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Mucilage from seeds of chia (*Salvia hispanica* L.) used as soil conditioner; effects on the sorption-desorption of four herbicides in three different soils

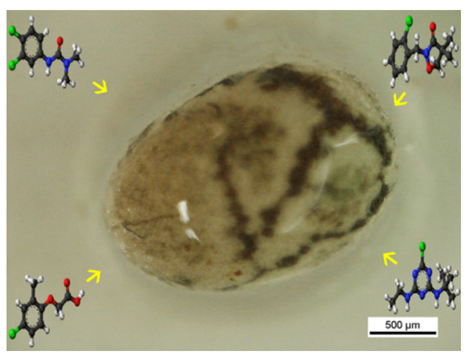
A. Di Marsico [a], L. Scrano [b,*], M. Amato [a], B. Gàmiz [c], M. Real [c], L. Cox [c]

[a] SAFE, University of Basilicata, V.le dell'Ateneo Lucano N° 10 c.a.p., 85100 Potenza, Italy
[b] DICEM, University of Basilicata, V.le dell'Ateneo Lucano N° 10 c.a.p., 85100 Potenza, Italy
[c] Instituto de Recursos Naturales y Agrobiología de Sevilla (IRNASE-CSIC), P.O. Box 1052, 41080 Sevilla, Spain

HIGHLIGHTS

- The effects of amendments with Chia seeds mucilage on physical properties of different agricultural soils were evaluated,
- Sorption-desorption processes of four herbicides was studied to assess the capability of amended soils to reduce their mobility,
- With amendments an improvement of soil microstructure was observed mostly in loam and in sandy-loam soils
- Sorption was more effective in the case of sandy loam- soil amended. Desorption was observed only for Terbuthylazine

GRAPHICAL ABSTRACT



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ABSTRACT

The objective of this work was to determine the effect of the mucilage extracted from Chia seeds (*Salvia hispanica* L.) as soil amendment on soil physical properties and on the sorption-desorption behaviour of four herbicides (MCPA, Diuron, Clomazone and Terbuthylazine) used in cereal crops. Three soils of different texture (sandy-loam, loam and clay-loam) were selected, and mercury intrusion porosimetry and surface area analysis were used to examine changes in the microstructural characteristics caused by the reactions that occur between the mucilage and soil particles. Laboratory studies were conducted to characterise the selected herbicides with regard their sorption on tested soils added or not with the mucilage.

Mucilage amendment resulted in a reduction in soil porosity, basically due to a reduction in larger pores (radius > 10 μm) and an important increase in finer pores (radius < 10 μm) and in partcles' surface. A higher herbicide sorption in the amended soils was ascertained when compared to unamended soils. The sorption percentage of herbicides in soils treated with mucilage increased in the order; sandy-loam < loam < clay-loam.

The increase in the organic carbon content upon amendment and the natural clay content of the soils are revealed to be responsible for the higher adsorption of Diuron when compared with Terbuthylazine, Clomazone and MCPA. Desorption of the herbicides was highly inhibited in the soils treated with mucilage; only Terbuthylazine showed a slight desorption in the case of loam and clay loam-soils.

* Corresponding author.
E-mail addresses: antonio.dimarsico@unibas.it (A. Di Marsico), laura.scrano@unibas.it (L. Scrano), mariana.amato@unibas.it (M. Amato), bgamiz@irnase.csic.es (B. Gàmiz), mreal@irnase.csic.es (M. Real), lcox@irnase.csic.es (L. Cox).

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This study leads to the conclusion that mucilage from Chia seeds used as soil conditioner can reduce the mobility of herbicides tested in agricultural soils with different physico-chemical properties.

1. Introduction

Modern agriculture relies heavily on herbicides for the control of weeds in crops and pastures. These compounds can become serious pollutants because of their possible toxicity, long environmental persistence, and bioaccumulation factors, which can be a threat to human health. For this reason, the environmental fate of herbicides has been taken into account by many researchers.

Pimentel and Levitan (1986) described that <0.1% of the pesticide applied to crops actually reaches the target organism, while Celis et al. (2002) specified that most formulations of herbicides commonly used contains the active substance in immediately available form, which moves quickly toward points away from the site of application. Retention and mobility of herbicides in soil are related to the adsorption and desorption processes (Laor et al., 1996; Boesten, 1993; Martins and Mermoud, 1998), witch extension depends on soil properties (mostly organic matter and clay content) and on chemical characteristics of the herbicides used (Singh, 2002).

The sorption of pesticides in a soil–water system is governed by a mechanism whereby pesticide molecules partition into the soil colloidal phases (Celis et al., 1998; Chiou et al., 1979; Karickhoff et al., 1979). Many researchers (Cox et al., 2000; Hwang and Cutright, 2004; Ling et al., 2006; Nemeth-Konda et al., 2002, Barriuso et al., 1992; Murphy et al., 1992; Welhouse and Bleam, 1992; Baskaran et al., 1996, Cabrera et al., 2007, 2008, Guo et al., 1991) showed that the sorption of pesticides increases with increasing organic matter content, reducing the level of pesticide leaching in soil and, consequently, limiting their availability in the environment. Researches tried to reduce the mobility of pesticides using different organic amendments like animal manure, biosolids, municipal solid waste composts, crop residues, blood and bone meal, sea weeds and humic substances. Unfortunately, some of the amendmends used as soil conditioners have been shown to be sources of further contamination due to their heavy metal and organic toxic substances content, and high microbial load (Abad et al., 2005; Harrison et al., 2006; Selma et al., 2007).

Recently, plant exudates and Chia (*Salvia hispanica* L.) seed exudates, commonly used as analogue of root exudates, have been studied as possible soil conditioners (Beck et al., 1993; Naveed et al., 2017, Capitani et al., 2013, Luo et al., 2006).

Chia is an annual herbaceous plant of the Lamiceae family, which has been studied by many authors for its nutraceutical properties (Ayerza and Coates, 2005; Ixtaina et al., 2008; Vázquez-Ovando et al., 2009; Segura-Campos et al., 2014) and pharmaceutical application (Bochicchio et al., 2015).

Chia seed mucilage is mainly composed of xylose, glucose and glucuronic acid forming a branched polysaccharide (Lin et al., 1994; Muñoz et al., 2012), which structure has been confirmed by De la Paz Salgado-Cruz et al. (2013) using scanning image analysis.

The mucilage forms a gel when it is hydrated and it turns to hydrophobic after drying (Ahmed et al., 2014). Considering its rheological properties the Chia mucilage has been used as an experimental model for the study of plant-soil-water relations by Kroener et al. (2014). Ahmed et al. (2014) demonstrated that mucilage from the seeds of Chia facilitates water flowing into the root zone, increasing the soil hydraulic conductivity. To the best of our knowledge the effect of Chia mucilage on the soil porosity and relationship between mucilage and herbicide mobility have not been studied yet.

This study is aimed at testing the effect of amendment with Chia seed exudates on the sorption–desorption processes in three soils characterized by different physical-chemical properties.

The main parameters affecting the sorption process, such as the soil microstructure and pore space, were examined.

The mobility of four herbicides commonly used in cereal cultivations were evaluated too.

2. Materials and methods

2.1. Agricultural soils

The soil samples used for the laboratory studies were collected from the surface layer (0 to 30 cm) of three soils in the province of Potenza (Southern Italy), in the agricultural areas of Valle di Vitalba, Piani del Mattino and Costa della Gaveta.

Soils were air-dried and gently sieved to obtain aggregates up to 2 mm. The physical and chemical properties of the soils are reported in Table 1. An aliquot of 20 g of soil samples was used to determine the water saturation capacity (field capacity) that ranged from 42% (sandy loam soil) to 55% (loam and clay-loam soils).

2.2. Mucilage

Black chia seeds obtained from Eichenhain (www.eichenhain.com) were used to extract mucilage following the procedure described by Muñoz et al. (2012), briefly: 10 g chia seeds were mixed with 200 g distilled water (ratio 1:20 w:w) at 40 °C for 4 h in special containers lined with baking paper, dried in a stove at 50 °C for about 48 h and sieved at 1 mm, in order to eliminate any impurities. The residual water content of mucilage (10%) was determined gravimetrically after oven drying at 70 °C. The total C content (44.8% of dry matter) was determined by using an elemental analyzer (Primac SCN100, Skalar, The Netherlands) furnished with an infrared detector. The ash content of mucilage (4.5% of dry matter was determined by igniting the oven-dried sample in a muffle furnace at 440 °C.

2.3. Herbicides

Chemical structures of herbicides MCPA [(4-chloro-2-methylphenoxy)acetic acid], diuron [3-(3,4-dichlorophenyl)-1,1-dimethylurea], clomazone [2-(2-chlorobenzyl)-4,4-dimethyl-1,2-oxazolidin-3-one] and terbuthylazine [2-N-tert-butyl-6-chloro-4-N-ethyl-1,3,5-triazine-2,4-diamine] are shown in Fig. 1. Herbicides used in experiments of adsorption-desorption were high purity products purchased from Sigma-Aldrich (St. Louis, MO, USA).

Physico-chemical characteristics of herbicides are shown in Table 2 (data from Trigo et al., 2010; DuPont, 2009; and Tomlin, 2006).

2.4. Mercury porosimetry

Samples of 1 g dry soils (sandy-loam, loam and clay-loam) were mixed with the mucilage at 2% w/w. Distilled water was added to bring soil samples to 30% of field capacity (Traoré et al., 2000) and left stand for 72 h. Control soil samples (without mucilage) were treated in the same way.

The distribution of pore radii of soil samples from 4×10^4 to 3.7 nm was determined using a mercury depression and intrusion porosimeter Autopore 9500 produced by Micromeritics, and instructions given by manufacturer. Small pieces of undisturbed soil aggregates were heated at 90 °C during 24 h and then outgassed at room temperature for 30 min before each experiment. A value for the surface tension of