



Soil quality recovery and crop yield enhancement by combined application of compost and wood to vegetables grown under plastic tunnels



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ARTICLE INFO

Article history:

Received 9 January 2014

Received in revised form 7 March 2014

Accepted 9 March 2014

Available online 24 April 2014

Keywords:

Organic amendment

Soil organic carbon

Total and mineral nitrogen

Phytotoxicity

Soil quality

Crop yield

ABSTRACT

Vegetable cultivation under plastic tunnels is a steadily growing agricultural sector but concern developed over environmental sustainability of this farming system. Our aim was to identify organic amendments with a biochemical quality that effectively balance the trade-off between organic carbon recovery, in terms of increasing soil organic C stock, and nutrient mineralization. A three-year field experiment was carried out in two farms of southern Italy characterized by plastic tunnel cultivation and contrasting soil characteristics. Two compost–wood mixtures were used, with final C/N ratio of 15 and 25, and supplied in two doses (30 and 60 Mg ha^{−1}). Vegetable yield was assessed by monitoring 14 cropping cycles, and soil quality by determining 18 soil parameters including chemical and biological properties. Crop yields were significantly higher in amendment plots, compared to unamended control plots under plastic tunnel, for 12 out of 14 cropping cycles. Combined application of compost and wood allowed an effective recovery of soil C content within three years. Soil amendments improved soil biological functions as revealed by a general trend of positive effects on dehydrogenase, phosphatase and β-glucosidase as well as on soil respiration. The higher C/N ratio mixture determined only a short-term restriction of mineral nitrogen availability. Organic amended plots showed a significant increase in soil exchangeable Na⁺ and electrical conductivity compared with untreated controls. Compost–woody combination can be used to recover soil carbon stock and fertility and, at the same time, to support vegetable production under plastic tunnels. However, the possible increase of soil salinity after compost amendment may negatively affect soil quality in the long-term.

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1. Introduction

Identifying long-term sustainable management strategies is crucial to design farming systems that effectively maintain or increase soil quality. Vegetable cultivation under plastic tunnels provides valuable economic profits to farmers and is a steadily growing agricultural sector that in the last years has reached more than 2 million ha worldwide (Scarascia-Mugnozza et al., 2011). In the Mediterranean Basin such cultivation systems cover about 190,000 ha mainly in Italy, Spain and Marocco (Pardossi et al.,

2004). Concern developed, however, over the long-term sustainability of this farming system towards soil fertility. In this regards, some studies point out that continuous cultivation under plastic cover negatively affects soil quality, reporting signs of crop yield decline. Chen et al. (2004) and Ju et al. (2007) reported that continuous cultivation under tunnels increased electrical conductivity and total soluble salts in Chinese agricultural soils, with a concomitant acidification, as a consequence of mineral fertilization overuse. A survey carried out in the Great Plains of the United States reports that under high tunnels soil salinity was slightly increased, but no negative impact on soil organic carbon (SOC) stock was found (Knewton et al., 2010). In southern Italy, Bonanomi et al. (2011a) found that soils cultivated under plastic tunnels, for 20 years on average, showed a sharp increase in salinity and Na⁺

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content, associated with a steep decline in SOC stock and, consequently, a decrease in soil microbial growth and activity. Under plastic cover SOC depletion can be related to the systematic removal and/or burning of crop residues to limit phytopathological problems. Moreover, favorable environmental conditions for a rapid SOC mineralization occur because of enhanced soil temperatures and supplying water and mineral nutrients by fertigation.

It should be pointed out that decline in SOC under intensive farming systems is a major reason of soil fertility losses. In fact, SOC is a critical functional component of soil ecosystem because it provides the substrate to decomposing microbes (that in turn supply mineral nutrients to plants), improves soil structure and water holding capacity (Abiven et al., 2009), increases natural suppressiveness against soil-borne pathogens (Bonanomi et al., 2010), and reduces heavy metal toxicity (D'Ascoli et al., 2006). In this scenario, a rapid recovery of depleted SOC and its maintenance to an adequate level is an urgent task. It has been shown that application of organic amendments such as compost is a reliable and effective tool to improve SOC (Smith et al., 1997) and, consequently, fertility and crop yield in soils (e.g. Chang et al., 2007). However, only few studies investigated the effectiveness of compost amendments for SOC stock recovery under plastic tunnels (Morra et al., 2010). Iovieno et al. (2009) reported a limited SOC stock recovery after three consecutive years of compost amendments (up to $45 \text{ t ha}^{-1} \text{ year}^{-1}$), likely as a result of the high chemical quality (i.e. C/N of 13) of the used compost that allowed a rapid mineralization.

In this context, it is clear the need of experimental studies able to identify specific organic amendments that can maximize a stable SOC stock recovery, and, at the same time, allow a sufficient release of mineral nutrients to sustain crop yield. SOC storage capability jointly depends on the amount of C inputs as well as on the amount of C outflows, principally regulated by temperature, water availability and quality of organic matter in soil, all factors influencing microbial activity (Parton et al., 1994). Because temperature and water availability, related to the irrigation regime, cannot be modified under plastic tunnel cultivation systems being crucial factors for increasing the number of cropping cycles and producing out-of-season vegetables, the alternative option is to modulate organic C quality.

Organic matter C/N ratio is considered a key parameter in order to assess mineralization rate and, consequently, the related patterns of nutrient release (Melillo et al., 1982; Parton et al., 2007). In fact, nitrogen mineralization dynamics can be interpreted in terms of critical threshold levels of litter C/N ratio above which N is temporarily immobilized within microbial biomass (Hodge et al., 2000). Crop residues with C/N ratio below 30 usually show a continuous N release. Conversely, organic matter with C/N ratio above the threshold value of 30–35 accumulates N, due to the growth of decomposing microbes that scavenge this element from the surrounding soil, thus impairing plant growth (Michelsen et al., 1995). Since decaying organic matter releases carbon at faster rate than nitrogen, the litter C/N ratio progressively decreases until a threshold value is attained, then allowing a direct N release into the soil (Berg and McLaugherty, 2008). However, N immobilization after soil amendment with organic C may last for weeks but in some cases even for years (Zimmerman et al., 1995), depending on amendment dose and the C/N ratio. Obviously, a net N immobilization is not acceptable under intensive farming systems where plant nutrition is finely tuned to match crop requirements. A crucial step for a sustainable management of soil fertility is to identify organic amendments with such a biochemical quality that effectively balance the trade-off between SOC stock recovery and nutrient mineralization.

In this work, we experimentally explored the possibility of a rapid and effective soil quality recovery and crop yield enhancement by combining the application of high-quality (a compost with

a C/N ratio of 13) and low-quality (wood scraps with a C/N ratio of 375) organic substrates. In detail, two compost–wood mixtures were used with a final C/N ratio of 15 and 25. This choice was based on the compromise to achieve an effective long-term SOC stock recovery and to not induce a soil N immobilization. A field experiment, lasting three years, was carried out in southern Italy under intensive cultivation system (plastic tunnel cultivation) in two farms with contrasting soil characteristics. We measured soil quality by assessing chemical and biological properties, and monitored the crop yields in the study time for a total of 14 cropping cycles.

Specific objectives of the study were:

- (1) To assess the effects of compost and wood scrap soil amendments on crop yields.
- (2) To quantify the change of soil quality due to different organic amendments.
- (3) Identify which soil parameters may better predict crop yield.

2. Materials and methods

2.1. Study site description

The study site is a productive area with more than 4000 ha cultivated under greenhouses and located in the Salerno district (southern Italy). Low-technology, unheated polyethylene-covered greenhouses (4–5 m height and $25 \text{ m} \times 100 \text{ m}$ large on average) are the main crop protection structures used in this area. The study site has a Mediterranean climate with a relatively dry summer (84 mm) and a mean annual rainfall of 988 mm, with monthly mean temperature ranging from 23.6°C in August and 9.0°C in January.

Two farms, afterwards named with F1 and F2 ($F1=40^\circ34'58.362''\text{N}$, $14^\circ59'42.438''\text{E}$, and $F2=40^\circ26'4.851''\text{N}$, $14^\circ59'18.369''\text{E}$, respectively), were chosen among a group of 20 farms that were characterized in a previous study to monitor the effects of plastic tunnel farming systems on soil quality (Bonanomi et al., 2011a). In both farms an intensive farming system was adopted for 9 and 23 years (in F1 and F2, respectively), based on repeated soil disinfestation treatments (i.e. solarization and application of Metham-Na), exclusive use of mineral fertilizers by fertigation (this practice was stopped during the entire experiment time) and an intensive tillage regime with 7 rototilling treatments per year on average.

As C cycle pathways are affected by soil type and texture (Piccolo, 1996), the two farms were selected for their great pedologic differences. In detail, F1 has calcaric sandy-loam soil with high electrical conductivity (EC), a very high carbonate content and a medium SOC availability, while F2 has a clay-loam soil with low EC and limestone and low SOC content (USDA, 1998; Supplementary Table S1).

2.2. Organic amendments and experimental setup

Two different organic fertilizers were used: (i) compost from the organic fraction of municipal solid waste (GeSeNu Srl, Perugia, Italy), with a C/N ratio of 13.3, supplied in pelletized form (Supplementary Table S1); (ii) wood scraps ($\sim 2\text{--}3 \text{ cm}$ in size) from poplar (*Populus nigra*) pruning, with a C/N ratio of 375. Compost and wood scraps were mixed to obtain two mixtures: (i) A1, composed of compost:wood at 10:1 ratio and having a final C/N ratio of 15; (ii) A2, composed of compost:wood at 2:1 ratio and having a final C/N ratio of 25. Both compost and wood scraps were characterized for phytotoxicity by using the *Lepidium sativum* bioassay because this plant is recognized as a sensitive plant for phytotoxic compounds (Bonanomi et al., 2011b). Briefly, twenty seeds were placed in

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