UNIVERSITY OF DEBRECEN
CENTRE OF AGRICULTURAL SCIENCES
FACULTY OF AGRICULTURAL SCIENCES

DOCTORAL SCHOOL OF

CROP PRODUCTION AND HORTICULTURE

Head of Doctoral School:

Zoltán Győri, D.Sc.

Doctor of Agricultural Sciences

Supervisor:

Zoltán Győri, D.Sc.

Doctor of Agricultural Sciences

Doctoral (Ph.D.) Thesis

CHEMICAL EXAMINATION OF VARIOUS ORGANIC WASTES AND THE PRODUCTS FORMED AFTER THEIR TREATMENT

by

Péter Simándi

Ph.D. candidate

DEBRECEN

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1. RESEARCH OBJECTIVES

The proper level of organic materials management is a major element in sustaining soil fertility. If processed properly, the organic matter content of waste can at least partly replenish the organic matters missing from the soil.

Various types of composts can be made from waste and the actual compost properties depend on the origin. Compost types include slurry compost, food processing waste compost, green compost, etc. The parameters used for farmyard manure description are necessary but seem insufficient for the assessment of composts. Actually, the macro-element analyses (N, P, K) and C/N ratio studies are not enough for the overall description of compost properties and, therefore, these must be completed with other parameters (TOC, respiration, biomass C and N content, etc.). We still do not have such an elaborate system of compost assessment that could judge correctly the agricultural benefits of compost.

Preserving soil quality is one of our basic obligations. If the quality of the compost we use in our environment is not adequate, the result will be lower crop yields and soil deterioration. That is why it is important to select the most suitable starting materials and composting technology and to perform it correctly.

In my thesis I will use chemical parameters to follow Hungary's two most widespread composting technologies:

- prism composting, and
- active aeration composting.

Composting time and compost quality are affected not only by the technology choice but also by the quality and quantity of organic compounds present in the starting material (e.g. lignin and cellulose volume and structure). I examined whether the degradation of the mixture of relatively high lignin content can be accelerated through some physical intervention i.e. heat treatment.

Although the composting process is finished, the material transformation processes are still going on in the prism. Humification continues, which can modify the value of the finished product. I examined if there is any difference as to germination index, respiration, C and N turnover, etc. between composts made with the same technology but from different starting materials and having a similar nutrient content following their application on the soil. These parameters must be determined so that we can find out the correct ratio of compost and soil.

During the study I compared various composts and green wastes in order to see the extent to which finished product quality is influenced by the starting mix of materials.

There is extensive worldwide research concerning the processes of various composting technologies and the quality of ready composts. During the study I used an integral system of my choice i.e. C-N turnover to look for correlations in the processes of the two most widespread composting technologies as well as in the aerobic and anaerobic use of already ripe composts put in commercial distribution but made from different starting materials. Furthermore, I examined whether heat treatment can accelerate the degradation process.

The main purpose of the thesis was to examine the following questions:

- How do the processes of material transformation take place during the production of composts made from different starting materials and with different composting technologies (carbon and nitrogen turnover)?
- How big is the difference between the typical quality parameters of the finished composts?
- How does the heat treatment of green wastes of high lignin and cellulose content influence the processes of humification and mineralization? Is it possible to replace composting with a high-temperature heat treatment of the raw materials?
- How do finished composts behave in soil under aerobic and anaerobic conditions?

2. PRECEDENTS

The processing of agricultural raw materials generates billions of tons of by-products. In today's world, to treat these as waste products is neither possible nor desirable. Instead, efforts should be made to recycle and utilize them e.g. for crop feeding and soil improvement in agriculture. The use of plant residues has become a major element in nutrient management. Organic by-products can be transformed with biological methods: compost making to increase the humus content of soils, biogas production from waste water, or animal fodder or feed additive manufacturing from the waste grains of breweries (SÁGI, 1995). The introduction of plant residues into the soil may modify the microbiological processes resulting in a higher volume of available nutrients and an improvement in soil fertility (MISHRA, B. et al., 2002; NAKAMURA et al., 2003). Introducing organic matter into the soil may have two purposes: the safe disposal of pollutants and an improvement in soil fertility (KISMÁNYOKY, 1993). This way it is possible to reduce fertilizer and other costs (e.g. fossil energy expenses) as an increase in the humus content of the soil will lead to an improvement in the structure, nutrient supply capacity and heat and water management of soils.

Composting is one of the most often performed processes in agriculture (RÁKOSI and SÁGI 1982). Composting is a spontaneous biological, chemical and physical process caused by microorganisms and taking place under aerobic conditions. In turn, during the ripening stage, humin compounds of large molecules are formed (DUNST, 1991). The organic matter is stabilized during the process, and mineralization and humification finally produce a harmless, stable and homogeneous finished product from the microbial metabolites (GRAY and BIDDLESTONE, 1981; VIEL et al., 1987). During the process the composted material is degraded through the involvement of various organisms into simple basic compounds such as carbon dioxide, sulfate, nitrate and water, while the non-mineralized organic matter turns into humus substances (GLATHE et al., 1985). We might say that composting is nothing other than humus manufacturing under human supervision (JÓCSIK, 1962; ALEXA and DÉR, 1998).

Composting provides an opportunity to recycle the otherwise non-usable organic matter content of wastes. For example, compost can be made from food processing, household and agricultural wastes, paper derivatives, slurry, tree cuttings, etc. During the composting process mineral phosphate can be added to increase the phosphor content of compost and thus to meet the phosphor requirement of plants (GANGULY et al., 2005).

For their survival microbes need nutrients, which they obtain from organic compounds. Carbon and nitrogen are the two most important nutrients. The speed of degradation depends on the presence of air and sufficient humidity in addition to the carbon and nitrogen content of the degraded material (KUTZNER and JÄGER, 1994; FISCHER and JAUCH, 1999). The ratio of C and N (C/N) influences the composting process and finished product quality. The C/N ratio is only a good indicator (BARBARIKA et al., 1985), referring to the total carbon and nitrogen content of the material, while the microbes can use only the form ready for uptake (INUBUSHI et al., 2001). The C/N ratio shows a constant change during composting. Actually, the C/N ratio may be reduced as a result of the nitrogen content of added fertilizers or the organic wastes of high nitrogen content such as for example slurry or chicken manure (IRANZO et al., 2004). A compost of reduced C/N ratio can be safely applied into the soil without nutrient immobilization and phytotoxicity.

Microbes can satisfy their oxygen demand from two sources: oxygen from the air and oxygen from organic compounds.

Only the former source, called decay, is suitable for the composting process. In this case the aerobic microbes oxidize the organic compounds and there is a formation of some simple compounds and CO_2 accompanied by the liberation of heat (NAKASAKI and OHTAKI, 2002).

Oxidation is most efficient when oxygen can get inside the particles and, therefore, the prism material should have a loose and crumbly structure. In many cases this can be ensured by mixing. Amongst other things, composting speed depends on material degradation and the velocity of oxygen transport. Generally, the oxygen transport represents the decisive factor (HAMELERS, 1995). Furthermore, constant stirring and aeration will inhibit overheating. Higher temperature leads to more intense evaporation which in turn will result in a drop in humidity.

If during composting the system cannot receive enough air, anaerobic conditions may arise under which the microbes will satisfy their oxygen demand through the reduction of organic matter. This leads to the formation of an unpleasant smell, which is due to the formation of ammonia, hydrogen sulfide and methane. This process is called rotting.

Both decay and rotting take place during composting. The conditions are mostly aerobic and anaerobic around the edge and in the inside of the compost pile, respectively. It is important to maintain a balance between the two processes during composting. It can be achieved through timely stirring and prism wetting (FORRÓ, 1998).

Microbes need humidity for their undisturbed operations. The lack or abundance of humidity substantially affects the activity of microorganisms and thus the level of organic matter degradation and the resulting temperature. It is hard to give an optimum value as humidity greatly depends on the quality and quantity of the organic matter and its air permeability (HAUG, 1993). The lower limit is around 30-40 w/w%, while the upper one varies from 50 to 70 w/w%.

In case of composts the potential for use is determined by ripeness and stability. Ripeness means the physical, chemical and biological stability of the composts (MATHUR et al., 1993a.). The different ripeness of composts depends on the exchange of the various components including mainly, in particular, the soluble components such as soluble carbon and the C/N and respiratory part of the soluble fraction, which are related to the soluble organic matter content (GOLUEKE, 1986; IANNOTTI et al., 1994). It is not easy to detect compost ripeness.

Normally, the most common methods used to determine compost ripeness are categorized into five groups. physical, chemical and microbiological tests, biological tests of plants, and examination of organic matter humification (JIMÉNEZ and GARCIA, 1989).

C/N ratio measurement at the beginning and end of the ripening phase is a method often used to describe compost ripeness (SENESI and BRUNETTI, 1996). In general, the starting ratio of about 30 drops below 20 by the end of the ripening phase. The ideal ratio of a ripe compost varies around 10. (MATHUR, 1991).

Compost phytotoxicity is a widely studied issue. Several articles have been published about the germination blocking and growth reducing effects of unripe composts (ZUCCONI et al. 1981b). In general, the seed germination and plant growth tests are used. A major disadvantage of these methods is their time consuming nature. DE VLEESCHAUWER et al. (1981) pointed out that short chain fatty acids are responsible for the phytotoxicity of fresh and unripe composts. ZUCCONI et al. (1981a) reported the presence of a phytotoxin of unknown composition in the degrading organic matter.

3. RESEARCH METHODS

I carried out the experimental part of the studies in 2003/2004 in the Soil Sciences Laboratory of the Faculty of Horticulture at the Chiba University in Japan. The results assessment and the mathematical/statistical computations were performed at the Department for Agricultural Chemistry and Soil Sciences of the Faculty of Water and Environment Management at Tessedik Sámuel College. Each test was made in 3 repetitions.

3.1. Composting technologies

3.1.2. Yamagata compost (active aeration)

This was produced under aerobic conditions with constant stirring provided by an automatic device. Use of raw materials: rice bran, manure, food wastes (Figure 1).

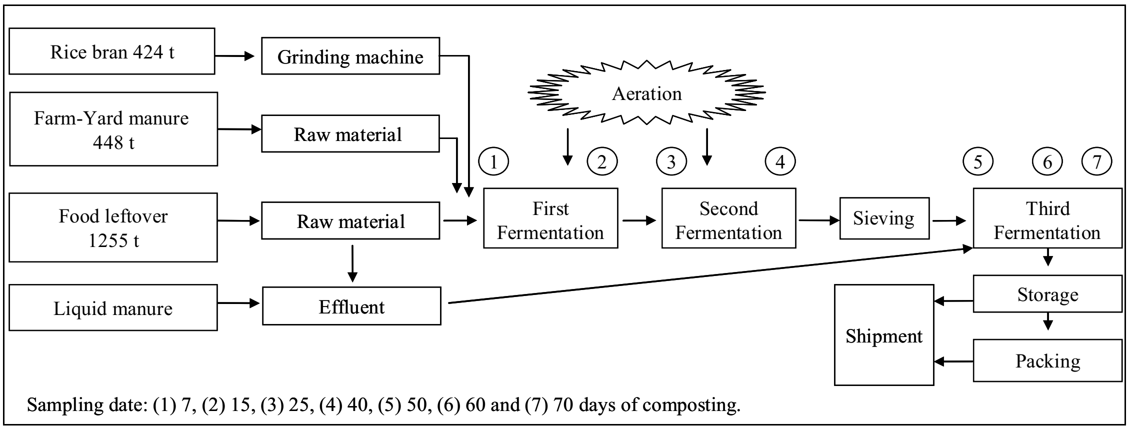

Figure 1 Schematic drawing of Yamagata compost making with an indication of the place and date of sampling*

3.1.2. Shimoduma compost (prism procedure)

This was produced under semi-aerobic conditions with periodic manual stirring. Use of raw materials: rice husks, food wastes, horse manure (Figure 2).

**Source: All of the tables in this thesis are derived from my own research based on the measurements and the applied technology.

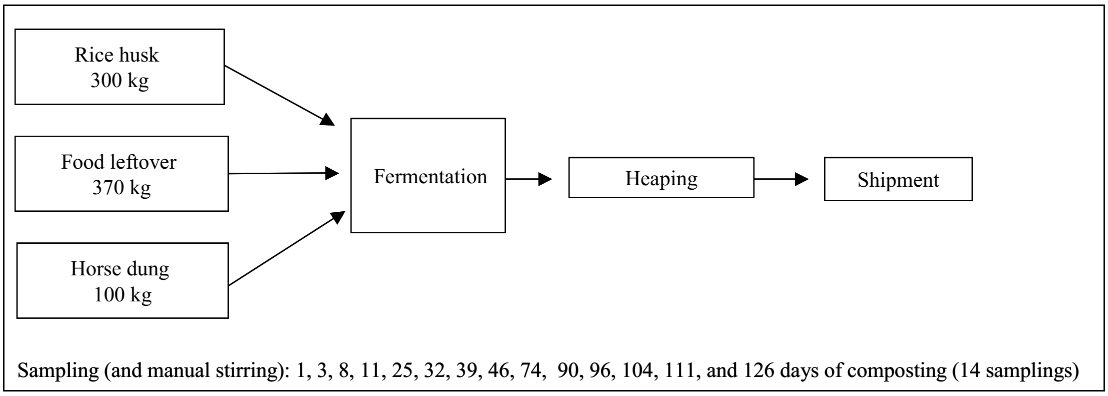

Figure 2 Schematic drawing of Shimoduma compost making with an indication of the place and date of sampling

3.2. Heat treatment of plant residues

I performed the heat treatment of plant residues (grass, walnut tree and pine tree cuttings) in a machine manufactured by Ishikawajima-Harima Heavy Industries Co., Ltd. It was done at high temperature (207 °C) and at high pressure (1.7 MPa) for 30 minutes. During the treatment the volume of plant materials decreased and I collected the resulting liquid phase for use in further experiments.

Untreated plant samples: I cut into pieces the air dry samples for use in further experiments.

3.3. Study of untreated and heat treated samples

Use of materials: heat treated and untreated grass, pine tree and walnut tree cuttings, Chiba Light-color Andosol soil.

I mixed the (treated and untreated) plant samples with soil in a ratio of 1:6 and then I placed the mixture in plastic bag and incubated it in a dark place under aerobic conditions at 25 °C for 10 weeks. I set the initial humidity at 64.4% of the soil's water capacity. Based on measurements, I adjusted the soil's constant humidity every week.

I used soil without plant residues as a control. Sampling was made on weeks 1, 2, 4, 7 and 10.

I set up three two-factor experiments to clarify the impact of pretreatment with vapor on the natural degradation of the grass and the two trees (grass, pine, walnut + control).

The experimental treatments were as follows.

Physical treatment

Factor "A": a_1 untreated

a_2 heat treated

Plants

Factor "B": treatment durations

b_1: Week 1

b_2: Week 2

b_3: Week 4

b_4: Week 7

b_5: Week 10

3.4. Anaerobic incubation

Prior to starting the experiment, I used each of the three compost types to prepare 10 g mixture with sandy soil in the above ratio in 3 repetitions. I used Chiba Light-color soil as control. The volume of the incubation vessel was 123 cm^3. At the start I weighed in all samples corresponding to the entire test period (12 weeks) and incubated them in a dark place at 25 °C. Each week I took out the actual samples and used their full quantity for the various tests (pH, EC, TOC, $NO_3^- - N$, $NH_4^+ - N$). The sampling of gases (CO_2 and CH_4) for test purposes was made from the gas space above the sample (Figure 3).

3.5. Aerobic incubation

Prior to starting the experiment, I used each of the three compost types to prepare 250 g mixture with sandy soil in the above ratio in 3 repetitions. I used Chiba Light-color soil as control. I set almost the same humidity values (*A*: 22.9%, *B*: 22.0%, *C*: 24.3% and the *control soil*: 20.3%). The volume of the incubation vessel was 860 cm^3. At the start I weighed 250 g samples in the vessels and then each week I took out quantities of 10 g for the various tests (pH, EC, TOC, $NO_3^- - N$, $NH_4^+ - N$). I checked the humidity by weight measurement every time and, if necessary, I reset the original value with the addition of water. In order to ensure aerobic conditions I left open the freshly taken sample for hours before closing it. The sampling of gases (CO_2 and CH_4) for test purposes was made from the gas space above the sample. Incubation was made in a dark place at 25 °C (Figure 3).

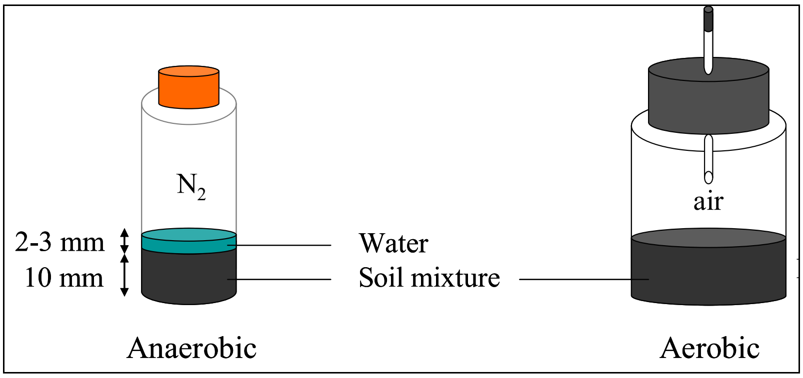

Figure 3 Incubation experiment setting under anaerobic and aerobic conditions

3.5. Analytical tests

Determination of microbial biomass carbon (MBC) and nitrogen (MBN)

Determination of water-soluble carbon and nitrogen content

pH measurement

Determination of dry matter content

Determination of electrical conductivity (EC)

Determination of organic acids

Determination of nitrate ion ($NO_3^- - N$)

Determination of ammonium ion ($NH_4^+ - N$)

Determination of germination index (GI)

CO_2-C measurement

CH_4-C measurement

Determination of carbon, nitrogen and C/N ratio

Determination of holocellulose

Determination of cellulose

Determination of lignin

Determination of crude fiber content

Variance analysis

4. MAIN FINDINGS OF THE THESIS

Composting is one of the most widespread methods for the utilization of organic wastes. Several technologies are used in the world. The actual method must be selected in view of organic matter properties as finished product quality depends on the starting mix of materials, the applied method and their interaction. During the elaboration of the thesis I compared the two technologies through the changes of C-N forms, measured the reactions of three composts in the soil and examined whether biological degradation can be replaced with some physical intervention.

4.1. Technology assessment research

Due to the physical differences (breathing, air permeability, heat capacity, etc.) between the two material mixes under review, the composting conditions are different. I ensured proper oxidation through stirring in the case of lower humidity (prism composting) and by way of air blowing for the higher humidity system (active aeration composting).

Numerous papers deal with such issues as the difference between the two technologies and with the duration, expenses, space requirement and investment demand of composting. Fewer test result comparisons are available for the finished products. The quality differences between the finished composts cannot be understood without the analysis of the material transformation processes and, in particular, the C-N turnover. I followed the transformation processes of the C compounds through the measurement of total C, CO_2 and carboxylic acids (formic acid, acetic acid, citric acid, lactic acid, valeric acid).

For the analysis of N compound changes, I measured the following nitrogen forms: total N, $NH_4^+ - N$, $NO_3^- - N$. At the time of comparing the technologies I also examined such parameters as germination index, total salt and pH.

In terms of material transformation processes, the two technologies show the following differences.

The *active aeration system* provides a better air supply. As a result, composting is shorter (about half) in duration and a greater share of the easily degradable C leaves for the atmosphere in the form of CO_2. The volume of carboxylic acids is low and the conditions inhibiting seed germination can be hardly felt either. As the $\frac{NH_4^+ \text{-} N}{NO_3^- \text{-} N}$ ratio is small, there is ground for nitrification (Figure 4).

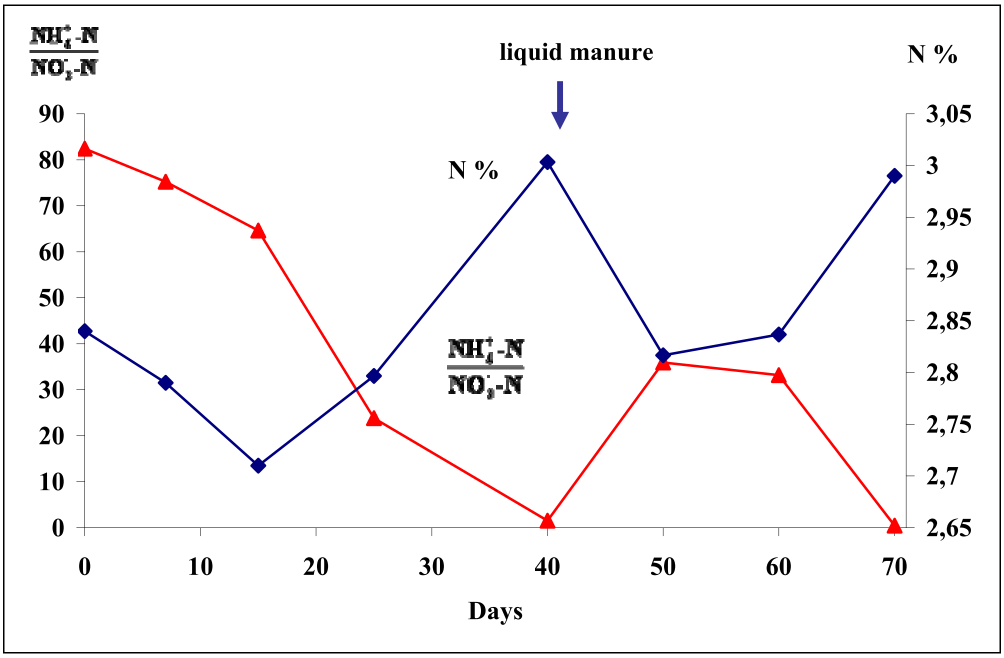

Figure 4 Changes of total N and $\frac{NH_4^+ - N}{NO_3^- - N}$ in the Yamagata composting technology

In the case of *prism composting* the material transformation processes are intermittent. The reason is that a part of the fibrous cellulose ensuring air permeability becomes mineralized and thus the compost pile flattens and the air is displaced. This is clearly indicated by the lower rate of respiration, the higher concentration of carboxylic acids and the $\frac{NH_4^+ - N}{NO_3^- - N}$ ratio, which is several times greater than for the composts made with active aeration (Figure 5).

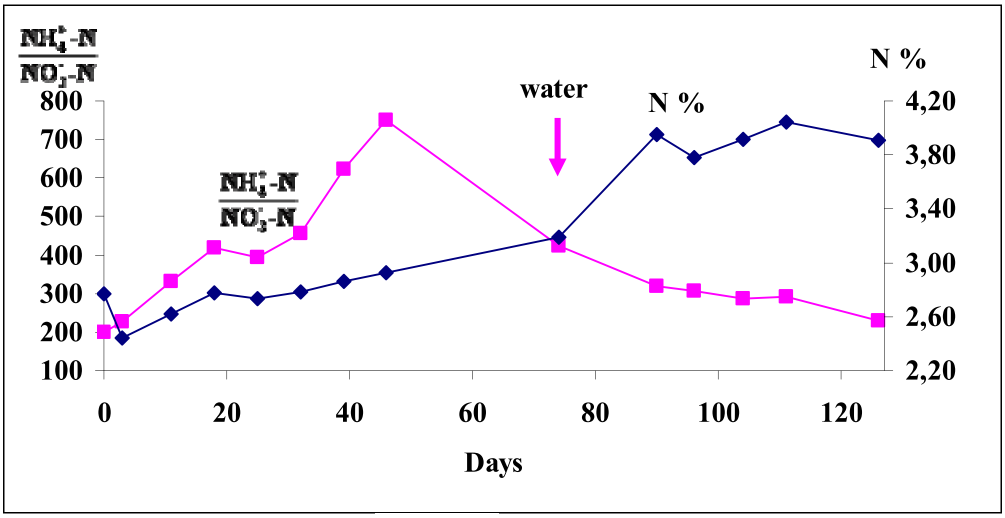

Figure 5 Changes of total N and $\frac{NH_4^+ - N}{NO_3^- - N}$ in the Shimoduma composting technology

The respiration, which is delayed due to the degradation of carboxylic acids and the greater volume of mineralizable part, leads to a poor germination percentage.

The finished products of the two technologies differ in that the initial parameters show a quicker and greater change in the case of active aeration. Material transformation is intermittent in prism composting. The aerobic phases are interrupted by anaerobic phases leading to a rising share of the poorly humificated fraction.

4.2. Tests performed for the transformation study of C-N forms

In most cases the organic matter of wastes is unsuitable for the preparation of a compost mixture with a sufficient content of biologically degradable parts. The tree wastes (wood shavings, branches) and the old soft-stemmed plants have a higher lignin content and lower levels of fat, sugar and protein. The situation is further aggravated if such glucosides, alkaloids or other microbial substances make part of the mix of materials that delay or slow down the process of enzymatic degradation (e.g. walnut tree leaves, sawdust with resin content, etc.). In this case such physical interventions may be required that will change the ratios of C forms and the electric charge on the surface of cellulose fibers i.e. disturb the chemical stability of cellulose, lignin and other organic compounds.

Hot water is able to transform holocellulose i.e. to change the solubility conditions of carbohydrates. I tested grass, pine and walnut by mixing the treated substrate with soil. I used chemical parameters to follow the changes caused by the soil microbes.

C turnover was shown by the change of the following indicators: total C, biomass C, water-soluble C, respiratory C. At the same time, N transformation was indicated by total N, biomass N, water-soluble N, mineralizable N, $NH_4^+ - N$, $NO_3^- - N$.

According to my tests, the hot water treatment reduced the cellulose content but increased the easily mobilizable C part. In the case of tree wastes the respiration follows the change in water-soluble C content. This correlation is weak for grass. It can be explained with the structural differences of cellulose and the lower C/N ratio of grass (Figure 6, 7).

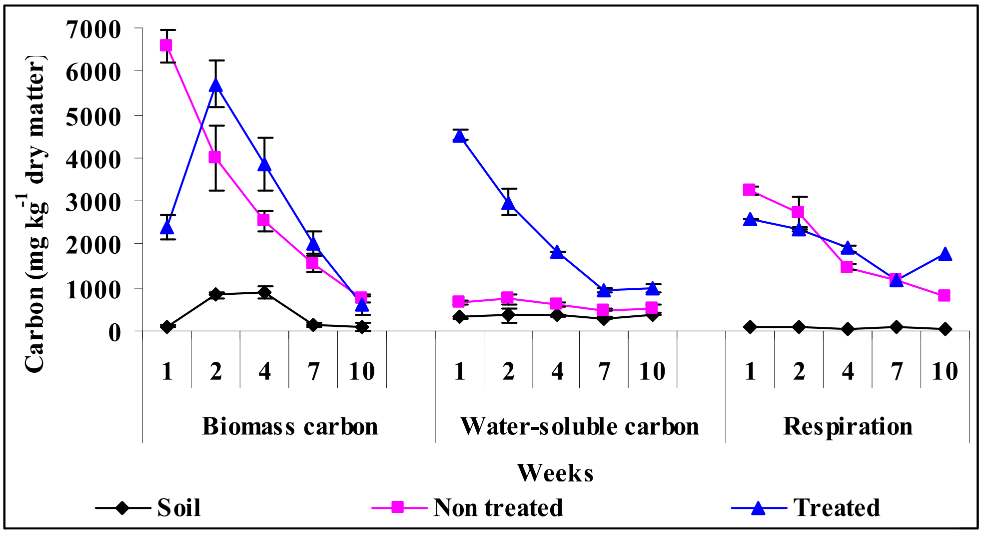

Figure 6 Carbon forms of grass in the function of time

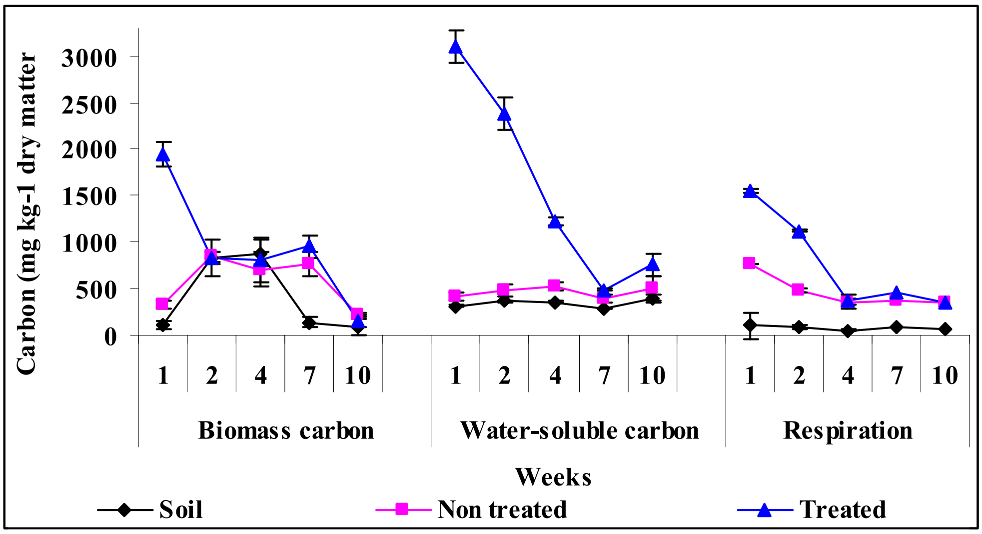

Figure 7 Carbon forms of pine in the function of time

I checked whether the mathematical/statistical studies support my previous findings. I studied the correlations between different treatment times, the impact of treatments (untreated, treated) on the various processes and the interactions of test intervals (weeks) within a treatment.

Biomass C: as to *grass,* there was no significant difference between the treatments (P=0.291), while there was a significant difference between treatment times and in the interactions of test intervals (weeks) within a treatment (P<0.001). Both *pine* and *walnut* produced a significant difference in all three cases (P<0.001), although no significant difference was found between the treatments for pine on week 2, 4 and 10 (P_2=0.701, P_4=0.054 and P_{10}=0.200) and for walnut on week 10 (P_{10}=0.987).

Water-soluble carbon: the obtained results indicated a significant difference ($P<0.001$) for all the three impacts in all the three untreated and treated samples (*grass, pine* and *walnut)*. However, the comparison of treatment times for untreated grass and pine gives a slightly greater deviation ($P_{grass}=0.007$, $P_{pine}=0.006$).

Respiration: as to *grass,* there was no significant difference between the treatments ($P=0.507$), while there was a significant difference between treatment times and in the interactions of test intervals (weeks) within a treatment ($P<0.001$). Both *pine* and *walnut* produced a significant difference in all three cases ($P<0.001$), although no significant difference was found between the treatments for pine on week 10 ($P_{10}=0.664$) and for walnut on week 7 and 10 ($P_7=0.055$ and $P_{10}=0.031$).

The difference between grass and tree wastes is particularly striking in the case of N forms. Most of the N content of grass is mobilizable. There is no difference for $NH_4^+ - N$ but $NO_3^- - N$ is high in grass. The low level of $NH_4^+ - N$ indicates that the conditions of nitrification are given.

4.3. The impact of composts on the C-N turnover of sandy soils

The role of composts in soil fertility can be best examined on sandy soils. The soil – compost interaction can be measured at optimum level of humidity. More information can be obtained from the study when sandy soil is measured in water-deficient or water-saturated conditions as sand has extreme water management properties including quick saturation and quick drying out. Experiments prove that, under water-saturated conditions, the redox potential of sand enriched with organic matter is substantially lower than that of the control because the remaining oxygen is used for organic matter degradation.

In the case of water-deficient sand the organic matter is able to supply N as a result of the temperature dependency of the mineralization process.

I used C turnover tests to follow the sandy soil – compost interaction. In an incubation experiment I measured such C forms as CO_2-C, CH_4-C and water-soluble C, such N forms as $NO_3^- - N$ and $NH_4^+ - N$, and such base values as EC and pH.

According to my test results, the highest water-soluble C content was found in a compost made mostly (78%) from animal manure. Also, this compost had the highest N content.

The CO_2-C and CH_4-C measurements clearly indicate the impacts of anaerobic and aerobic conditions. The cumulative values of CO_2-C development can be described with a linear function under aerobic conditions (Figure 8). However, under anaerobic conditions, the gas volumetric measurements produce substantially different results (Figure 9).

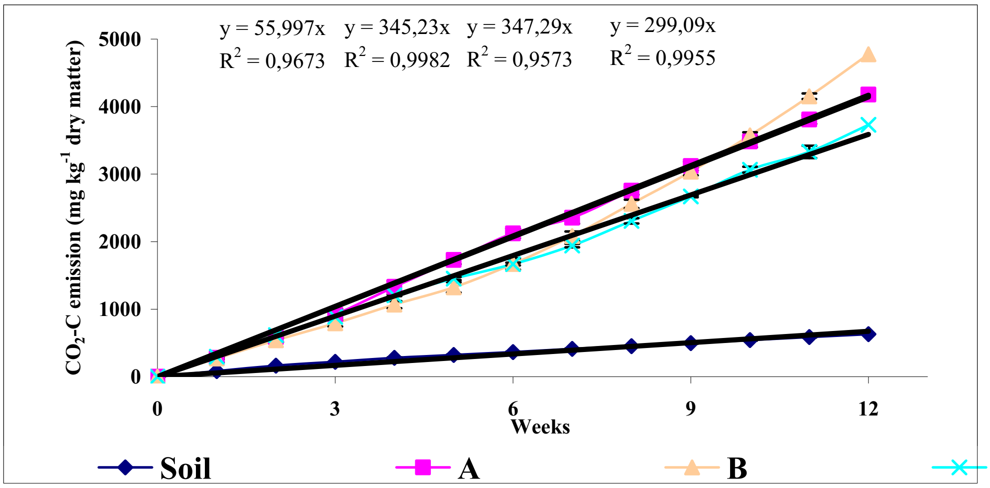

Figure 8 CO_2-C formation under aerobic conditions

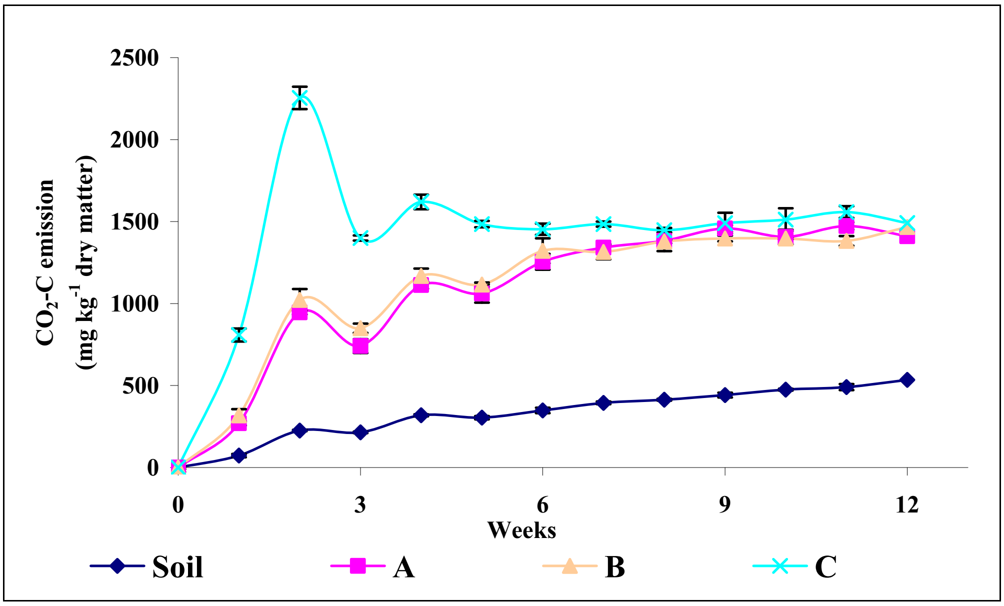

Figure 9 CO_2-C formation under anaerobic conditions

Under aerobic conditions CH_4-C development is significant only in the initial phases of incubation. Under anaerobic conditions the CH_4-C values represent a stronger reference to differences between composts than the CO_2-C curves.

Under aerobic conditions, in sandy soil, the $NH_4^+ - N$ form accounts for one-tenth of the $NO_3^- - N$ form. Under anaerobic conditions the quantities are very similar. Under aerobic conditions $NH_4^+ - N$ and $NO_3^- - N$ produce maximum curves with a time shift, while under anaerobic conditions no such rule can be identified in the relationship between the two forms.

5. NEW AND NOVEL RESULTS OF THE THESIS

1. The organic matter produced with prism composting has poorer quality (less ripe and stable) than the one obtained through active aeration.

2. In the case of tree cuttings heat treatment may replace the composting process and lead to cost savings. The application of this method to grasses did not bring any result.

3. At the time of compost assessment it is advisable to categorize the finished products in quality classes as the processing technology is unable to make up for the differences between the starting materials.

4. Water-soluble organic C content shows a relationship with CO_2-C. The stronger the correlation, the better this indicator reflects the success of composting.

5. It is advisable to use the $\frac{NH_4^+ - N}{NO_3^- - N}$ parameter for compost assessment. If this value is low (~2) then compost quality is good. If it is high, compost quality is poorer as the nitrification conditions were not fully satisfied.

6. C/N ratio refers to mineralization potential. The chemical conditions of composting may be better described with the ratio of water-soluble C and mineralizable N.

7. Composting technologies can be compared through the measuring of low molecular weight carboxylic acids.

8. According to measurement evidences, the pH of the starting material will have an impact on the nitrogen content of the finished product. The lower the pH value, the more nitrogen is bound in $NH_4^+ - N$ form to the partly humificated organic matter.

9. According to study results, it is advisable to spread the compost right after the completion of mineralization because the material transformation processes are not finished yet. The storage of composts entails nitrogen loss.

6. PRACTICAL USE OF THE RESULTS

The municipalities and the waste water treatment plants utilizing organic matter in agriculture through composting must compete for investment funds. In many cases, however, the purchased composting technology little matches the organic matter properties. According to experiences, the desired efficiency will be present only if the technology matches the organic matter of the waste to be composted. The studies point out that it is advisable to develop an efficient substrate mix for the technology. Mixes of higher humidity can be better composted through active aeration. If the composition of organic wastes (ratio of grass and tree cuttings) is variable, it is advisable to use prism composting as this technology allows for certain modifications in the composting process.

The Christian part of the world produces a large volume of pine waste after each Christmas. It can be processed with various methods. One possibility is to treat the cut pine waste with vapor under pressure in a dedicated machine. This corresponds to a wet oxidation procedure performed at medium pressure, which is very popular in the field of waste treatment. Mixed directly into the soil, the resulting substance will degrade quicker than the starting material. When performed at lower pressure and temperature, the treatment results in a substance that can be composted in a shorter time.

The purpose of all composting technologies is to produce the highest possible compost quality within the shortest possible time. In fact, composts made from different starting materials and with different technologies have a wide range of qualities and that is why it is important to assess composts on the basis of uniform criteria. When assessing composts, we usually consider such parameters as dry and organic matter content, C/N ratio and nutrient volume. A more precise assessment would also require the determination of parameters like water-soluble organic carbon content, respiration and germination index. According to my measurements, the chemical conditions of composting may be better described with the ratio of water-soluble C and mineralizable N than with the C/N ratio.

7. LIST OF PUBLICATIONS ASSOCIATED WITH THE TOPIC OF THE THESIS

PUBLISHED ARTICLES

1. KOCSIS I. – **SIMÁNDI P.** – SELMECZY J. (1997): Gázvolumetrikus C meghatározási módszerek a szervesanyagok talajerőgazdálkodási felhasználásánál. I. Alföldi Tudományos Tájgazdálkodási Napok. Mezőtúr. 1997. október 29-30. 248-253. p.
2. KOCSIS I. - DARÓCZI S. - **SIMÁNDI P.** (1997): Légjárhatóság-mérés homoktalajon. Tiszántúli Mezőgazdasági Tudományos Napok Kiadványa Karcag. 1997. június 12-13. 102-103. p.
3. **SIMÁNDI P.** – CSIZMARIK G. – INUBUSHI K. – BOROSSAY J. (1999): Mikrobiális lebontás halastavak, víztározók kiszáradó üledékében. 42. Magyar Spektrokémiai Vándorgyűlés kiadványa. Veszprém 1999. jún. 28-30. 174-179. p.
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