<sub>3</sub> (Witter and Loper-Real 1987; Martins and Dewes 1992), but may also occur as N<sub>2</sub> (Mahimairaja et. al.1994) and NO<sub>x</sub> (Martins and Dewes 1992) including N<sub>2</sub>O (Sibbesen and Lind 1993).

The composting materials with a high content of easily degradable nitrogen in relation to the content of available carbon (energy) source leads to an accumulation and subsequent loss of ammonia nitrogen. Such losses can account to more than 50 % of the nitrogen initially present during the composting of sewage sludge and manure (Witter and Loper-Real 1987), 50-60 % of the separated house-hold wastes (Kirchman and Widen 1994; Brink 1995), and 77 % of gaseous N losses were accounted for composting of manure (Martins and Dewes 1992).

Emissions of nitrogenous gas not only reduce the agronomic value of the end-product and represent a waste of an essential plant nutrient, but also contribute to pollution of the environment. Larger-scale sewage sludge composting facilities are often associated with significant levels of odour (Warren 1984; Waller et al.1986), a larger proportion of which may be caused by ammonia emissions. Also in composting of horse manure and straw for mushroom production, ammonia was the main component of odour (Van Harreveld 1981).

Release of ammonia into the atmosphere also enhances the wet deposition of sulphate (Breeman et.al.1982; Möller and Schlieferdecker 1985; Pitman 1985; Schaarkes 1986), which results in acidification of the soil due to increased sulphate deposition and nitrification of the deposited ammonium.

Factors affecting ammonia formation and losses during composting (Witter and Loper-Real 1989) are pH, temperature, aeration level ammonia, ammonium adsorbing capacity of the added materials (Witter and Kirchman 1981), and presence of available energy source, that may lead to immobilisation of N (Kirchman 1985; Kirchman and Witter 1989).

Possible ways to reduce ammonia losses is by increasing C/N ratio of the composting material, the addition of easily degradable carbon sources as the ammonium formed will become rapidly immobilized into new microbial biomass (Hoyle and Mattingly 1954; Van Fassen and Van Dijk 1979; Kirchman 1985). Also by using ammonia adsorbents e.g. zeolite clinoptilolite, in which more than 90 % of all the ammonia volatilized was trapped, and a layer of clay soil can reduce loss of ammonia by nearly 60 % (Witter and Loper-Real 1988).

Mineralization of nitrogen when organic material is incubated in soils depends on many factors; the most important is the C/N ratio of the decomposing organic material.

Organic material with wide C/N ratio decomposes slowly (Parr and Papendick 1978), since the micro-organisms are N deficient and therefore have a slow population growth. In contrast, a low C to N ratio often means an excess of N in relation to energy and can lead to large gaseous N losses (Eklind 1998).

When material having C:N ratio of 18-102 was added to soil, no significant loss of gaseous form of N occurred and with ratios 3-15 marked N losses occurred as the nitrogen content increased (Pink et al.1950).

With C:N ratio of about 25 or less (Keeney 1985) and N content > 1.5 (Hausenbuiller 1972), net N mineralization occurs quickly. According to the data in the literature (Harmsen and Van Schreven 1955), it is generally believed that mineral nitrogen will be formed during the five weeks after incubation of organic material in the soil if the nitrogen exceeds 2 percent (dry-weight basis), while the mineral nitrogen is not generally formed during the initial incubation period if the organic material contains less than 1.5 percent nitrogen or if the C:N ratio of the material is greater than 25 to 27.

Net immobilisation might also occur in organic materials with low N contents or wide C:N ratio for a longer period of time than materials having high N contents and narrower C:N ratios.

It is known that when plant residues are incorporated in soil, the soil microbial biomass pool and its activity increase and this is reflected in greater respiratory output from the soil. Plant residues and their decomposition products provide energy and nutrients to the soil microbial population.

Nitrogen dynamics may be markedly affected by the composition, amount and method of addition of plant remains. Some investigators have reported that the net nitrogen mineralization occurs only when the N concentration of the residue is above 2 % (Haynes 1986; Palm and Schanchez 1991) and when the C:N ratio is less than 20-30 (Paul and Clark 1989). In our study reduced N mineralization in response to the addition of biogenic material may be due to the poor quality of the organic material used as indicated by its low nitrogen concentration (2.83 %). Therefore, mineralization and immobilisation of nitrogen during decomposition are the key processes in the N cycle (Ibrahima et.al.1995; Watkins and Barraclough 1996) and both the quantity and quality of plant residue added to soil determine the rate of decomposition and dynamics of mineral N (Mary et.al. 1996).



Changes in N dynamics following the addition of organic material may also result from either loss of N through denitrification or through direct inhibition of mineralization by compounds added in the residue. The addition of labile carbon sources has shown to increase the potential for denitrification (Dendooven et.al.1996) especially where high amounts of nitrates are present and oxygen supply is restricted.

In aerobic decomposition, living organisms which utilise oxygen, feed upon organic matter and develop cell protoplasm from the nitrogen, phosphorous, some of the carbon and other required nutrients. Much of the carbon serves as a source of energy for the organisms and is burned up and respired as carbon dioxide (CO<sub>2</sub>). Since carbon serves both as a source of energy and an element in the cell protoplasm, much more carbon than nitrogen is needed. Generally about two-thirds of the carbon is respired as CO<sub>2</sub>, while the other third is combined with nitrogen in the living cells (Gotaas 1956). If the excess of carbon over nitrogen in organic materials being decomposed is too great, biological activity diminishes and several cycles of organisms may be required to burn up most of the carbon. When some of the organisms die, their store nitrogen and carbon become available to other organisms. The utilisation of the nitrogen from dead cells by other organisms to form new cell material once more requires the burning of excess carbon to CO<sub>2</sub>. Thus, the amount of carbon is reduced and the limited amount of nitrogen is re-cycled. Finally, when the ratio of available carbon to available nitrogen is sufficiently low, nitrogen is released as ammonia and under favourable conditions some ammonia may be oxidised to nitrate.

The decrease in total C and NH<sub>4</sub>-N concentrations coincides with the increase in ignition residue percentages and NO<sub>3</sub>-N contents. The decreasing trend in total C and NH<sub>4</sub>-N and increasing trend in ignition residue and NO<sub>3</sub>-N contents were the results of nitrification process and the oxidation of C to CO<sub>2</sub> by the micro-organisms during decomposition process.

The decrease in NH<sub>4</sub>-N content consists mainly from volatilisation and denitrification processes. With increasing the amount of organic material added more nitrogen is lost as NH<sub>3</sub>, a proportion of this nitrogen is eventually be re-mineralised

### **4.3.Transformation of Mineral Compounds during Decomposition of Organic Material**

It is well known that the diversity of organic material that enter the soil presents to the micro flora a variety of substances which are both physically and chemically heterogeneous. Organic materials are commonly divided into organic constituents (cellulose about 15-60 % of dry weight; hemicelluloses 10-30 %, lignin 5-30 %, the water- soluble fraction 5-30 %, ether- and alcohol-soluble constituents and proteins) and mineral constituents, usually estimated by aching, vary from 1 to 13 percent of the total tissue (Alexander 1977).

During organic matter decomposition in soils both mineralization and immobilisation take place changing the mineral status of the organic material added. For example, phosphorous immobilizes during decomposition of plant residue is closer to 0.2 percent of the dry weight of the organic matter i.e. the critical level of phosphorous that serves as a balance between immobilisation and mineralization is about 0.2 % (Alexander 1977). The microbial abundance puts a great demand on the phosphate supply, consequently the carbonaceous residue be deficient in phosphorous.

Many factors control the mineralization-immobilisation of minerals during decomposition of organic matter in soils; pH, temperature, aeration, nitrogen and carbon availability. As most plants contain 0.05 to 0.5 % phosphorous and 20 to 50 % carbon on a dry weight basis, mineralization will be the net effect when the C:P ratio of crop remains is less than 200:1, while immobilisation predominates during the initial stages of decomposition when the C:P ratio of the added organic matter is greater than 300:1 (Alexander 1977).

There is also a high relation between the rates of nitrogen and phosphorous conversion to inorganic forms, the nitrogen mineralization being from 8 to 15 times the amount of phosphate made available (Alexander 1977).

For sulphur, upon the addition of organic matter to a soil and under aerobic conditions, the sulphur contained therein is mineralised. A portion of the inorganic products is utilised by the micro flora for cell synthesis and the terminal inorganic product is sulphate. The critical C:S ratio in carbonaceous materials above which immobilisation is dominant to mineralization is reported to be in the range of 200:1 to 400:1 (Barrow 1960, and Stewart et.al.1966), equivalent to about 0.1 to 0.2 sulphur.

Mineralization will predominate with organic materials having lower C:S ratios or higher sulphur percentage, but immobilisation will be more prominent with substances with wider C:S ratios or lower sulphur contents.

Many other elements undergo microbiologically induced transformations during decomposition of organic matter into a soil. There is evidence for direct or indirect biological alterations in the availability, solubility or oxidation states of potassium, calcium and magnesium.

## 5. Summary

Under the different possibilities of composting biogenous wastes of gardens, public greens and kitchens in the industrial Middle Europe actually prevails the biomass composting without addition of soil material- in like manner with respect to technical or to individual garden scale. There are some biochemical, ecological and hygienic problems connected with, which focus new interest on the technique of mixed composting of plant and animal wastes together with soil material, the so called ``earth composting``, which is the topic of this thesis.

New aspects for research were not ``how to produce a good compost``, what ever this means, but to use the added soil material like a biological catalyst for rapid mineralization of repeatedly added organic wastes, and like a physical or a chemical sorbent of the mineralization products:

Cold bio Catalytic Combustion Composting. The question was, which process does govern qualitatively and quantitatively the mineralization process of biogenic substances in contact with soil material, a problem about which only very few serious scientific literature exists.

The methodical arrangement was: Dried lawn grass as a bio-standard, calcareous loess (loam), cube formed cage like reaction vessels with a compost load capacity up to 100 kg, which could be composed to a roof covered plastic mantled stack for use in field or green house without any leaching. Fractionation of the compost for chemical analysis at different stages of progress was done by sieving and suspending in water, opted for separating ``grass`` remnants (fraction F1), ``moder``, histologically not long structured but organic (F2a) and ``mull humus`` fixed chemically to the loess clay. The ratios loam:grass diverged between 10 and 54 also including conditions which occur by under-ploughing harvest remnants in the field. Mechanical turbation of the compost between the data of grass admixing were omitted, being conscious of delaying the process but getting more time for observation.

The fractions F1 and F2a are only transition fractions for the final mineralization or mull humus formation. Percentage and relations of and between these fractions are widely independent of the amount of grass that has been added before. This and together with the fact that there occur limitations in the progress of decay after certain times strength the theory that in the case of earth composting the fix number of contact points between the microorganisms colonies and setting and fixed on the soil aggregates and the plant residue are the governing aspect. To overcome restrictions in progress of these initial stages of composting, caused by the steric fixation of bio-decay, a repeated turbo-mixing is helpful.

On contrary the F2b-mull humus fraction increases, strongly depending on the mixture ratios. This accumulation is an advantage by the use of clay containing soil admixture to composting, offering sites for binding humates. This humus accumulation increases the cation exchange capacity and works as a sink for N and S being liberated by mineralization. But the number of sites decreases with progressing mull formation. Since mineralization and humus formation are competitive processes, after reaching that point of exhaustion mineralization will dominate and the function of a humus sink comes to an end. For progressing accumulation of mull humus the known formula based on the repeated rate of biomass addition, specific conservation quotient and number of repetitions seems to be valid, but the observation time was not long enough to detect a saturation development in the accumulation curves.

The use of the same soil material for the composting of repeated admixtures of biomaterial becomes finished much earlier than by the end of humus accumulation and that means latest at the decay of about 350 g organic residues per kg of loam.

Contrary to organic carbon which leaves the system as CO<sub>2</sub>, all the other nutritive elements are kept in the system where leaching is prohibited. This involves N too, which only in some cases where compacted grass flakes promote denitrification, get lost in gaseous form.

The anions of phosphate, sulphate and nitrate form salts. The total of Ca set free by mineralization is used for precipitation of phosphate and gypsum which mainly become enriched in form of precipitates. Nitrate accumulates as Na, Mg and Ca (from soil reserves) salt in the pore water solution creating there concentrations which could be toxic for plants and possibly also for soil organisms.

The fate of the liberated potassium seems to be the fixation inside the expended clay minerals. The question whether a calcareous or a non-calcareous loam material is of a higher advantage for composting is with respect to the results of lower significance. The storage capacity for water and salt solution plays a more important role for the number of composting repetitions. The use of a loam material without lime and a higher degree of  $H^+$ - saturation of the adsorption complex could be helpful in promoting the adsorption of K and Mg and the use of the base surplus of liberated elements for upgrading the base saturation degree of the soil material, but otherwise the expansion of three layered clay mineral, important for K fixation, will be reduced by Ca deficiency.

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