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A comparative survey of recent results on humic-like fractions in organic amendments and effects on native soil humic substances

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Abstract

The main scope of the wide use of organic amendments of various origin and nature in modern agriculture is to increase and/or restore the organic matter content in organically poor or depleted soils in order to maintain and/or increase crop production and reduce soil exposure to degradation, erosion, desertification and pollution. The agronomically efficient and environmentally safe use of any organic amendment requires, however, an adequate control not only of the chemical quality of the humic substance (HS)-like fractions contained, which is an important indicator of the maturity and stability achieved by organic matter in the amendment, but also of the effects that these HS may have on native soil HS. In this review, the most recent results obtained on this topic by the research groups operating in Bari, Italy, and in Madrid, Spain, are discussed comparatively with results recently published by other research groups. Overall, HS-like components of organic amendments are characterized by higher aliphatic character and molecular heterogeneity, lower contents of O, acidic functional groups and organic free radicals, and lower degrees of aromatic ring polycondensation, polymerization and humification than native soil HS. These differences are less evident for composted materials. The composition, structure and functionalities of HS in amended soils may be affected in different ways and at various extents on dependence of the nature, origin and rate of amendment. In general, these properties are intermediate between those of the unamended soil HS and the HS-like fractions in the amendment, but generally resemble more the former than the latter, especially with increasing time after amendment application.

Keywords: Soil organic amendment; Municipal solid waste compost; Sewage sludge; Pig slurry; Olive oil mill waste; Humic substances; Elemental and functional group composition; FTIR spectroscopy; Fluorescence spectroscopy; ESR and NMR spectroscopies

1. Introduction

Soil organic matter (SOM) is universally recognized to be among the most important factors responsible for soil fertility, crop production, and land protection from contamination, degradation, erosion and desertification, especially in semiarid and arid areas (Flaig et al., 1977; Chen and Avnimelech, 1986; Soane, 1990; Wilson, 1991; Piccolo, 1996). Crop residues and animal manures have traditionally been applied to soil as a means for maintaining and increasing SOM content and related fertility functions. In recent years the intensive cropping of SOM-rich soils with consequent SOM depletion, the necessity to cultivate and/or enhance crop production of intrinsically SOM-poor soils, and the need to protect soils from degradation and/or erosion has urged a series of efforts in finding alternative practices aiming to restore and/or improve SOM content and functions. As a result, recycling as soil organic amendments of the large amounts of organic residues, byproducts, wastes and effluents, such as municipal sewage sludges and urban solid wastes, food industry and wood processing wastes, agricultural crop residues and animal wastes, has became a very popular and efficient agricultural practice (De Bertoldi et al., 1987, 1996; Senesi, 1989; MacCarthy et al., 1990).

Soil application of organic wastes and effluents of any type requires, however, that these materials be previously subjected to appropriate treatments that usually depend on the nature and composition of the organic waste and on the type and properties of the end-product desired. Most common treatments of organic wastes include aerobic and

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anaerobic digestion, various fermentation processes, and composting. The main purposes of any of these processes are: (a) to destroy pathogens and phytotoxic organic substances originally present in the substrate or formed in the early stages of the organic matter (OM) decomposition; (b) to reduce or, possibly, eliminate polluting and/or phytotoxic trace metals and organic contaminants originally contained in the substrate; and (c) to obtain a mature and stabilized organic material in which the humification process typically occurring under natural soil conditions has developed to an adequate degree for producing humic substance (HS)-like materials (Senesi, 1989). In particular, the amount and quality of HS-like components in an organic amendment are considered as important indicators of its maturity and stability and a guarantee for a safe impact and successful performance in soil.

Currently, a number of criteria and parameters have been proposed and are used as guidelines for testing the evolution and modifications occurring in the organic material during its treatment and for evaluating the degree of maturity achieved in the end-product. Recent reviews have been provided on this topic by several authors (Senesi, 1989; Boyd and Sommers, 1990; Inbar et al., 1990a; He et al., 1992). However, most of the physical and chemical methods, microbiological tests, plant bioassays and humification indexes in use are empirically based criteria, which are often not self-consistent. Further, these approaches are not of general application, mainly because of the extreme diversity in the origin and processing of the organic substrates. As a consequence, the most appropriate and reliable criteria to evaluate maturity of any organic amendment should be based on the chemical and physico-chemical analyses of the molecular, structural and functional "identity" and properties of HS-like components, i.e., the humic acid (HA)-like and fulvic acid (FA)-like fractions in the organic amendment. Further, the evaluation of these properties should be made in comparison with the properties of corresponding native soil HAs and FAs. This approach would allow a direct insight, on a molecular basis, to the intrinsic properties of organic amendments, and also provide a powerful means for the evaluation of possible modifications induced by organic amendments on the status, quality, chemistry and functions of native soil HAs and FAs.

Methods and techniques applied to study HA-like and FA-like fractions of organic amendments include, among others: elemental and acidic functional group analyses, gel-filtration chromatography, electrophoresis, isoelectrofocusing, pyrolysis, thermochemolysis and ultraviolet/visable, infrared, nuclear magnetic resonance (NMR), electron spin resonance (ESR) and fluorescence spectroscopies (Senesi et al., 1996; Chen, 2003). Results of these studies have shown that, in general, HS-like fractions from organic amendments differ from native soil HS for their lower aromatic and carboxyl group contents and higher aliphatic character and levels of N-containing and polysaccharide-like structures (Senesi et al., 1996; Chen, 2003). During the maturation and stabilization of any organic amendment, OM mineralization and humification occur, and the HS-like components undergo concomitant changes. In particular, the chemical, physico-chemical and spectroscopic characteristics tend to approach those typical of native soil HS, which indicates the occurred partial decomposition of aliphatic, polypeptidic and polysaccharide-like components and increase of the degrees of aromatic ring polycondensation and polymerization (Senesi et al., 1996; Chen, 2003). Since soil HS contribute essential functions to global soil fertility and health, the greater the amount and the more the compositional, structural and functional properties of HS-like fractions resemble those of native soil HS, the more agronomically efficient, environmentally safe and economically valuable is the organic amendment (Senesi and Brunetti, 1996).

Most studies, however, have been conducted for evaluating the effects of organic amendments on total and available amounts of nutrient elements added to soil, phytotoxic hazard to crops, potential modifications of soil microbial populations and activities, and effects of toxic trace metals and organic chemicals on crops and waters (Page et al., 1987; De Bertoldi et al., 1987,1996; Amberger, 1990; Rosen et al., 1997). In contrast, relatively little attention has been devoted to study the effects that organic amendments may exert on the chemical status, environmental role and fertility functions of the most abundant and active reserve of SOM, that are HS. Only a limited number of investigations have dealt with the analytical and molecular properties of HS-like components in organic amendments, and even fewer studies have been conducted on the short-term and/or long-term effects of these additions on the status and quality of indigenous soil HS (Senesi et al., 1996; Senesi and Brunetti, 1996; Francioso et al., 2000).

The main objective of this paper is to provide a brief review and discussion of the most relevant and recent results obtained by the research groups operating in the University of Bari, Italy, and the Centro de Ciencias Medioambientales, CSIC, Madrid, Spain. A second objective is to compare results published by other research groups on: (a) the chemical and physico-chemical properties of HS-like components in organic amendments of various origin and nature; and (b) the effects of organic amendments on the composition, structure and reactivity of native soil HS.

2. Composts from municipal solid wastes

Field plot experiments were conducted on a barley-cropped sandy loam soil with low organic C content classified as a Typic Haploxeralf (Soil Survey Staff, 2003), which was amended at rates of 20 and 80 t ha^{-1} with a compost obtained from the organic fraction separated from a municipal solid waste (MWC) collected in a waste treatment plant in Madrid, Spain (García-Gil et al., 2000, 2004a). After the first year of MWC application, each plot