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Green manure as part of organic management cycle: Effects on changes in organic matter characteristics across the soil profile

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ABSTRACT

Green manure (GM) cultivation and incorporation (i.e., GM management) may change soil organic matter (SOM) composition and the agroecosystem functioning. However, the understanding of GM effects on SOM composition, specifically in deeper soil layers, is limited. The objectives of this study were to examine the effects of GM management (as part of an organic agriculture practice), following two years of various doses of compost application, on the changes in SOM and water-extractable organic matter (WEOM) compositional characteristics up to a soil depth of 60 cm. Soil samples from a two years compost amended field that was subsequently subjected to GM management were taken in four intervals to a depth of 60 cm (0–5, 5–15, 15–30 and 30–60 cm) and characterized for organic C content and SOM composition, by FT-IR transmission. Characterization of WEOM included excitation-emission matrices (EEMs) of fluorescence, UV absorbance and dissolved organic C (DOC) measurements. The response of SOM and WEOM to GM management resulted in some opposite trends. The SOM became rather aromatic, with aliphatic CH-containing structures contributing to a greater extent to SOM composition at deeper layers following GM management. By contrast, GM management resulted in (i) a substantial increase in dissolved organic C concentration, (ii) WEOM becoming enriched by hydrophilic aliphatic organic compounds, and (iii) aromatic and fluorescent components increasingly being found at deeper soil layers and hydrophilic aliphatic components at the surface soil. Fluorescent portion of WEOM became enriched by relatively less biodegradable and weaker-soil adsorbing humic-like components; this enrichment increased in deeper soil layers. The effects of past compost application rates on the changes in SOM and WEOM characteristics were either non-significant or negative. In the latter case, an increase in application rate decreased the changes in SOM content of hydrophilic groups and in the fractions of fluorescent components in WEOM. Growing and incorporating plant biomass may mask, at least on a short time scale, the effects of earlier compost applications on changes in SOM and WEOM compositional characteristics.

1. Introduction

Green manure (GM) practice, involving growing cover crops, their uprooting and incorporation into the soil, has long been used in agriculture and, specifically, in organic farming, aiming at increasing soil organic C and N contents (Hill, 1926; Pieters, 1927; Cherr et al., 2006). Use of GM is known to increase soil productivity and crop quality, contribute to C sequestration and N accumulation with reduced losses compared to those of mineral N, to allow a slow N release, enhance microbial biomass and rates of enzyme activity in soil and to increase aggregate stability (Aulakh et al., 2001; Becker et al., 1995; Danga et al., 2009; Drinkwater et al., 1998; Elfstrand et al., 2007; Kimetu et al., 2008; Krull et al., 2004; Montemurro et al., 2013; Cherr et al., 2006). Contrary to freshly applied or composted animal manure, GM application allows avoiding excessive P loading and salinization (Cherr et al., 2006; Zhang et al., 2011).

Organic amendments have the potential to change soil organic matter (SOM) composition, and, therefore, the agroecosystem

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functioning and adoption of best possible management practices (Peltre et al., 2017). This potential could be linked to the nature of organic input sources which, in turn, influences the biodegradation of the organic matter added, and, thus, further turnover of SOM (Kögel-Knabner, 2002, 2016; Leifeld et al., 2002; Beraud et al., 2005; Antil et al., 2011; Crème et al., 2016). Therefore, it is of interest to study the compositional characteristics of SOM under GM incorporation. Examination of the top soil from a long-term field experiment involving different organic amendments revealed that isotopic composition of SOM changed with adding GM but no changes in extractable humic substances, as compared with non-amended soils, were detected by means of FT-IR measurements (Gerzabek et al., 1997). On the other hand, soil content of labile humic substances was related to the chemical composition of GM, as expressed in terms of C to N ratio, cellulose and lignin contents (Tripolskaja et al., 2014). The combination of GM with straw and mineral N fertilization led to an enrichment of carboxyl groups in SOM in top soils (Ellerbrock et al., 1999). Effect of GM (among other organic amendments) was examined on SOM pools and C-13 natural abundances in various particle-size fractions from top soil (Gerzabek et al., 2001). The composition of water-extractable organic matter (WEOM) obtained from top soil samples and characterized by means of excitation-emission matrices (EEMs) of fluorescence was hardly affected by GM (and other) amendments; alternatively, changes in WEOM, if any, occurred among non-fluorescent WEOM components (Ohno and Bro, 2006). Carbohydrate content of SOM was enhanced by applying GM treatment within lab incubation of soil samples (Zubair et al., 2012). Accumulation of soil organic C affected by GM and its association with different size-aggregates in the 0–100 cm depth profile was a part of a work by Blanco-Canqui et al. (2017), but this study did not examine changes in SOM composition. When pyrolysis gas chromatography was applied to soil samples, a difference was seen between soils treated with mineral fertilizer (ammonium nitrate) and GM, which transpired in higher levels of formed benzene, phenol and pyrrole in the latter case (Macci et al., 2012). The formation of these products was linked to the GM-stimulated organic matter turnover and humification. Transformation of SOM associated with its labile fractions in surface soil from 13 tomato fields managed with a series of organic amendments including vetch could be related to changes in aliphatic CH abundance determined by infrared absorbance (Margenot et al., 2015). However, despite some results were reported regarding the effects of GM application on SOM composition, systematic studies are yet desirable, especially because the investigations on GM application paid attention mostly to the top soil layer. Examination of changes in SOM composition in deeper layers of soil under GM application is also of interest and is, therefore, novel. This is particularly interesting in cases of in situ cultivation and incorporation of green manure, as leguminous roots like vetch can reach depth of tens of centimeters (Ramirez-Garcia et al., 2015) and degrade slower than shoot biomass (Puget and Drinkwater, 2001).

Recently, we have characterized organic matter composition within 0–60 cm of the soil profile in an organically managed field subjected to multiple compost applications, using spectroscopic techniques requiring no or minimal soil sample pre-treatment (i.e., transmission FT-IR spectroscopy of the whole soil samples, EEMs of fluorescence and absorbance measurements of WEOM; Sharma et al., 2017). Enrichment of compost-treated soil by hydrophobic aliphatic CH-containing organic matter and water-extractable aromatic and humic-like components, decrease of the SOM content of hydrophilic groups due to compost addition (with their elevation in deeper soil layers), were among the findings of this work. Continuation of that field experiment involved in situ cultivation and incorporation of leguminous green manure (vetch), whose ability to enrich the soil with N and to enhance soil fertility is well recognized (Drinkwater et al., 1998; Danga et al., 2009).

Further dynamics of SOM and WEOM in the aforementioned experimental platform may naturally be affected both by the history of earlier compost application and by recently added GM. Therefore, the objectives of this study were to examine whether (i) the changes (if any) in SOM and WEOM compositional characteristics following GM rotation are related to earlier compost applications, and (ii) these changes may also appear in subsoil layers (below 0–20 cm soil layer). These objectives were addressed by using IR, fluorescence and UV absorbance spectroscopies to characterize organic matter in soil sampled to a depth 60 cm.

2. Materials and methods

2.1. Study site, soil characterization and experimental design

We used the same experimental field platform that was studied by Sharma et al. (2017) and is described therein in detail. Briefly, the platform, located at Newe Ya'ar Research Center, the Jezre'el Valley, northern Israel, was originally established in late 2009 to examine factors which affect soil fertility under organic management. Local climate conditions and selected properties of the soil (a Vertisol-type, classified as Chromic Haploxeret, fine clayey, montmorillonitic, thermic) are reported by Sharma et al. (2017). The experimental field comprises a total area of one hectare where a randomized block design was used to accommodate four compost treatments (0 [control], 20, 40, and 60 $m^3\ ha^{-1}\ yr^{-1}$), in five replicate plots. The control treatment was fertilized with synthetic fertilizer following soil tests and the recommended doses in conventional agriculture.

The field was converted to organic management, first, by growing vetch in 2009 and applying it as GM in 2010. Then, in 2010, a 60 $m^3\ ha^{-1}$ of compost was uniformly applied to all the plots, except the control treatments, and incorporated to a depth of 10–15 cm. Between 2011 and 2012, wheat, corn and sunflower were grown, and the soil was fertilized either with compost (in 2011, 2012; at the application levels specified above) or with urea (control). Compost characterization, details on fertilization and C and N quantities added with GM (vetch) in 2010 are provided in detail by Sharma et al. (2017). Vetch (*Vicia faba* cv. Sadot) serving as a leguminous GM and as an additional source of N besides compost was sown at 70 Kg per hectare on November 22nd, 2012. The vetch was harvested on April 14th, 2013 and left on soil surface for two weeks until April 28th, 2013 on which it was incorporated into a depth of 15 cm by a disk harrow and thereafter the soil was flattened by a roller. The above ground dry biomasses of the vetch in the control, 20, 40, and 60 $m^3\ ha^{-1}\ yr^{-1}$ treatments were 7.49, 7.76, 7.87 and 7.76 $t\ ha^{-1}$, respectively and were not significantly different among treatments ($p \leq 0.05$).

The present study examined soil samples taken on May 21st, 2013, 23 days after vetch incorporation and 8 days following additional soil disk harrowing. The time selected for soil sampling (23 days after GM incorporation; i.e., 37 days after vetch harvesting) was a compromise between, on one hand, the time required to let decomposition process to stabilize and, on the other hand, the fact that sampling of the Newe Ya'ar clayey soil becomes difficult after a long drying period. Based on literature data from warm climate regions (Njunie et al., 2004; Danga et al., 2009; Danga et al., 2013), the optimal time for sampling may vary between 4 and 6 weeks after biomass incorporation, however most of the decomposition takes place in the first 3–4 weeks. Hence, the 23 days period was considered to be representative for residues decomposition.

The soil was sampled from four depths: 0–5, 5–15, 15–30 and 30–60 cm. Altogether a total of 80 soil samples (4 treatments × 4 depths × 5 replicate plots) were collected, air-dried, passed through a 2 mm-sieve and stored in the refrigerator at 4–7 °C.

2.2. Organic matter characterization

Total organic C (TOC) content of soil samples was determined by dry combustion with a Flashea™ 1112 NC elemental analyzer (Thermo Fi Elementar, Hanau, Germany). Examination of the whole pre-dried