Production of an innovative biowaste-derived fertilizer: Rapid monitoring of physical-chemical parameters by hyperspectral imaging

S. Serranti [a], A. Trella [a], G. Bonifazi [a,*], C. Garcia Izquierdo [b]

[a] Department of Chemical Engineering, Materials & Environment, Sapienza University of Rome, Italy
[b] CEBAS-CSIC, Department of Soil and Water Conservation and Organic Wastes Management, Campus Universitario de Espinardo, 30100 Murcia, Spain

ABSTRACT

In this work the possibility to apply hyperspectral imaging as a fast and non-destructive technique for the monitoring of the production process at pilot plant scale of an innovative biowaste-derived fertilizer was explored. Different mixtures of urban organic waste, farm organic residues, biochar and vegetable active principles were selected and utilized in two different European countries, Italy and Spain, for the production of the innovative fertilizer. The biowaste-derived fertilizer samples were collected from the pilot plant piles at different curing time and acquired by the hyperspectral imaging device. Spectra have been collected in the near infrared wavelength range (1000–1700 nm). Conventional analyses were carried out on the same samples in order to find correlations between the physical-chemical parameters detected at laboratory scale, and the acquired reflectance spectra. The investigated parameters were: pH, electrical conductivity, soluble total organic carbon and soluble total nitrogen.

Hyperspectral data were processed adopting chemometric strategies through the application of principal component analysis, for exploratory purposes, and partial least squares analysis to establish correlations between spectral features and measured physical-chemical parameters. Good correlations, with R^2 ranging between 0.85 and 0.96, were obtained for all the investigated parameters. Results showed as the proposed approach, based on hyperspectral imaging, is suitable to be adopted for a rapid and non-destructive monitoring of waste-derived fertilizer production.

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1. Introduction

The use of composted organic wastes to improve soil structure and fertility, as well as plant growth, has been widely investigated in the last decades and is of growing interest (Chen et al., 1992; Bernal et al., 2009; Moral et al., 2009; Mehta et al., 2014; Jensen et al., 2017; Samara et al., 2017; Sharma et al., 2017).

The utilization of biowaste-derived fertilizers has many positive effects, not only related to the increase of recycled waste, but also to the reduction of the use of chemical fertilizers, characterized by an heavy impact on environment, regarding both pollution and consumption of non-renewable resources (Vilalba et al., 2008). Chemical fertilizer production is also a highly energy demanding process, requiring significant amounts of fossil fuels (Soliman, 2014).

In order to be used, biowaste-derived fertilizers have to respect the same constraints, in terms of efficiency and quality (i.e. different nutrients bioavailability, presence of contaminants) of the

chemical fertilizers (Kruger, 2016). These aspects are particularly crucial for the waste derived fertilizers considering that, as well outlined by Kruger (2016), they "*may have so far unknown properties and some constituents, nutrients as well as contaminants, may behave different in different matrices*".

Conventional methods commonly adopted to evaluate fertilizer quality and characteristics are based on measurements of physical-chemical parameters carried out in laboratory. Such methods are time consuming, labor intensive and expensive, requiring sample collection, transport and preparation and in most cases being invasive and destructive.

The possibility to use *in-situ* rapid, non-destructive and reliable analytical techniques, thus represents one of the main factors to efficiently approach the production of new biowaste-derived fertilizers.

In this perspective, the production monitoring at pilot plant scale of a reduced salinity fertilizer obtained from different organic wastes based on **H**yper **S**pectral **I**maging (HSI) is introduced in this paper.

HSI combines classical spectroscopy and image analysis providing simultaneously spectral and spatial information of the

investigated sample. For each pixel of the acquired image, a full spectrum is collected, constituted by all the wavelengths belonging to the selected spectral range, usually Visible (VIS), Near Infrared (NIR) or Short Wave Infrared (SWIR) (Hyvarinen et al., (1998); Geladi et al., 2007). In comparison with the traditional analytical techniques, HSI has the main advantage, once the model is built, that the analytical response is obtained real time directly acting on the materials (i.e. monitoring of biowaste-derived fertilizer production process) and/or products (i.e. biowaste-derived fertilizers quality assessment) without any preliminary sample collection and preparation. Such technique offers many other advantages, being non-invasive, non-destructive, fast and relatively cheap. Furthermore, other advantages include simplicity of data acquisition and simultaneous detection of different parameters (Dale et al., 2013). However, in comparison to most of the conventional analytical techniques, it is important to highlight that HSI is an indirect method and calibration models must be developed and implemented. This is obtained combining HSI acquisition systems with chemometric techniques, utilizing multivariate statistical analysis to extract chemical information from data.

The use of HSI is rapidly growing in the last years in many sectors, including agriculture, with applications related to vegetation mapping (Herrmann et al., 2013), crop disease, stress and yield detection, component identification in plants and detection of impurities (Dale et al., 2013; Serranti et al., 2013a; Serranti et al., 2013b). Concerning soils, HSI applications were mainly focused on the prediction of nutrient contents, pH, humidity, organic matter, etc. (Lu et al., 2015, Jia et al., 2017; Qi et al., 2018). Such evaluations are possible thank to the detection and characterization of the reflectance spectral signature that is influenced by the overtones and combinations of molecular vibrations of the functional groups Carbon-Hydrogen (C—H), Oxygen-Hydrogen (O—H), Nitrogen- Hydrogen (N—H) (Ilani et al., 2016). Despite the wide literature related to the application of HSI to evaluate soil properties, to our knowledge few studies were addressed to the monitoring of biowaste-derived fertilizer production by HSI.

Main aim of this study was thus to evaluate the validity of the HSI approach in the NIR range for the prediction of some physical-chemical parameters measured during the production process of an innovative biowaste-derived fertilizer. Conventional chemical analyses of pH, electrical conductivity (EC), soluble total organic carbon (STOC) and soluble total nitrogen (STN) were carried out on the same samples to establish correlations with the reflectance spectral signatures acquired by HSI. The work was carried out in the framework of the "LIFE RESAFE Project" whose main objective was to demonstrate the production and use of a fertilizer characterized by reduced salinity, obtained from **U**rban **O**rganic **W**aste (UOW), **B**io-**C**har (BC), **F**arm **O**rganic **R**esidues (FOR) mixed with **V**egetable **A**ctive **P**rinciples (VAP) (Serranti and Bonifazi, 2014). The fertilizer was preliminary produced at laboratory scale to select the best "recipe" of mixed organic waste (i.e. quality and quantity of raw materials) (Dall'Ara et al., 2015; Serranti et al., 2015).

2. Materials and methods

2.1. Investigated samples

Different organic wastes (i.e. UOW, FOR and BC) were selected and used in order to produce the RESAFE fertilizer in two different countries, Italy and Spain, based on the local availability. For the Italian fertilizer recipe, UOW comes from recycled kitchen waste, collected by private citizens or by collective and commercial structures, as well as from agro-industrial activities; FOR consists of dried poultry manure and BC is a charcoal, specifically obtained from the biomass pyrolysis. In the Spanish fertilizer recipe, UOW comes from an industrial composting process, characterized by a medium level of degradation; FOR consists of fresh horse manure and BC, not degradable and stable, is of industrial origin. In both countries the biowastes were mixed with VAP, an innovative vegetable complex enzymatic blend prepared from selected plants (Amek, CTI (2002)) developed with the main aim to accelerate the process of aerobic stabilization of biomass and already tested in different applications (Dall'Ara et al., (2015)).

In order to produce the fertilizer at pilot plant scale (Fig. 1), both in Italy and Spain three different heaps were realized using in total 6690 kg of biowaste (2230 kg for each heap). In Italy the proportion of materials used for each heap was: 1000 kg (50%) FOR + 1000 kg (50%) UOW + 200 kg (10%) BC + 30 kg VAP, whereas in Spain was: 800 kg (40%) FOR + 1200 kg (60%) UOW + 200 kg (10%) BC + 30 kg VAP.

At the base of each heap, a layer of 40 cm of waste mixture was placed (Fig. 1a) and the VAP was put in the center of the pile (Fig. 1b). A mixture of UOW, FOR and BC was then utilized to cover the whole layer (Fig. 1c). The coverage was about 50 cm thick. Furthermore, in order to reduce heap breathability and water losses a layer of compost characterized by a fine texture was utilized to realize the final heat coverage. Finally the three heaps were covered by a plastic tunnel to maintain heap optimal humidity and temperature conditions. The curing time for the fertilizer production was set at 90 days.

For each heap, three samples were collected at the beginning (T = 0) and at the end (T = 90 days) of the curing process, for a total of 18 samples in Italy and 18 samples in Spain.

2.2. Analytical methods

Classical physical-chemical analyses and hyperspectral imaging coupled with chemometric were carried out on the investigated Italian and Spanish samples, in order to correlate the chemical parameters and the reflectance spectral signatures of the samples.

Fig. 1. Image sequence showing the different phases of pilot plant preparation for the production of the biowaste-derived fertilizer. a: preparation of a layer of 40 cm waste mixture at the base of the heap, b: VAP addition in the middle of the heap and c: final heap obtained adding the waste mixture.