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Neural image analysis for maturity classification of sewage sludge composted with maize straw

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ABSTRACT

This study uses the methods of computer image analysis and neural modelling for the construction of classification models to identify the stage of early maturity in composted material based on sewage sludge and maize straw. The research material was produced in strictly controlled laboratory conditions with a six-chamber bioreactor. Samples of the material were subjected to image acquisition in visible light (VIS), ultraviolet light from the UV-A range and mixed light (MIX, VIS + UV-A). The acquired images were subjected to broad analysis. As a result the values of 46 parameters providing information about the colour and texture were obtained. The colour was analysed for the RGB, HSV and greyscale model. The texture analysis determined the grey level co-occurrence matrixes (GLCM). The parameters acquired from the image were the basis of train, validation and test sets which were used for the construction of neural classification models. The models were based on the MLP (Multilayer Perceptron) topology. The process of their construction went on in the iterative manner, where the potentially insignificant input parameters were eliminated by means of sensitivity analysis. Finally 21 such models were generated. The classification error for the best model in the MIX light was 1.56%. On the other hand, the models with the best accuracy in the UV-A and VIS light showed the error, which was 1.83% and 2.87% greater than the best model for the MIX light, respectively.

1. Introduction

In recent years in Poland there has been a considerable increase in the production of communal sewage sludge (Malinska and Zabochnicka-Swiatek, 2013). It largely results from improved effectiveness of sewage treatment, which is the effect of the introduction of new technologies in response to the increasing requirements concerning the quality of treated sewage discharged to the environment. Apart from that, in poorly urbanised areas the length of the sewerage system is growing dynamically. This harmonises with investments in new sewage treatment plants. The sludge produced as a result of wastewater treatment is a potentially harmful material, which must be handled somehow. From 2016 the storage of sewage sludge in Poland, so far the basic handling method, will be prohibited due to the adaptation of the Polish law to the EU standards. In the new legal situation there will be two basic methods of sewage sludge recycling, i.e. using it (after drying) as energetic material in waste incineration plants or composting. In view of the fact that the construction of a waste incineration plant is beyond the financial capacity of not only rural communes but also counties, the only reasonable alternative related with the handling of communal sewage sludge located outside big cities is the construction of small composting plants. Sewage sludge subjected to the composting process may be used for soil fertilisation (Kosobucki et al., 2000; Waszkielis et al., 2013). Taking into account the possibility of the future application in agriculture it is assumed that sewage sludge with reduced content of heavy metals is adequate to the composting process. It means that the content of heavy metals in the final product should not exceed the limit values for farmland fertilisation. This sludge usually comes from small and medium-sized sewage treatment plants located in the areas which are not strongly industrialised. On the other hand, the considerable increase in temperature which accompanies the composting process leads to the pasteurisation and destruction of pathogenic organisms in sewage sludge (Haug, 1980; Wolna-Maruwka et al., 2012).

Composting of sewage sludge is possible only if when mixed with the structure creative material, i.e. various types of residues

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from the agricultural or wood production, such as sawdust or straw. Under the project entitled "The use of maize straw as a substrate for methane fermentation and structural material in composting process", financed by the Polish Ministry of Science (2010–13) were studied the possibilities of wider use of maize straw due to the increase of the prices of typical substrates in recent years (Dach et al., 2014). It has been stated that under Polish conditions the most suitable is maize straw, which is a residue of the maize tillage for grain. Relatively high humidity of this material in the fresh state (Kaliyan and Morey, 2009; Womac et al., 2005) causes that the possibilities of its rational use for heating purposes are strictly limited. That is why the maize straw has considerably less of the potential buyers, and thus clearly lower price than straw from the cereals ears or even rape production. The use of maize straw as addition to the composted sewage sludge allows to improve its structure as it provides an adequate porosity much longer than the typical cereal straw. Due to improvement of the C:N ratio by introducing a large number of readily available organic carbon it is also visible a significant reduction of ammonia emissions from composted sewage sludge (Boniecki et al., 2012a).

In a rational composting process it is important to identify the moment when the material reaches the stage of early maturity as soon as possible. At that stage the decomposition processes become clearly inhibited. The material which reaches this stage may be stored in high heaps up to 4 m. This has influence on saving the area of the compost platform, which is relatively expensive. It is a problem to precisely identify that stage. This can be done by physiochemical analyses concerning the intensity and composition of gases emitted from the composted biomass, checking the C:N ratio or by checking the content of humus (Piotrowska-Cyplik et al., 2009, 2013; Dach et al., 2008; Dach, 2010a,b). However, in practice this cannot be done by the staff of a composting plant. Therefore, it was necessary to develop a quick and effective method of verification of the degree of maturity of the composted sewage sludge in order to support the decision to move the composted sewage sludge to the maturing facility.

The issue of using artificial neural networks to investigate the processes of biomaterial composting is not fully appreciated. In fact, in recent years there have been few studies where these tools were used for such investigations. Artificial neural networks were used for the prediction of ammonia emission from the composted biomass (Boniecki et al., 2012a), the prediction of heat loss (Boniecki et al., 2013) and the classification of the degree of maturity on the basis of selected physical and microbiological parameters (Gao et al., 2007). They were also used for the optimisation of the composting process based on the achievement of appropriate courses of the curves of variance in pH, temperature and CO_2 concentration (Díaz et al., 2012). The application of the methods of computer image analysis in such studies is even more limited. Except for few studies (Boniecki et al., 2012b; Kujawa et al., 2013) the literature does not provide any publications about the application of these methods to investigate the composting processes. However, the methods of computer image analysis proved to be an adequate and credible tool supporting the classification and assessment of the state of different biomaterials (Delwiche et al., 2013; Majumdar and Jayas, 1999, 2000a,b,c,d; Manickavasagan et al., 2008; Rodríguez-Pulido et al., 2012; Szczypiński and Zapotoczny, 2012). They are often used in combination with neural modelling. The combination of both tools, which is also called the neural image analysis, is applied for the assessment of damage to cereal grains (Nowakowski et al., 2009, 2011) and fruit (Guyer and Yang, 2000). Apart from that it is also used for the identification of cereal grain varieties (Chen et al., 2010; Nowakowski et al., 2012; Pourreza et al., 2012; Zapotoczny, 2011). In view of the broad classification potential offered by the neural image analysis the authors decided to use it for research on the determination of compost maturity. The aim of the study was to develop neural classification models to identify the stage of early maturity in the composted sewage sludge and maize straw mixture on the basis of the information included in images of the composted material acquired in different light variants.

2. Materials and methods

2.1. Research material acquisition

The research material was acquired in 2012 by means of a six-chamber bioreactor (Wolna-Maruwka and Dach, 2009; Wolna-Maruwka et al., 2012) from the Ecotechnology Laboratory, Poznań University of Life Sciences, Poland. The composting material consisted of sewage sludge mixed in different proportions with the structure-forming material of maize straw, both in an ensiled and non-ensiled form (Table 1). The sludge used in the research came from the sewage treatment plant in Szamotuły near Poznań (Greater Poland Voivodeship). It had reduced content of heavy metals. The straw came from farms also located near this city.

The experiments were made in strictly controlled laboratory conditions. During and at the end of each process samples of the material were collected for photographs and physic-chemical analyses. The following parameters were identified for the samples collected: dry mass, pH, conductivity, density, ash and organic matter, ammonium nitrogen, total nitrogen and organic carbon. During the composting processes the temperature of the material was registered, the concentrations of oxygen and carbon dioxide in the air escaping from the bioreactor chambers were determined and the emissions of ammonia, hydrogen sulphide and methane were also analysed. In order to classify the composted material as the one which achieved the stage of early maturity the authors used the opinion of experts who had been conducting research on biological waste processing for a long time and the results of physiochemical analyses. The experts developed and used the following criteria to classify the composted material as the one which achieved the stage of early maturity:

- the material should be dark-coloured and smell like garden soil or duff; putrefactive or specific and offensive odour resulting from intensified ammonia or hydrogen sulphide emission is unacceptable,
- the material should undergo the process of hygienisation, i.e. during the process its temperature should be maintained at a level of at least 55 °C for at least 1 day or reach at least 70 °C for at least 1 h (this parameter was mentioned in EC Regulation 1774/2002),
- the temperature of the acquired material should not exceed 30 °C,
- the material should be relatively stable; the content of oxygen in the air escaping from the bioreactor chambers should be greater than 18%, whereas the content of carbon dioxide should not exceed 2.9%,
- the content of dry substance in the product obtained as a result of composting in the bioreactor should be higher than 25%,
- at the end of the process the pH of the material should range from 7 to 9.

Totally 8 experiments were conducted. The period of the experiments 1–3 was 36 days, while the period of the experiments 4–6 was 29 days, and the period of the experiments 7–9 was 39 days. Fig. 1 shows variations in the temperature of the composted material. Fig. 2 shows variations in the concentration of oxygen in the air escaping from the bioreactor chambers. The characteristics of both parameters were found to be satisfactory. In 7 out of 8 experiments the compost met all the criteria of early maturity.