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Compost Quality – Trends and Tools

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Abstract
A short historical overview focusing on the milestones of biological treatment strategies and composting is given and the outlook to the future approach of compost management and quality definition is presented. A standard quality is taken for granted; however, several properties such as nutrients, phytosanitary aspects and humic substance contents have a determining influence on the quality of organic matter. This study focuses on humification and the use of innovative analytical tools such as FTIR spectroscopy and thermal analysis to evaluate stability and humification. The transition from research to practical application by means of multivariate data analysis is presented.

1 From the dumping of organic waste to resource recovery
Over the last decades the definition of compost quality has been subjected to considerable change. In the transition from dumping to municipal solid waste composting, establishment of separate collection and composting of the biogenic fraction, the definition of standard quality focusing on the absence of pollutants, and the implementation of adequate regulations represented milestones in the development of strategies applied in the handling of biogenic waste materials. The first target of separate collection was to achieve a better quality compost. Simultaneously, following the decreased presence of organic matter in municipal solid waste, the negative environmental impact produced by the latter in landfills has been reduced. In Austria and Germany the separate collection of different organic fractions was established. Separate collection resulted in a better compost quality with regard to organic and inorganic pollutants. As a consequence, the requirements of different compost qualities were defined by national regulations. Following the establishing of regulations governing the absence of pollutants and the daily practice of separate biowaste bin collection and composting, activities that favorably enhance compost properties, leading to the exceeding of required standard quality parameters, have been highlighted. the period of “compulsory exercise” has been replaced by a “free section”. In the past scarce attention was paid to the quality of organic matter. Targets and standards suited to the specific application purposes should be defined for future “compost design”. In this con-

text composting is intended as the "best means of using existing raw materials" through biological treatment. In particular, the following characteristics of compost should be focused on:

- nutrient content and release (Diez and Krauss, 1997),
- phytosanitary properties (Ryckeboer et al., 1996), and
- humic substance contents (Smidt et al., 2004)

Nutrient content is a product of organic matter present in the process to be mineralized and released in line with process kinetics. Research studies will be required in order to ascertain the best way of reaching targets using appropriate mixtures of input materials, including residues from anaerobic digestion, and through process operation. Promotion of humification represents a fundamental issue due to the manifold benefits of humic substances that have attracted much interest in soil science in the past (Tan, 2003; Campitelli et al., 2006). It should be emphasized that composting is the only technology available for the synthesizing of the above chemical compounds by means of a biotechnological process. Besides the benefits for soils and plants the contribution to carbon sequestration is the most important environmental aspect.

Comprehensive characterization of organic matter has enhanced the application of new analytical tools. Spectroscopic (Chen, 2003; Smidt and Schwanninger, 2005) and thermal methods (Dell'Abate et al., 2000; Melis and Castaldi, 2004; Smidt and Lechner, 2005) have been used to assess compost quality. Several methods have proved promising for practical application in the future.

The present paper focuses on factors that improve humification, on determination of humic substances, and on innovative analytical and evaluation tools for use in the characterization of compost organic matter.

2 Benefits of compost organic matter

Why does compost organic matter deserve closer attention? The transformation processes occurring during degradation of biogenic materials result in new chemical compounds characterized by unique properties and functions that can only be achieved by means of composting processes. In contrast to mineralization products identified in the past, there is still considerable lack of knowledge as to synthesized "humified matter", although many efforts have been made to shed more light on the nature of the latter. Depending on the material involved the transformation products of these complex processes may imply a wide range of variations. To date it has not been demonstrated whether biomolecules of high molecular weight are synthesized or smaller molecules are combined in aggregates. The more recent hypothesis of "micelles" has received greater impetus over the last few years by several authors (Sutton and Sposito, 2006). Another approach focuses on the elucidation of functional aspects of humified matter. The essential role of the latter in aggregate stabilization, water and nutrient holding capacity and microbial activity in soils is unquestioned. Benefits afforded to

plant growth by the application of compost are closely related to the positive impact produced on soils, whilst suppressive effects on plant pathogens and the support of microbial communities are currently undergoing intensive investigation. In addition to humified matter numerous other fractions constitute the organic fraction of compost. The role played by organic molecules immobilized on mineral surfaces has yet to be clarified. The influence of mineral compounds on activities performed by organic matter has not yet been investigated systematically, although it can be assumed that turnover rates, decomposition kinetics, and nutrient release are largely affected by the presence of mineral components in the compost. With regard to "compost design" the correlation between input materials, chemical composition of composts and functions should be elucidated in the future.

3 Factors that influence humification

It is an acknowledged fact that humification requires aromatic compounds and a balanced mixture of easily, moderately, and scarcely degradable biogenic compounds. These different degrees of degradability ensure that microbial activity is maintained for a longer time and are sufficient to initiate decomposition of more resistant compounds and to provide transformation to humified matter (Smidt et al., 2004). Although natural processes do not take place under "optimized" conditions from the technical-economic (anthropogenic) point of view, organic matter degradation and humification in natural systems, i.e. soils, provide considerable information on kinetics and conditions of transformation processes. In practice mineralization is promoted and humification is rather an accidental by-product. It is an objective of current research to identify the crucial mechanisms of process operation towards humification.

Extractable humic acids have been proven to be a suitable parameter for use in assessing progressing humification in composts. Usually composts, containing yard and kitchen waste (fruits, vegetables), reach higher humic acid contents than sewage sludge composts. Humic acid contents of an extensive series of biowaste composts were found to be between 30 % and 46 % referring to waste organic matter (ODM). Depending on other compost ingredients values between 8 % and 20 % (ODM) were measured in sewage sludge composts.

Aromatic compounds improve the synthesis of humic substances. Figure 1 illustrates humic acid formation in two composting processes. Process BIO1 was operated with biowaste and yard waste, process SSL with sewage sludge, paper sludge and charred pomace. Higher humic acid contents were obtained in BIO1. Composting of biogenic materials with a wide range of different compounds, more aromatics, a higher transformation rate in terms of microbial activity and higher temperatures provide better results with regard to humification.

Respiration activity (RA_4) was between 67.0 and 4.3 mg O_2 g^{-1} DM (dry matter) in BIO1 and between 22.0 mg and 1.5 mg O_2 g^{-1} DM in SSL. These results confirm the role of microbial activity in transformation processes.

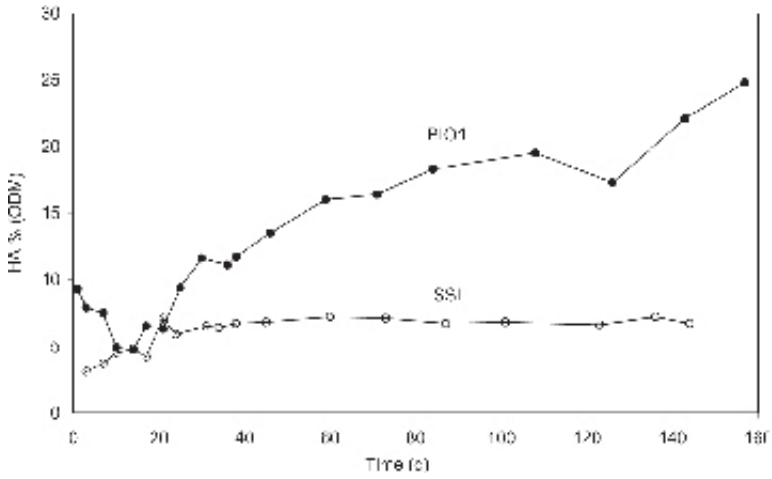


Fig. 1: Humic acid synthesis during composting of biowaste/ yard waste (BIO1), and sewage sludge (SSL)

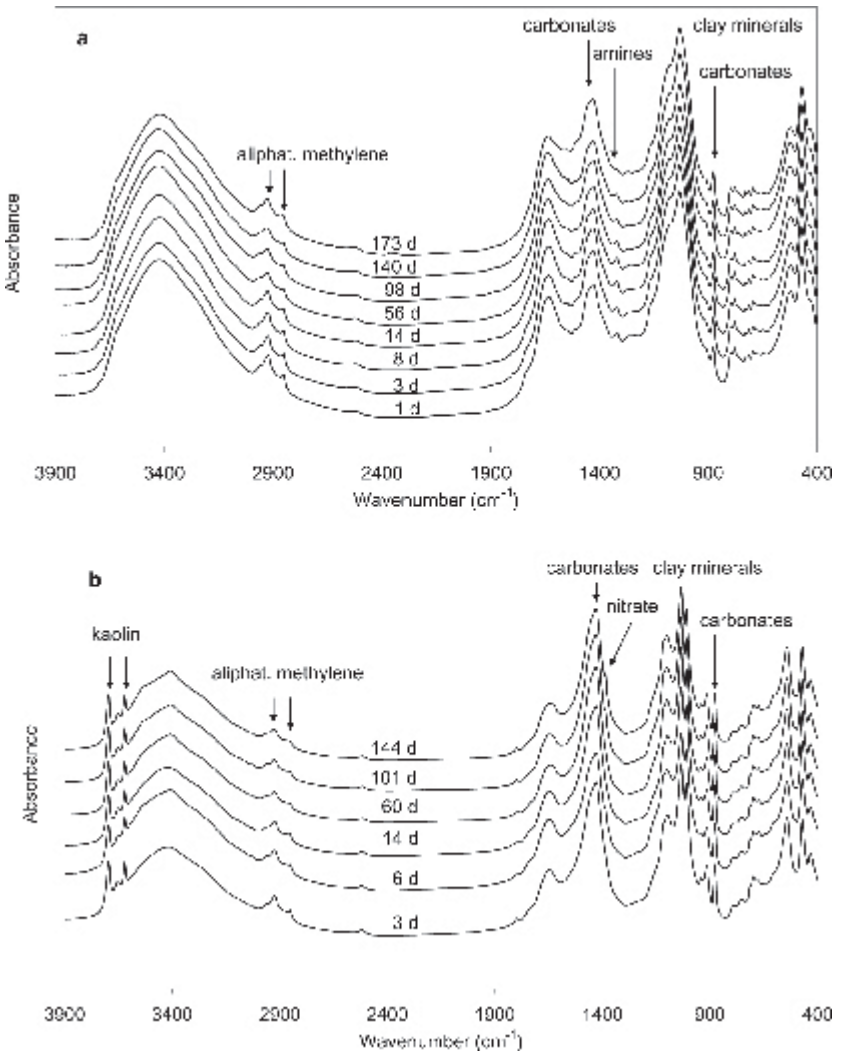
4 Analytical tools and evaluation procedure to assess compost organic matter quality

Compost organic matter is usually characterized by several sum parameters such as loss on ignition, organic carbon, organic nitrogen, and the C/N ratio. Within a process these parameters indicate progressing degradation and stabilization. The significance is limited if different processes are compared, in view of the wide range of variation of the parameters. More information on stability is provided by biological tests, i.e. by the oxygen uptake (respiration activity) over a 4 day period. Detailed chemical analyses are expensive and not appropriate for practical use.

Further to providing a more comprehensive insight into the chemical composition infrared spectroscopy is particularly useful in yielding very fast results.

4.1 FTIR spectroscopy

FTIR spectroscopy has been proven to be a suitable tool with which to describe compost organic matter quality. Quality in this context comprises stability, which includes low respiration activity and plant compatibility, and high humic acid contents. Figures 2a and 2b show the spectroscopic pattern of two progressing composting processes mentioned above, one process operating biowaste (BIO2),



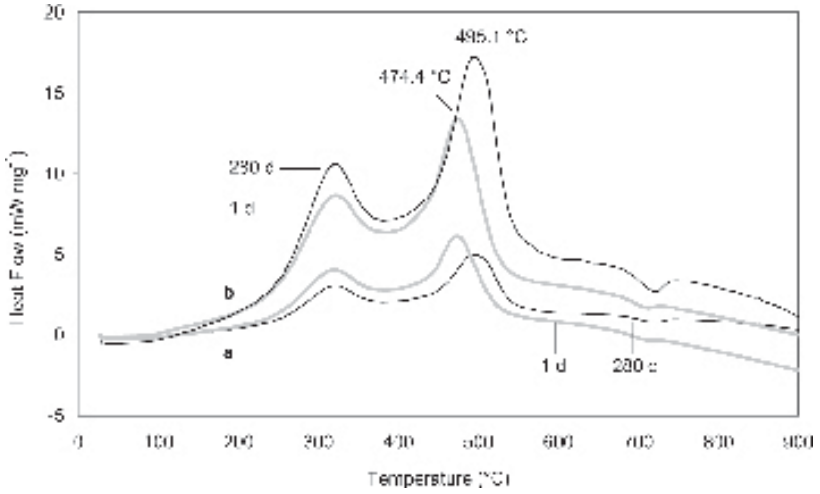
another treating sewage sludge (SSL). Several characteristic indicator bands are specified (Smidt and Schwanninger, 2005). Despite the same indicator bands, their proportions and dynamics differ. Such differences in the chemical composition are recorded by the infrared spectrum and distinguish different materials and processes. Multivariate data analysis supports the discovery of these diversities.

Fig. 2a-b: Infrared spectroscopic pattern of progressing stages of (a) biowaste BIO2 and

(b) sewage sludge SSL composting

4.2 Thermal analysis

Degradation of molecules and humification are reflected by changing thermal behavior and enthalpies. For this reason, assessment and evaluation of compost quality using thermal methods is enabled. The heat flow recorded during combustion (differential scanning calorimetry, DSC) reveals the exothermic and endothermic reactions of the sample. Peak location, peak shift to higher temperatures, decrease and increase of peak intensities are strongly related to the material and the stage of decomposition and stabilization/ humification, respectively. Figure 3 shows the heat flow of the initial and final samples (composting process BIO3)



referring to 1 mg DM (a) and to 1 mg ODM (b). Degradation of organic matter causes the heat flow to decrease. Referring to organic matter the heat flow increases due to the positive contribution of humification. The shift of the second exothermic peak to higher temperatures with time is clearly visible.

Fig. 3: Heat flow of the initial and the final sample of biowaste composting (BIO3) referring to dry matter (a) and organic dry matter (b)

The location of the second exothermic peak at high temperatures can be assigned to humification. Heat flow profiles of the residues after alkaline extraction of humic acids no longer display a second peak. Enriched scarcely degradable compounds such as wood show the second exothermic peak at lower temperatures (at around 470° C). Enthalpies of the sample can be calculated by integration of the peak area below the DSC profile.

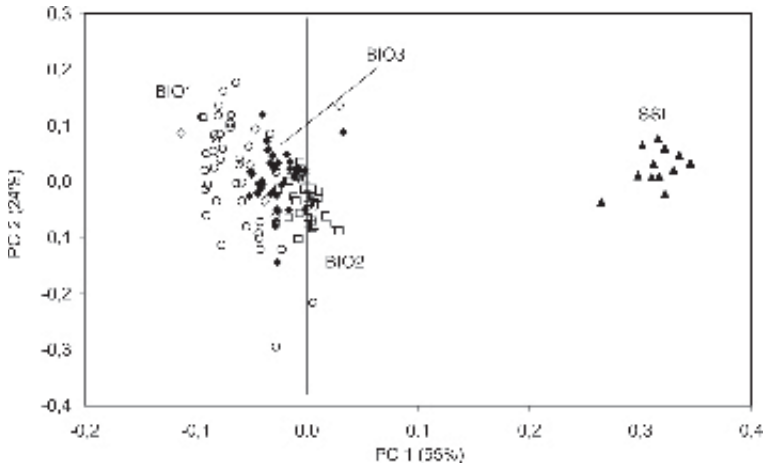
4.3 Multivariate data analysis

4.3.1 Principal Component Analysis (PCA)

The generation of huge data pools by FTIR spectroscopy and thermal methods promoted the application of multivariate data analysis, on the one hand to extract more information from these data, on the other hand to provide the transition from research to practice making such powerful analytical tools available for daily business. The intrinsic data structure is revealed by Principal Component Analysis (PCA) which supports interpretation of data and assignment to inherent features of the sample. In addition Principal Component Analysis serves as a basis for other multivariate methods (Esbensen, 2002; Meissl et al., 2006).

Principal Component Analysis visualizes the differences observed between the four composting processes mentioned before BIO1, BIO2, BIO3 and SSL (Figure 4). Samples of processes BIO1 and BIO2 originated from the same biowaste composting plant in Vienna (investigated in 2000 and 2006). Differences in decomposition stages and process operation are revealed by the spectral pattern. Process BIO2 was more uniform than process BIO1 in 2000. Samples of the sewage sludge composting process are clustered very close to each other due to marginal changes during the process. They were also confirmed by conventional parameters.

The spectral pattern of biowaste composts shows slight differences due to the presence of specific input materials and / or individual process operation uncov-



ered by PCA. The distance between the cluster of sewage sludge composts and biowaste composts is more distinct due to the significant difference in the chemi-

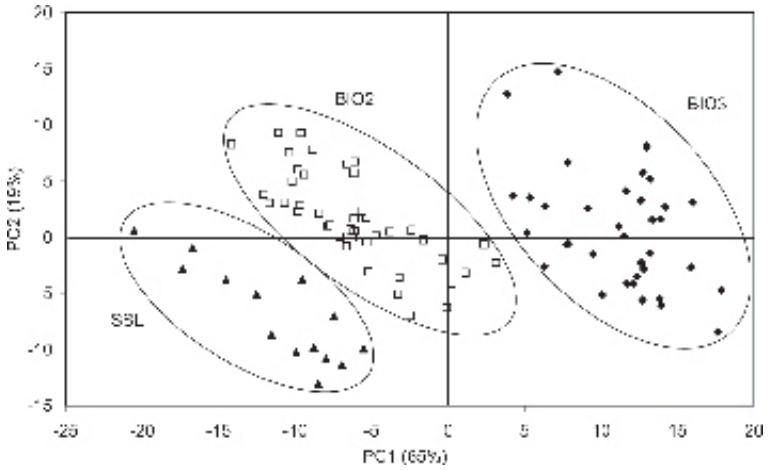


Fig. 5: PCA of different composts (BIO2, BIO3, SSL) based on DSC profiles

cal composition.

Fig. 4: PCA of different composting processes BIO1, BIO2, and BIO3 (biowaste compost), SSL (sewage sludge compost) based on the infrared spectral pattern

PCA was also carried out for DSC profiles of the biowastes mentioned above (BIO2, BIO3, and SSL). Figure 5 confirms that thermal features of the sample enable the distinguishing of different kinds of composts.

4.3.2 Classification based on the infrared spectral pattern

With regard to compost quality the unequivocal assignment of unknown composts to the class of biowaste composts according to Austrian standards (separate source collection and best quality) should prove possible on the basis of their infrared spectral characteristics. Two classes have been defined by infrared spectra of typical representatives of biowaste compost and MBT material. Unknown samples are assigned to the defined groups (MBT model or compost model) if they belong to one of them. If they do not, they are found out of range (samples SSL and RAD) which is graphically visualized by the Coomans plot. Figure 6 demonstrates the model of the defined classes (gray) and the assigned unknown compost spectra (black square symbols).

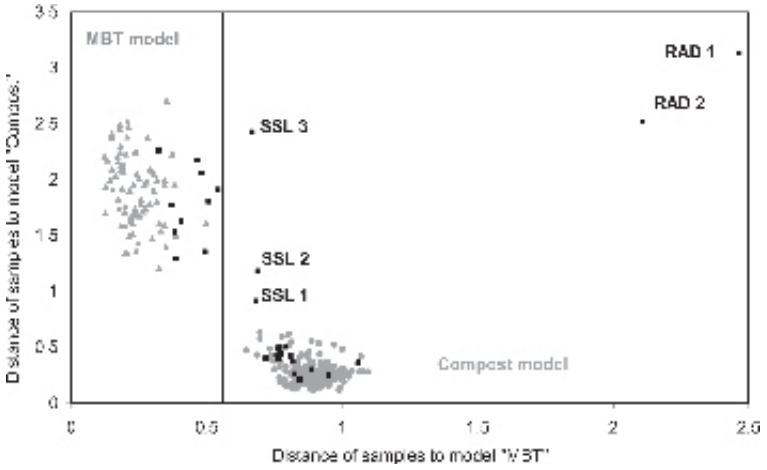


Fig. 6: Coomans plot of the classification model; assignment of unknown samples to defined classes and outliers (SSL and RAD), visualized by the Coomans plot

It is clearly visible that not all composts can meet the standard of high quality composts. Sewage sludge composts (SSL) and residues from anaerobic digestion (RAD) are found in the "outsider" area. Other infrared spectra were assigned to the MBT class or the compost class. Verification of accurate assignment was performed by conventional parameters.

4.3.3 Prediction of respiration activity and humic acid content based on the infrared spectral pattern

Parameters providing information on stability and humic acid contents require the application of time-consuming analyses. Oxygen uptake is measured over a 4 day period with the aim of determining reactivity / stability of the sample by respiration activity (RA_4). Humic acid determination is performed by repeated extraction for 4 days. Thus, the main objective was to predict these parameters by means of infrared spectrum. It can be assumed that both parameters are reflected in the spectrum as they are closely related to the chemical composition. Figure 7 shows the prediction models for respiration activity (a) and humic acid contents (b). The model for respiration activity prediction was calculated using 194 spectra, with an RMSCV (Root Mean Square Error Of Cross Validation) of 2.9 mg O_2 g^{-1} DM and a correlation of $R^2 = 0.91$. The model of humic acid prediction is based on 360 spectra, with an RMSCV of 2.4 % ODM and $R^2 = 0.87$.

5 Conclusion

New approaches in composting strategies require a clear concept of targets to be reached and a comprehensive definition of compost quality. In addition analytical

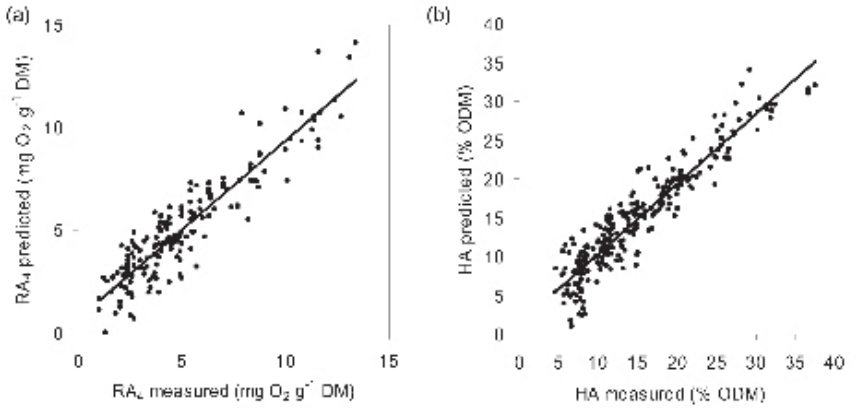


Fig. 7a-b: Prediction of respiration activity (a) and humic acid contents (b) based on infrared spectroscopic characteristics and Partial Least Squares Regression (PLS-R)

tools are necessary to assess adequately compost quality. Humification is considered a useful parameter indicating compost quality. Analytical tools such as FTIR spectroscopy and thermal analysis, that provide further insight into the quality of organic matter are ready to be introduced into practice. Moreover, knowledge of the quality of a specific organic matter present in compost will undoubtedly enhance market value of the product. Future research should focus on several economic aspects, with particular concern for the issue of carbon sequestration and potential monetary worth of the latter in the economy of composting.

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