Science of the Total Environment 487 (2014) 443–451

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Benefits for agriculture and the environment from urban waste

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HIGHLIGHTS

- Urban biowaste soluble substances enhance tomato plant photosynthesis.
- Urban biowaste soluble substances enhance tomato plant productivity.
- Urban biowaste soluble substances promote C fixation or mineralization.
- Economic and environmental benefits from urban biowaste valorization.
- Friendly products from biowastes for sustainable ecosystem.

ARTICLE INFO

Article history:
Received 11 December 2013
Received in revised form 2 April 2014
Accepted 6 April 2014
Available online 4 May 2014

Editor: Simon Pollard

Keywords:
Municipal biowastes
Chlorophyll
CO_2 exchange rate
Photo sensitizers
Plant photosynthetic activity
Plant growth and productivity

ABSTRACT

Soluble bio-based substances (SBO) that have been isolated from urban biowaste have recently been reported to enhance plant leaf chlorophyll content and growth. The same SBO have also been shown to enhance the photochemical degradation of organic pollutants in industrial effluent. These findings suggest that SBO may promote either C fixation or mineralization, according to operating conditions. The present work aims to investigate SBO performance, as a function of source material. Thus, three materials have been sampled from a municipal waste treatment plant: (i) the digestate of the anaerobic fermentation of a humid organic fraction, (ii) a whole vegetable compost made from gardening residues and (iii) compost made from a mixture of digestate, gardening residues and sewage sludge. These materials were hydrolyzed at pH 13 and 60 °C to yield SBO that display different chemical compositions. These products were applied to soil at 30, 145 and 500 kg ha^{-1} doses for tomato cultivation. Soil and plant leaf chemical composition, plant growth, leaf chlorophyll content and CO_2 exchange rate as well as fruit quality and production rate were measured. Although it did not affect the soil's chemical composition, SBO were found to significantly increase plant photosynthetic activity, growth and productivity up to the maximum value achieved at 145 kg ha^{-1}. The effects were analyzed as a function of SBO chemical composition and applied dose. The results of this work, compared with those of previous works, indicate that urban biowaste, if properly exploited, may furnish conjugate economic and environmental benefits, within a friendly sustainable ecosystem.

1. Introduction

The environmental impact of urban waste has dramatically increased as a result of increasing population, urbanization and consumption habits. This fact means society must deal with a significant economic waste management and/or disposal burden. However, it is also a potential source of benefit. Through urbanization and municipal collection practices, urban biowaste has become a low entropy sustainable source of energy and chemicals for industry and society. It provides advantages over biowaste from other sources, such as agriculture, animal husbandry or the agro industry, and is available worldwide in large quantities which are concentrated in the confined spaces of urban areas. Collection costs are paid by taxpayers. Thus, urban biowaste has been defined as a negative cost source of concentrated renewable organic matter (Sheldon-Coulson, 2011). Recent research (Montoneri et al., 2011) has shown that the recalcitrant lignin-like fraction in urban biowaste is a cost-effective source of soluble bio-based substances (SBO). SBO are described as mixtures of macromolecules with a weighted average molecular weight (Mw) ranging from 67 to 463 kg mol^{-1} and polydispersity indexes (Mw/Mn) in the 6–53 range. They are formed of long aliphatic C chains that bear aromatic rings and several functional groups, such as COOH, CON, C = O,

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Abbreviations: D, digestate; CV, whole vegetable compost; CVDF, compost from digestate, vegetable residues and sewage sludge; SBO, soluble substances.

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http://dx.doi.org/10.1016/j.scitotenv.2014.04.027

PhOH, O-alkyl, OAr, OCO, OMe and NRR′, where R and R′ are alkyl and/or aryl substituents. These organic moieties are probably the memory of the main constituents of the sourcing bio-organic waste which are not completely mineralized during aging under aerobic fermentation conditions. The SBO bear chemical similarities with the natural organic matter (NOM) present in soil and water. For these reasons, no adverse environmental impact is expected from SBO.

A number of properties and uses have been proven for SBO that have been isolated from different urban bio-waste sources. These substances also behave like anionic surfactants because of the presence of lipophilic, aliphatic and aromatic moieties and of hydrophilic functional groups. They have accordingly been shown to be effective (Montoneri et al., 2011) as detergents, auxiliaries for textile dyeing, emulsifiers, flocculants and dispersants, binding agents for ceramic manufacture, templates for the fabrication of nanostructured materials for chemical and biochemical catalysis as well as being active agents for cleaning polluted soil via surfactant assisted washing. More recent studies point to a possible role for these substances in the ecosystem C cycle.

Studies on the *in vitro* fermentation of animal feed (Montoneri et al., 2013) and *in vivo* animal weaning (Dinuccio et al., 2013) have shown that SBO are capable of decreasing the mineralization of organic N during anaerobic digestion, when added to the cecal content of pig or rabbit feed, and therefore of reducing emissions of ammonia and greenhouse gases from animal husbandry.

Several organic molecules, typically found in the effluents of many chemical industrial processes, have been shown to degrade rapidly with relevant organic C mineralization, when exposed in solution to solar light in the presence of SBO (Bianco Prevot et al., 2010, 2012; Avetta et al., 2013). Gomis et al. (2013) have reported that these effects derive from the capacity of SBO to interact with the target organic pollutant and form a photoactive complex, or perhaps from the presence of functional groups with strong metal chelating power.

Concurrent with the above findings is a separate study which has reported that SBO, isolated from a composted mix of food and vegetable residues and applied to soil as organic fertilizer for tomato cultivation in greenhouses, enhance leaf chlorophyll content and plant growth (Sortino et al., 2012). The idea that SBO could also promote photosynthesis was rather intriguing.

In the present work, three different SBO, hereinafter referred to by the acronyms D, CV and CVDF, were isolated from the three major products of a municipal waste treatment plant located in North Italy: D is sourced from the digestate obtained from the anaerobic digestion of the organic humid fraction, CV is from the compost obtained from home gardening and public park trimmings and CVDF is from a composted mix of gardening and park trimmings, digestate and sewage sludge. The SBO were applied to soil for the cultivation of tomato at three different doses. Plant leaf CO_2 exchange rate and chlorophyll content, growth and fruit productivity were monitored. The objectives of the experimental work were (i) to find direct evidence of the effect SBO have on plant photosynthetic activity and biomass production, (ii) to study these effects as a function of dose and (iii) to assess whether the effects are general for SBO obtained from the major product of urban waste treatment plants and/or how they are related to SBO chemical composition.

2. Materials and methods

2.1. Materials

SBO sourcing materials were obtained from the Acea Pinerolese Industriale plant located in Pinerolo (TO), Italy. The plant carried out the anaerobic and aerobic digestion of urban biowaste. Anaerobic digestion was carried out for 15 days with the organic humid fraction of urban waste from a separate source collection. This process yielded biogas and a solid digestate containing residual organic matter that was not converted into biogas. Aerobic digestion was performed on two different wastes; home gardening and park trimming residues were composted for 180 days to yield whole vegetable compost, and secondly a mix of digestate, home gardening and park trimming residues as well as sewage sludge, at a 3.5/5.5/1 respective weight ratio, which was composted for 110 days. Each of the three plant products (i.e., the digestate and the two composts) was separately further hydrolyzed with KOH alkaline water at pH 13 and 60 °C to obtain the SBO. The hydrolyzate was run through an ultra filtration polysulphone membrane with 5 kDa cutoff. The membrane retentate was dried at 60 °C to yield the final SBO product as black solid in a 15–20% yield, relative to the starting material. Further experimental details for all processes and product analytical characterization have been reported by Sortino et al. (2012). The tomato (*Lycopersicon esculentum* Mill.) seeds were produced in Kenya and were supplied by Syngenta Seeds (Syngenta Seeds s.p.a., Milano, Italy). Nursery plants for transplanting in the cultivation soil were grown from these seeds.

2.2. Set up of cultivation trials

Tomato cultivation trials were carried out on the same farm as in the previously reported tomato study (Sortino et al., 2012). Farm soil was classified as loamy-sandy based on its texture: sand 79.9 ± 2.5, fine sand 5.3 ± 0.7, silt 10.6 ± 1.8, clay 4.2 ± 0.4% w/w. The experiment was set up as a completely randomized design with 3 replications in a greenhouse constructed from 0.15 mm thick polyethylene film supported by cement and wood. Greenhouse soil was divided into 30 parcels, each containing 10 m^2 soil surface. Three control parcels had no added SBO. The other 27 parcels were divided into three groups of nine parcels each: one group was treated with D, one group with CVDF and the third group with CV. Each group of nine parcels was treated with three doses of SBO in triplicates: i.e., three plots with 30 kg ha^{-1}, three plots with 145 kg ha^{-1} and three plots with a 500 kg ha^{-1} dose. The solid SBO were incorporated into the soil on November 21, 2011. Two days later, 10 cm long nursery test plants, each with 6 true leaves, were transplanted in all parcels to yield three sets of double rows per parcel, with a distance of 120 cm between sets, 80 cm between rows in each set and 30 cm between plants in each row. Plant density was 3.3 plants m^{-2}. After transplanting, the soil was covered with white polyethylene film equipped for sub-surface drip irrigation. All other cultivation details were the same for all parcels and carried out according to the protocol adopted by the hosting farm in its normal cultivation practice (Sortino et al., 2012). Thus, all plots of soil in the greenhouse had the following base mineral fertilization (Dorais, 2007; Chapagain and Wiesman, 2004): P_2O_5 60 kg ha^{-1} supplied as mineral ammonium phosphate and K_2O 100 kg ha^{-1} supplied as potassium sulfate. This was followed by the addition of the SBO, and then by nursery plant transplantation. The experimental plan was carried out over about 7 months from transplanting to harvesting (April to June 2012). Over this time, soil irrigation was performed using the drip irrigation system (Ho, 1984) to supplement natural soil water and mineral depletion and fulfil plant needs over the plant growth and production cycles. To this end, the above phosphate and sulfate products were used in conjunction with a mineral nitrogen fertilizer containing 32.4% total N as nitrate, ammonia and urea in 1:1:2.5 weight ratio, respectively. The frequency of irrigation depended on weather conditions and was the same for all soil plots. Irrigation was performed approximately every 10–15 days and covered the whole harvest production cycle in order to provide different N/K ratios according to plants' growth/production stage: i.e., 1:3 N/K from transplanting to flowering; N to encourage plant flowering; 1:2 N/K at beginning of fruit-setting of the fourth cluster; 1:1 N/K after the start of fruit ripening to promote leaf development. Throughout the entire harvest cycle, the total amount of supplied nutrients was at about 800 N kg ha^{-1} and 1000 K kg ha^{-1}. The plants were pruned in March in order to stop vegetative growth and enhance fruit production. Thus, monitoring of the plant biometric data ended on the same date. The soil, plants, leaves and fruit were analyzed at time