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# Benefits of winter cover crops and no-tillage for microbial parameters in a Brazilian Oxisol: A long-term study

Elcio L. Balota [a,*], Ademir Calegari [a], Andre S. Nakatani [b], Mark S. Coyne [c]

[a] IAPAR – Agronomic Institute of Paraná State, 86001-970 Londrina, Paraná, Brazil
[b] EMBRAPA Soja, Caixa Postal 231, CEP 86001-970 Londrina, Paraná, Brazil
[c] Department of Plant and Soil Sciences, University of Kentucky, Lexington, KY 40546, USA

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ABSTRACT

Soil degradation in Brazil is a concern due to intensive agricultural production. Combining conservation practice, such as no-tillage, with winter cover crops may increase microbial activity and enhance soil quality more than either practice alone. This research evaluated the benefits of long-term (23 years) winter cover crops and reduced tillage on soil microbial quality indicators in an Oxisol from Paraná State, Southern Brazil. The winter cover treatments were: fallow, black oat, wheat, radish, blue lupin, and hairy vetch in conventional (plow) or no-tillage management; the summer crop was a soybean/maize rotation. Soil quality parameters included organic C, microbial biomass C and N, total and labile polysaccharide, easily extractable and total glomalin-related soil protein, and enzyme activity. Winter crops increased soil microbial quality parameters compared to fallow in both tillage systems, with greater relative increase in conventional than no-tillage. No-tillage had higher microbial biomass, polysaccharide, glomalin-related soil protein, and soil enzyme activity than conventional tillage. Including legumes in the crop rotation was important for N balance in the soil–plant system, increasing soil organic C content, and enhancing soil quality parameters to a greater extent than grasses or radish. The microbial parameters proved to be more sensitive indicators of soil change than soil organic C. Cultivating winter cover crop with either tillage is a beneficial practice enhancing soil microbial quality and also soil organic C stocks.


## 1. Introduction

Many native vegetation areas in Brazil are now being intensely cultivated to satisfy increased demands for food, forage, and fiber. Intensification can cause soil erosion, deplete organic matter, and decrease soil quality. Key points to sustainability of agricultural soil are practices that can increase the soil carbon status and related soil processes, or at least minimize decreases in soil organic carbon (SOC). Soil tillage alters soil structural stability, resulting in considerable loss of SOC and microbial activity (Franchini et al., 2007; Green et al., 2007; Frazão et al., 2010). No-tillage (NT) sows directly through mulch and litter with minimal soil disturbance. The minimal soil disturbance associated with increased crop residue decreases soil erosion and increases SOC and biodiversity (Bayer et al., 2000; Bolliger et al., 2006; Calegari et al., 2008). Current Brazilian grain production covers an area greater than 48 million hectares. More than 50% of this area (25.5 Mha) is devoted to NT systems, which have increased more than 350% in the last ten years (FEBRAPDP, 2014).

Crop rotation and/or cover crop use are other important conservation practices, which can change soil habitat by affecting nutrient status, rooting depth, amount and quality of residue, aggregation, microbial habitat, and may stimulate soil microbial diversity and activity. Winter cover crops are used to minimize soil erosion, to promote nutrient recycling, and to produce soil cover, which prevents water loss and increases soil organic C and biological activity (Calegari et al., 2008; Bolliger et al., 2006). However, significant areas of Brazil intended for grain production remain in fallow during winter because the benefits of cover crops for soil productive capacity are unquantified.

Soil productive capacity is affected by the soil's properties, especially its microbiological properties. These properties play important roles in nutrient cycling and soil quality. They can be understood, from an agricultural perspective, as the soil's capacity to sustainably retain desirable soil characteristics, such as organic

* Corresponding author. Tel.: +55 4333762353.
*E-mail addresses:* balota@iapar.br, balotae@yahoo.com, elcio.balota@gmail.com (E.L. Balota).

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matter content, aggregate stability, and microbial activity. Microbial parameters have been utilized to indicate change in soil quality due to different soil management such as tillage or cover crop (He et al., 2003; Gil-Sotres et al., 2005; Franchini et al., 2007; Babujia et al., 2010; Balota and Auler, 2011) because microbial indicators – being more sensitive than gross physical properties – express soil alteration sooner than physical or chemical parameters (He et al., 2003; Gil-Sotres et al., 2005).

Microbial biomass comprises up to 5% (approximately) of total soil organic carbon, and represents an important reservoir of labile nutrients (Jenkinson and Ladd, 1981; He et al., 2003). Soil nutrient turnover is mediated by microorganisms, which produce enzymes catalyzing innumerable reactions necessary for their own metabolic processes. These enzyme activities can be used to indicate the intensity of specific biochemical processes (Tabatabai, 1994; Dick, 1997).

Microorganisms are also responsible for producing polysaccharides and glomalin, which affect soil stability and C sequestration. Most soil polysaccharides are produced by microorganisms and may represent about a quarter of the soil organic matter, with a high correlation to soil aggregate stability (Spaccini et al., 2004; Liu et al., 2005). Glomalin is a glycoprotein produced by arbuscular mycorrhizal fungi (AMF); no other fungal group produces glomalin in significant amount. Glomalin or glomalin-related soil protein (GRSP) concentration is related to the formation and stabilization of aggregates (Wright et al., 2007). Glomalin is also of potential importance to the soil C pool (Rillig et al., 2001). Although glomalin is extremely resistant, with a turnover time of up to 42 years in tropical forests (Rillig et al., 2001), it is possible to detect changes in its pools during short-term soil management (Rillig et al., 2003; Wright et al., 2007).

The objective of this work was to evaluate the changes in microbial soil quality indicators due to the long-term (23 years) cultivation with winter crops in different soil tillage systems. Our hypothesis was that no-tillage, combined with crop rotations including winter cover crops that return high amounts of crop residues annually to the soil, significantly increase SOC content, microbial biomass, and microbial activity, making these management systems, in tropical and subtropical conditions, more sustainable.

## 2. Material and methods

### 2.1. Experiment design and soil description

Prior to sampling the experiment had been conducted for 23 years (since 1986) at the IAPAR Experimental Station in Pato Branco, southwestern of Paraná State Brazil (52°41′W, 26°07′S, 700 m altitude). The soil is a clayey Oxisol (72% clay, 14% silt, and 14% sand), acid (<4.6), that is classified as a typical ferric aluminum red latosol according to the Brazilian soil classification (Rhodic Hapludox by Soil Taxonomy).

At the beginning of the experiment (1986) the soil had 19.0 g kg$^{-1}$ organic C, pH was 4.7 ($CaCl_2$), Mehlich extractable P was 3.0 mg kg$^{-1}$, CEC was 11.7 cmol$_c$ kg$^{-1}$, aluminum saturation was 2.35%, and base saturation was 51% in the 20 cm surface soil layer (Calegari et al., 2013). Other physical and chemical characteristics are reported in Calegari et al. (2008); Tiecher et al. (2012); Calegari et al. (2013).

The experiment was conducted using a split plot design with winter crop as the main plot (12 m × 20 m) and the tillage systems as the subplot (6 m × 20 m). The plots were separated by a 2.0 m buffer. The experiment design consisted of blocks with three replicates. Soil tillage treatments consisted of no tillage (NT), which entailed planting into undisturbed soil by opening a narrow trench, or conventional (plow) tillage (CT) in which disc plowing occurred to a depth of 20 cm and the field was lightly harrowed twice for seedbed preparation.

The winter cover crops included: black oat (*Avena strigosa* Schreb.), winter wheat (*Triticum aestivum* L.), oilseed radish (*Raphanus sativus* L.), blue lupin (*Lupinus angustifolius* L.), hairy vetch (*Vicia villosa* Roth), and fallow. These treatments were applied in winter from 1986 to 1990, 1999 to 2001, 2005, and 2008. During the winters of 1991, 1995, 1996, 1998, 2006, and 2009 the entire experimental area (except fallow) was cultivated with black oat while in 1997, 2002–2004, and 2007 black oat + radish were cultivated. In 1993 the entire experimental area remained under fallow. The area was cultivated in summer with soybean (*Glycine max* L.) or maize (*Zea mays* L.). The total above-ground dry biomass yield (winter cover crops and summer crops) over 23 years in different tillage systems are shown in Table 1. Each year, crop stubble was either retained on the surface in NT or plowed in CT to a 20 cm depth after harvest in both fall and spring. Additional information about fertilizer and lime applications and experiment management can be found in Calegari et al. (2008); Tiecher et al. (2012); Calegari et al. (2013).

Ten sub-samples of soil were randomly collected within each replicate at 0–5, 5–10, and 10–20 cm depth in October 2009 (at about winter crop flowering season). The previous summer annual crop had been maize, and the samples were removed 20 cm from the maize row. Large plant material was removed from each sample and the soil was sieved through a 4 mm screen. Organic C was measured by the Walkley–Black potassium dichromate sulfuric acid oxidation procedure. Samples were stored at 4 °C until microbial analysis. The microbial analyses were conducted in triplicate and expressed on a dry weight basis.

**Table 1**
Total above-ground dry biomass yield over 23 years in different winter cover crops in no-tillage (NT) and conventional (plow) tillage (CT).

| Winter crop | Winter cover crops[a] | | Summer crops residues[b] | | Total | | Annual mean | |
|---|---|---|---|---|---|---|---|---|
| | CT | NT | CT | NT | CT | NT | CT | NT |
| | Mg ha$^{-1}$ | | | | | | | |
| Fallow[c] | 31.0 | 42.5 | 91.7 | 93.1 | 122.7 | 135.5 | 5.3 | 5.9 |
| Oat | 87.5 | 99.9 | 93.6 | 95.4 | 181.1 | 195.3 | 7.9 | 8.5 |
| Wheat | 68.6 | 75.0 | 86.0 | 89.9 | 154.6 | 164.9 | 6.7 | 7.2 |
| Radish | 69.5 | 84.9 | 97.1 | 99.0 | 166.5 | 183.9 | 7.2 | 8.0 |
| Lupin | 76.0 | 87.5 | 91.1 | 97.2 | 167.1 | 184.7 | 7.3 | 8.0 |
| Vetch | 73.3 | 85.6 | 91.0 | 97.7 | 164.3 | 183.3 | 7.1 | 8.0 |
| **Mean** | **405.9** | **475.4** | **550.5** | **572.3** | **956.3** | **1047.6** | **41.5** | **45.6** |

[a] Values are the sum of biomass yield of the winter cover crop used as treatments in 1986–1990, 1992, 1994, 1999–2001, and 2005; plus black oat biomass yield in 1991, 1995, 1996, and 1998; plus black oat + radish biomass yield in 1997, 2002–2004.
[b] Values are the sum of crops residues produced by maize cultivated in 1986–1988, 1992, 1994, 1996, 1999 and 2003 and by soybean cultivated in 1989–1991, 1993, 1995, 1997, 1998, 2000–2002, and 2004.
[c] The fallow biomass yield consisted of weed biomass.