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Scaling-up: cover crops differentially influence soil carbon in agricultural fields with diverse topography

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ABSTRACT

The use of cover crops is a management technique that can potentially increase the amount of carbon (C) sequestered in soil. However, information on cover crop's role in increasing soil C comes mostly from small experimental plots, while the magnitude of C gains in large agricultural fields may vary spatially in response to topographic and soil variability. Here we assess cover crop effects on soil organic C in 20 large agricultural fields across a topographically diverse landscape under conventional, low-input, and organic managements in corn-soybean-wheat rotation. The low-input and organic managements included rye and red clover cover crops in their rotations. Micro-plots with and without cover crops were laid out within each studied field at three contrasting topographical positions of depression, slope and summit. Soil samples were collected and analyzed for total organic carbon (TOC), particulate organic carbon (POC) and short-term mineralizable carbon (SMC). The magnitude of cover crop effects on SMC and POC varied across topography. The contributions of cover crop's presence to soil C variables tended to be the highest on topographical slopes and summits. Positive correlations between effects of cover crop presence on SMC with cover crop biomass also were primarily observed on slopes and summits. The results indicate that in the studied agricultural environments preferential placement of cover crops on eroded low fertility elements of the relief can be a particularly effective strategy from both environmental and management standpoints.

1. Introduction

Intensive agriculture increases the release of C from soil to the atmosphere (Lal, 2002) thus contributing to increasing levels of atmospheric CO_2 and changing climate. A conservation practice that can potentially slow or even reverse soil C depletion is the inclusion of winter cover crops in agricultural rotations (e.g., Thomsen and Christensen, 2004; Sainju et al., 2006; Motta et al., 2007; Weil and Kremen, 2007; Mutegi et al., 2013; Abdollahi and Munkholm, 2014; Hurisso et al., 2014). Cover crops are grown in between consecutive main crops and are typically planted in fall and terminated in spring, thus providing continuous live vegetative coverage.

Row crop farming is most often implemented in large agricultural fields, which in the US Midwest are commonly characterized by undulating topography. In such settings cover crop contribution to soil C cycle can be expected to be a subject of substantial spatial variations. The numerous sources of these variations are driven by interwoven soil/hydrological/plant interactions. Differences in the amounts of above- and below-ground biomass produced by cover crops is arguably the leading source of variation in cover crop effects on soil C (Gardner and Sarrantonio, 2012; McDaniel et al., 2014). Cover crop production can be significantly influenced by topography (Muñoz et al., 2014). For example, cover crop growth in topographical depressions of undulating agricultural fields is often enhanced (Muñoz et al., 2014) due to more favorable edaphic and hydrological settings, as compared to other topographical positions (Chan et al., 2007; Corre et al., 2002; Bennie et al., 2008). The other source of variation is topography-driven differences in soil moisture and temperature and their effects on decomposition rates of cover crop residue (Jacinthe et al., 2002), e.g., enhancing decomposition in soil of slopes and summits as compared to colder and wetter topographical depressions. Combined, these influences can lead to increased

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spatial variability of soil C across topographically diverse fields, enhancing soil C gains in topographical depressions as opposed to higher terrain.

On the other hand, cover crop presence is known to limit soil erosion. Reduction in erosion can decrease C redistribution across topographic gradients, and thus produce the opposite effect of reducing the spatial variability of soil C (Jacinthe et al., 2004; Ritchie et al., 2007). Moreover, it is possible that in historically C-enriched topographical depressions soil can be closer to the state of C saturation, which can result in lower C sequestration capabilities due to cover crop inputs. Because of the variety of these counter-acting influences, the effects of conservation management practices with cover crops on soil C may vary across agricultural fields with diverse topography (VandenBygaart et al., 2002; Jacinthe et al., 2004; Senthilkumar et al., 2009).

Despite a general understanding that topography can moderate cover crop management effects on soil C, the interactions between topography and cover crops have not been adequately addressed in field experimentation. Most cover crop research is performed in small experimental plots where conditions are far more controlled and homogeneous and topographic variations are minimal as compared to large agricultural fields (VandenBygaart, 2006). Substantial resource demands for large scale experimentation and logistic difficulties in designing the experiments where unequivocal isolation of topographical and management effects could be possible are the understandable reasons. However, the lack of knowledge on (i) cover crop performance in undulating agricultural landscapes and (ii) on their effects on soil C limits accurate assessment of the potential contribution that cover crops can make to increase soil organic C and improve soil health. The uncertainty about the performance of cover crops in real size agricultural fields complicates management decisions and may inhibit farmers' willingness to include cover crops in cropping rotations.

Our study takes advantage of a unique replicated large scale experiment where three contrasting management systems, i.e., conventional row crop management and two cover crop based practices, were tested each at 4–5 large undulating agricultural fields. Topographical diversity of the studied fields enabled us to address the effects of management on the spatial patterns in soil C at the field scale. Multiple sets of paired micro-plots established at contrasting topographical positions within cover crop fields enabled us to perform quantitative assessment of the cover crop contribution to soil C, while avoiding confounding effects of other contributing factors.

We hypothesize that, while positive effect of cover crops will be present everywhere, its magnitude will vary at different topographical positions. The variations result from several competing processes, including topographically driven differences in cover crop growth patterns, differences in residue decomposition rates as well as cover crop influences on processes of soil erosion. The topographical depressions in the studied landscape typically support substantially greater plant growth and, due to their tendency for higher soil moisture and lower soil temperature levels, might be less conducive to decomposition of freshly added plant inputs. Thus, we expect greater benefits of cover crop presence to be observed in topographical depressions as opposed to summits and slopes.

Since soil total organic carbon (TOC) relatively slowly responds to land management and land use changes (Nascente et al., 2013; Haynes, 2000; Plaza-Bonilla et al., 2014), in our study we focused on the C characteristics related to labile C pools, specifically, particulate organic C (POC) and short term mineralizable C (SMC). The labile pools have a turnover rate of days to a few years (Hungate et al., 1995; Paul et al., 1999; Six et al., 2001). Thus, their assessment can reveal the short-term effects of management practices on C processes (Marriott and Wander, 2006; Awale et al., 2013). Both POM and SMC were demonstrated to be closely related to several labile pools of organic C and to be sensitive to management changes (Cambardella and Elliott 1992; Collins et al., 2000; Chan, 2001; Haynes, 2005; Franzluebbers et al., 2000; Culman et al., 2013; Ladoni et al., 2015).

The overall goal of this study is to assess how the presence of cover crops influences soil C on a topographically diverse landscape. The first objective is to compare three management practices in their effects on soil C, as represented by TOC, POC and SMC, across diverse terrain. The three practices include a conventional practice that completely relays on the use of synthetic fertilizers, and two conservational practices that use cover crops with reduced fertilizer inputs (low input) and with no chemical inputs (organic). The second objective is to assess the specific contributions that the presence of cover crops makes to changes in labile soil C fractions, POC and SMC, at contrasting topographical positions within large agricultural fields.

2. Methods

2.1. Study site

The study was conducted at the Scale-up experiment established in 2006 at the Kellogg Biological Station Long Term Ecological Research (LTER) site in southwest Michigan (42°24′N, 85°24′W) (Robertson and Hamilton 2015). The dominant soil series are Kalamazoo (fine-loamy, mixed, mesic Typic Hapludalfs) and Oshtemo (coarse-loamy, mixed, mesic Typic Hapludalfs).

The Scale-up experiment consisted of a total of 27 agricultural fields, with fields ranging in size from 3.1 to 7.9 ha. Scale-up experiment studied three agricultural management practices, namely, conventional, low-input and organic. Each practice was assigned to 9 randomly selected fields. The studied fields were in corn-soybean-wheat rotation, and every year all three phases of the rotation were present in all three studied management practices. Thus, each year for each management practice there were three replicated fields in corn, three in soybean, and three in wheat present in the Scale-up experiment.

2.2. Treatment and experiment design

Our study consisted of three factors, namely, management practice with three levels (conventional, low-input, and organic), crop with two levels (corn and soybean), and topographical position with three levels (depression, slope, and summit). Data for this study were collected in 2011, 2012 and 2013. Each year we worked only with the Scale-up fields that were either in corn or in soybean. Out of the total of 18 of corn and soybean fields available each year from the entire Scale-up experiment we selected only the fields with sufficiently diverse topography. In 2011, we sampled 4 fields from conventional management, 6 fields from low-input management, and 5 fields from organic management. In 2012, we sampled 4 fields from conventional management, 4 fields from low-input management, and 4 fields from organic management. In 2013, we sampled 4, 4, and 5 fields from conventional, low-input, and organic managements, respectively. Fig. 1 shows locations of the fields used in the study along with the years at which each field was sampled.

Topographical attributes of the fields were derived from the digital elevation model of the area at 2 m resolution. The attributes included relative elevation, terrain slope, flow length, and flow accumulation. Linear discriminant analysis was applied to the topographical attributes to classify the studied fields into three topographical positions: summit, slope and depression as described by Muñoz and Kravchenko (2012).

Within each field we identified topographical transects across summit, slope, and depression positions (Fig. 1). The number of