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Review Article

Application of an Integrated NIRS Method for Determining the Stability/ Maturity of Compost

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ABSTRACT

Producing compost with consistent stability and maturity is critical for the successful marketing of compost as part of growth media. Therefore, simple and effective method for determination of maturity and stability of compost is needed. Near infrared spectroscopy (NIRS) allows rapid simultaneous determination of chemical and physical properties of organic materials. The previously developed NIRS model in which NIR spectral data were combined with various parameters describing degradability and stability of composts during the composting process (respirometric, photometric, C / N extraction, Solvita™) using well known maturity test and chemical analyzes. This model was used for analysis of compost samples from various composting sites with different technologies and with different composition of starting materials. The measurement revealed that NIRS method can be used as simple, fast, and cheap method for indication of compost maturity.

Keywords: NIRS; Compost maturity; Compost stability

INTRODUCTION

Composting is the biological transformation of biodegradable waste under controlled conditions into a relatively bio stable product with a high proportion of humus, which positively affects soil fertility [1,2]. The aim is to produce a stabilized product, ie. a product that can be stored without further treatment and used as an additive of improving soil quality.

To successfully marketing of compost as a growth medium, compost must have consistent stability and maturity. Therefore, it is essential to have reliable methods for evaluating the stability and maturity of compost.

Compost stability is defined as the degree of stabilization of organic matter in the compost. It is inversely proportional to the microbial activity and bioavailability of organic matter.

Maturity is the degree of decomposition of phytotoxic substances formed during the decomposition process, such as NH3 or short-chain organic acids, and the suitability of compost for plant growth. The definition of compost maturity is influenced by its use, and therefore acceptable maturity varies depending on the end use of the compost [3-5].

The most active component of compost is water-soluble organic matter. It directly reflects the transformation process of organic matter. Soluble and easily degradable carbon sources, such as monosaccharide's and lipids, are used by microorganisms in the thermophiles and mesospheric stages of composting. This is generally reflected in changes in the concentration of water-soluble carbon (organic matter) [6].

Insufficiently stable compost contains a significant proportion of biodegradable matter in which high microbial activity can be maintained. Respiration is directly related to the metabolic activity of the microbial population. For this reason, respirometric has been commonly used to evaluate microbial activity and thus the stability of a compost sample [7].

The amount of ammonium and nitrate nitrogen is an important indicator of mature compost. Where ammonium nitrogen predominates at the beginning of the process, but as the maturation progresses, the levels of nitrate-N in the compost begin to exceed ammonium-N levels. For this reason, determining the ratio of ammonium-N to nitrate-N is a useful parameter to assess the degree of maturity [8].

Near-Infrared Spectroscopy (NIRS) is an analytical method that

allows determining, depending on the calibration method, more parameters of the test substance (both chemical and physical). NIRS spectroscopy uses near-infrared radiation absorption (650-2500 nm) that penetrates several millimeters into the sample, allowing the analysis of complex inhomogeneous samples (eg compost) and it is possible to perform analyzes directly without sample modification (without dissolution, dilution). Today, it is used for rapid and non-destructive analysis of various types of samples in healthcare, pharmacy, but also food and agriculture.

Up to date, only a few attempts have been made to use NIRS to measure various compost parameters (most commonly total concentration of carbon and nitrogen) [9,10]. Recently, Bio Forschung Austria (BFA) has started to develop a method based on NIRS for simple and reliable determination of compost maturity [11]. The model developed by BFA for monitoring compost using NIRS is based on the correlation of the NIRS method with classical methods describing compost maturity and combining them into one index (integrated stability index). The monitored parameters were: oxygen consumption rate, Solvity index, DOC and NOx and NH_4 content. Based on a cooperation between BFA and ZERA agency this method and model was applied on various compost plants which using different technology of composting. The results of this research are summarized in the following text.

MATERIALS AND METHODS

Material

For application of the NIRS method 56 of compost samples were used. Those composts were produced with different raw material composition and with different technology or technological equipment of the composting plant.

Methods

For samples intended for method verification, nitrogen forms were tested in an accredited laboratory by the following methods.

Determination of Total Nitrogen (*Kjeldahl method*): The sample is mineralized with a mixture of sulphuric acid and hydrogen peroxide. Subsequently, the nitrogen content is determined by back titration with sulphuric acid after liberation of ammoniac nitrogen in an alkaline medium and its conversion by distillation into a boric acid solution.

Determination of Ammonia Nitrogen: Ammonia nitrogen is extracted from solid samples with a solution of neutral salt - K_2SO_4 (1% solution). After extraction, the suspension is filtered. The ammonium ion content is determined by titration with sulphuric acid after distillation of this extract in to alkaline medium.

Determination of Nitrate Nitrogen: Nitrate nitrogen is extracted from solid samples with a solution of neutral salt - K_2SO_4 (1% solution). After extraction, the suspension is filtered. The nitrate nitrogen content is determined by an ion-selective electrode, where the nitrates present in the extract cause a change in the potential of the electrode.

NIRS measurements were performed on dried and ground (<0.1 mm) samples using a Brimrose AOTF diffusion reflectance spectrometer in sample rotation mode or on Spectra Star 1400 XT-3 sample rotation spectrometer in wavelengths ranges 1400 nm - 2600 nm. The spectral data were smoothed using Norris's 1st derivative transformation. Partial least squares regression (PLS-R) models were calculated to predict the integrated "stability index".

Statistical calculations were performed using CAMO Unscrambler software.

RESULTS

The model developed by BFA for monitoring compost using NIRS is based on the correlation of the NIRS method with classical methods describing compost maturity and combining them into one index (integrated stability index). The monitored parameters were: oxygen consumption rate, Solvity index, DOC and NOx and NH_4 content.

The application of NIRS model was performed on 56 compost samples from various composting plants in Czech Republic. The input raw material composition was either only biodegradable municipal waste (hereinafter BMW) as a mix of vegetable character or a mix of BMW with waste with a high content of total nitrogen (eg sludge - product of municipal wastewater treatment plants; manure - agricultural production). From these samples, 69% were from open-area composting technologies with a compost turner, 23% of open-area composting with a loader (extensive technology) and 8% of closed box technologies (intensive technologies). This percentage of technologies corresponds to the average structure of technological equipment of composting plants in the Czech Republic. Compost samples were taken at the stage of process which was defined by the composting plant operator as completed composting - therefore, the mature compost was expected. The NIRS "stability index" model describe the maturity of compost by single number where higher number represents more mature compost. For mature compost is "stability index" between 8 and 12.

For verification on compost maturity the total content of mineral nitrogen and its form (N-NH_4, N-NO_3), the ratio of both forms (NH_4: NO_3) were also analyzed for each sample.

These parameters were chosen as parameters for verifying the composting process management, where the structure and content of mineral nitrogen forms predict the resulting maturity of compost and the possibilities of its further use and they are also a support for determination and interpretation of the compost stability. High concentrations of NH_4-N (more than 500 ppm) and high ratios of NH_4-N: NO_3-N (greater than 10) indicate that the compost is not mature or not completely composted [12].

The NIRS method was used to compare the maturity of composts with different input raw material composition and with different technological equipment of the composting plant (Table 1 and 2).

In the case of composts with various raw material compositions (Table 1), samples from whole range of maturity were taken (from minimum values of the stability index (un measurable) to samples with maximum values of the stability index (8 - 12)).

Composts which contain of 40 - 60% of its mass the raw materials with a high nitrogen content, show measurable values for determining the stability index. In the case that rich nitrogen material is add to BMW only in 10 - 20% of mass the maturity index reached the maximum values (8 - 12).

Determination of compost stability by NIRS method can also be used to determine the effect of composting technology on the resulting quality (Table 2). The classical composting technology on free-area with excavation using compost turner ensures oxygen supply by rotating the compost pile across its entire cross-section.

Table 1: Mean values and standard deviations according to the raw material composition.

Parameters for determining maturity and stability	BMW	BMW + raw materials with high N content - summary	BMW + raw materials with a high N content (40-60%)	BMW + raw materials with high N content (10-20%)
	n = 45	n = 11	n = 7	n = 4
NH4-N in $CaCl_2$ extract [mg / kg dry matter]	336 (± 478)	506 (± 4123)	4970 (± 4412)	356 (± 124)
NOx-N in $CaCl_2$ extract [mg / kg dry matter]	320 (± 335)	506 (± 553)	462 (± 628)	557 (± 480)
N-mineral [mg / kg dry matter]	766 (± 485,5)	1600 (± 3972)	5010 (± 4164)	1014 (± 500)
NIRS maturity index	7.5 (± 1.7)	5.2 (± 4.5)	0 (± 2.6)	8.4 (± 2.8)

Table 2: Mean values and standard deviations (results 2019.2020) by technology.

Parameters for determining maturity and stability	Excavation	Loader	Boxes
	n = 36	n = 12	n = 4
NH4-N in $CaCl_2$ extract [mg / kg dry matter]	357 (± 515)	337 (± 3014)	6370 (± 3624)
NOx-N in $CaCl_2$ extract [mg / kg dry matter]	326 (± 439)	417 (± 342)	397 (± 367)
N-mineral [mg / kg dry matter]	891,5 (± 561,6)	903 (± 2955.9)	6851.3(± 3714.1)
NIRS maturity index	7 (± 1.89)	7.9 (± 3.4)	0 (± 1.2)

Table 3: Parameter values for determining maturity and stability – box technology.

Parameters for determining maturity and stability	Technology boxes			
	sample 1	sample 2	sample 3	sample 4
NH_4-N in $CaCl_2$ extract [mg / kg dry matter]	945	9160	4970	7770
NOx-N in $CaCl_2$ extract [mg / kg dry matter]	462	331	41	922
N-mineral [mg / kg dry matter]	1410	9490	5011	8692
NIRS maturity index	5.2	0	0	0

Contrary when a loader is used instead of a compost turner, the pile is aerated in homogeneously. In the box technology the aeration is performed without mechanical rotation.

The technology of closed boxes showed significantly different values for the maturity parameter (N-NH_4 and N-NOx) and maturity index in various samples. For clarity of the values obtained from the closed box technology the results from all samples are listed in Table 3.

DISCUSSION

The application of a new method for easy verification of the stability and maturity of compost using NIR spectroscopy has shown the applicability of this method in practice. The resulting maturity indexes are correlating with the assumption of the maximum content of ammoniac nitrogen (-NH_4) in stable composts, when this content should not exceed the limit of 500 mg / kg in the compost dry matter. From the trend of nitrogen content parameters can be also deduced the right raw material composition, which is required to achieve good stability and maturity of compost (Table 1). It is clearly visible that the BMW enriched with raw materials with high N content (40 – 60 %) needs much longer time to complete composting that was indicated by the composting plant. On the other hand composting process of BMW with raw materials with N content (10-20 %) proceeds very well. It has also been shown that this method can be used to monitor composts from various technologies (Table 2 and 3). Since for composting using box technology the raw material with high N content (40-60% by weight) was used, it is not surprising, in respect of the results showed in Table 1, that the low maturity compost was detected.

CONCLUSIONS

In general this NIRS method can be used for monitoring of composting process for various composting methods or material composition regardless the calibration condition.

Since, all technologies are capable to provide stabile and mature compost when the fundamental requirements for composting process are fulfilled (material composition, temperature profile of thermophiles phase). This method looks to be promising approach for simple, cheap and reliable method for practical determination of compost maturity and stability, and therefore can help to composting facilities with determination and verification of theirs composting process.

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