Agriculture, Ecosystems and Environment 233 (2016) 343–351

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Selected soil biological parameters measured in the 19th year of a long term organic-conventional comparison study in Canada

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ARTICLE INFO

Article history:
Received 11 November 2015
Received in revised form 27 September 2016
Accepted 28 September 2016
Available online xxx

Keywords:
Nitrous oxide
Grassland
Soil health
Organic farming
Long-term studies

ABSTRACT

TheGlenlea long-term study in Manitoba, Canada compares annual grain and forage-grain rotations under organic and conventional management. Organic systems are split into compost manure amended and no compost treatments. The objective of this study was to evaluate selected soil biological parameters over one entire growing season (2011). Microbial biomass carbon (MBC), microbial metabolic quotient (qCO_2), and microbial biomass phosphorus (MBP) were measured five times in spring wheat (*Triticum aestivum* L.) and compared with a restored prairie grassland system. Significant interactions between management system and sample occasion were attributed to stronger recovery for MBC and MBP after soil rewetting in the organic vs the conventional system. The qCO_2 was lowest (0.37 mg C g MBC h^{-1}) under dry mid-summer conditions and highest in late spring and after soil rewetting in fall (1.19 mg C g MBC h^{-1}). When qCO_2 levels increased, the increase was greater in the forage-grain than the annual grain rotation. Organic management increased MBC compared with conventional management in the forage-grain rotation (1718 vs 1476 $\mu g\,g^{-1}$) but decreased MBC in the annual grain rotation (1080 vs 1115 $\mu g\,g^{-1}$). Among the six arable treatments, only the organic treatments in the forage-grain rotation behaved similarly ($P > 0.05$) to the grassland in terms of MBC, soil respiration and qCO_2. N_2O emissions per unit of MBC were 60–80% lower in organic compared with conventional systems. In conclusion, seasonal changes in soil biological C and P parameters were observed. Under conditions conducive to increased soil biological activity, organic systems outperformed conventional systems, especially in the forage-based rotation.

1. Introduction

Long-term field studies help us understand the ecology of agricultural systems (McGill and Cole, 1981). The growth of organic agriculture demands that we learn how long-term organic management affects soil health. Previous studies show that organic or biodynamic systems often have higher levels of microbial biomass carbon (MBC) (Heinze et al., 2010) and soil aggregation (Porter et al., 2006). Organic C levels however are more variable with total soil surface amounts having been higher (Gattinger et al., 2012) and subsoil organic C stocks lower (Bell et al., 2012).

The microbial metabolic quotient (qCO_2; Anderson and Domsch, 1993) expresses microbial respiration with respect to amount of MBC. It is believed to be an indicator of energy use efficiency of soil food webs. qCO_2 has been shown positively (Anderson and Domsch, 1985) and negatively related to microbial biomass (Wardle and Ghani, 1995); negatively to inorganic P concentrations (Hartman and Richardson, 2013; Hu et al., 2011), soil pH (Hartman and Richardson, 2013; Anderson and Domsch, 1993) and clay content (Hartman and Richardson, 2013); and positively to total organic carbon (Leita et al., 1999). In the DOK trial in Switzerland (Biodynamic – D; Organic – O; Conventional – K), organic and biodynamic systems had lower qCO_2, indicating better energy use efficiency as less energy was required to sustain the same amount of soil microbial biomass compared with conventional systems (Fleissbach et al., 2007). No differences were detected between organic and conventional management in the MASCOT trial in Italy (Mazzoncini et al., 2004), though the age of the experiment was less than the required 15 years for qCO_2 stabilization suggested by Anderson and Domsch (1985).

Animal manure additions in longer-term organic production systems have improved soil pH, microbial biomass, soil organic matter, and microbial activity levels (Fleissbach et al., 2007; Heinze et al., 2010; Porter et al., 2006). Böhme et al. (2005) measured qCO_2 in long-term experiments from Germany (initiated in 1902) and

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http://dx.doi.org/10.1016/j.agee.2016.09.035
0167-8809/

Hungary (initiated in 1963). Both sites had similar soil types, nutrient status and annual crop rotations including small/large grains and potatoes (*Solanum tuberosum* L.)/sugar beet (*Beta vulgaris* L.). Of three management treatments examined (no-fertilizer, conventional + raw farmyard manure, and conventional + synthetic fertilizer), soils amended with the manure had the lowest qCO_2 values.

Agriculture is the major source for greenhouse gas Nitrous oxide. The ratio of N_2O to MBC, termed qN_2O here, may be a useful indicator of intensity of emission from microbial communities in soil. Facultative anaerobic bacteria (Firestone, 1982) and nitrifying bacteria (Kool et al., 2011; Wrage et al., 2001) are the main groups responsible for emission N_2O from agricultural soils. Organic systems may promote the microbial activity/function to decrease the N_2O emissions from soils.

Organic forms of phosphorus serve as important P sources in organic production where plant-available forms are often in short supply (e.g., Welsh et al., 2009). Microbial activity is the principal mean for soil organic P mineralization from recalcitrant to labile forms that are plant available (Richardson and Simpson, 2011; Brookes, 1982). Phosphorus is mineralized through the activity of microbial phosphohydrolase enzymes, which are produced in response to P requirement and repressed by adequate supply of P (McGill and Cole, 1981; Fraser et al., 2015). The P taken up by microorganisms is cycled through their biomass and mineralized to increase plant-available forms (Sugito et al., 2010; Seeling and Zasoski, 1993) with annual amounts of 29 kg P ha^{-1} (Perrott et al., 1990). Microbial biomass P (MBP) can quickly turnover and be mineralized following the death of soil microorganism from abiotic stresses such as freezing and drying (Blackwell et al., 2010; He et al., 1997). Previous long-term studies showed increased MBP in organic or biodynamic systems compared with conventional agriculture (Heinze et al., 2010). Similarly, Buchanan and King (1992) demonstrated MBP increased with reduced P fertilizer addition in fields with continuous maize and maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-soybean (*Glycines max* L.) rotations.

The Glenlea study site was established in 1992 to compare organic and conventional production in two different crop rotations (annual grain vs. forage-grain). These systems are compared with a restored native perennial grass planting. Previously we reported on plant-available P (Welsh et al., 2009), mycorrhizal colonization (Welsh, 2007; Entz et al., 2004), nematode (Briar et al., 2012) and bacterial communities (Ru et al., 2012), water-soluble C, N and P (Xu et al., 2012), phosphatase enzyme activity (Fraser et al., 2015), and agronomic performance (Entz et al., 2014) from the Glenlea site. The present study set out to evaluate the effect of annual grain and forage-grain rotations under organic and conventional management on the soil parameters, MBC, MBP, qCO_2, and qN_2O. We were also interested in comparing soil parameters in our arable systems with those in the restored grassland system which is included in the experimental design at Glenlea

Most previous evaluations in long-term studies take measures once per year, yet soil processes such as accumulation of MBC are dynamic and strongly influenced by soil water (Liu et al., 2012) and the growing crop (Sekon and Black, 1969). Therefore, a third major objective was to measure soil biological parameters at monthly intervals during a growing season and to test the interaction between management and rotation with time of growing season.

2. Materials and methods

Details of the Glenlea rotation study and the soil and environmental conditions of the area are provided by Welsh et al. (2009) and Bell et al. (2012). Briefly, the study was established in 1992 to compare organic and conventional management practices in two different crop rotations. A perennial-annual rotation includes spring wheat (*Triticum aestivum* L.) and flax (*Linum usitatissimum* L.), followed by a two-year forage mixture: alfalfa (*Medicago sativa* L.), red clover (*Trifolium pretense* L.), orchardgrass (*Dactylis glomerata* L.) and timothy (*Phleum pretense* L.). It is referred to as the forage-grain rotation. An annual rotation includes wheat, flax, oat (*Avena sativa* L.) and soybean (*Glycine max* L.) (in the conventional system) or pea (*Pisum sativum* L.) with barley (*Hordeum vulgare* L.) green manure (in the organic system). It is referred to as the annual grain rotation. A restored native perennial grass treatment includes several native perennial grasses (Bell et al., 2012). The restored native perennial grass is burned every 4 to 5 years, including in early June, 2011. Each treatment has three replicate plots with the layout of plots being a 2 (rotation) × 3 (arable treatments) factorial plus restored native perennial grass in completely randomized design.

Starting in late 2007, the organic plots were split into compost amended (20 Mg ha^{-1} conventional solid beef cattle manure) and non-amended treatments. The characteristics of the compost was N = 25.2, P = 5.0, K = 24.5, S = 2.5, and dry matter = 490 g kg^{-1} with the compost sourced from the Agriculture and Agri-Food Canada, Brandon Research Station, Brandon MB.

All sampling for soil health analysis occurred in the wheat phase of all rotations. Hard red spring wheat (cv. Waskada) was seeded on May 19th, 2011 at a rate of 112 kg ha^{-1}. It was direct-seeded in conventional plots while tillage with a cultivator and harrow was performed immediately before seeding the organic plots. In the conventional plots, fertilizer was applied based on soil test and product recommendation (84 N kg ha^{-1} as urea and 39 P_20_5 kg ha^{-1}). Mature wheat was harvested with a small plot combine on August 29, 2011. All plots were rotor-tilled to 8 cm depth post-harvest on September 20, 2011.

2.1. Soil sampling and analysis

Soil samples were taken on five occasions from May to October in 2011 (pre-seeding May 17, 127 growing degree days (GDD); tillering June 21, 478 GDD; grain soft dough July 25, 989 GDD; grain maturity August 18, 1353 GDD; and post-harvest October 11, 1944 GDD). Sample times were selected to capture microbial dynamics during a typical wheat growth cycle.

Since conventional plots were twice the size of organic plots, only half of each conventional plot was selected for soil sampling on each occasion. A new random sample pattern was used for each sample occasion with all arable plots sampled in the same pattern. In the restored native grassland plots, soil samples were taken at random. Three soil samples were taken within a plot on each occasion.

In the morning of each sampling date, three intact soil cores (5 cm × 15 cm^2) were taken using an AMS soil core sampler (Signature SCS Complete, American Falls, ID) from each plot for a total of nine cores per treatment. Half of the core area was from the crop row and the other between the rows. When plants were not growing, proximity to the row was not considered in arable plots. The soil cores were placed in plastic bags and in an ice chest and transported to the laboratory.

2.2. Soil gas production (CO_2 and N_2O)

At the laboratory in early afternoon of each sampling date, the soil cores were placed in a growth chamber set at 21 °C in the dark for four hours. After, the cores were placed in separate 1.5 L jars and sealed with a lid containing a rubber septum sampling port. After two hours, 20 ml headspace gas of the jar was drawn using a disposable syringe. Gas was inserted into 12 ml evacuated and He flushed Exetainer vials (Labco, High Wycombe, UK) for CO_2 and