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Cover crop effect on corn growth and yield as influenced by topography

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A B S T R A C T

The use of cover crops is reported to enhance ecosystem services, however their adoption by farmers has remained limited. A challenge to farmer uptake is high spatial and temporal variability in cover crop growth and performance. Since topography plays an important role in spatial processes that ultimately affect plant performance, it could be used to quantify cover crop spatial variability and cover crop contribution to a subsequent cash crop. We assessed the effects of topography and cover crop (red clover) biomass on corn yields. Hierarchical path analysis was used to identify direct and indirect relationships among topography, red clover biomass, and corn yield, while taking into account the effects of agricultural management practices, multiple years, and multiple experimental fields. We observed that topography contribute significantly to explaining the variability in both red clover biomass and corn yields. Higher red clover biomass was produced in flat areas, whereas higher corn yield was produced in areas with high curvature. Red clover biomass positively influenced corn yield, however, the magnitude of that effect varied both temporally and spatially. The effect of red clover on corn yields was significant only in the years with lowest precipitation; and its magnitude was more pronounced at summit and slope topographical positions. Therefore, a good cover crop stand will be most beneficial to subsequent corn crop at summit and slope positions. Accounting for variability in fields and years using a hierarchical model significantly improved analysis of the interactive relationships between topography, red clover, and corn; therefore we encouraged its use in agroecological research.

1. Introduction

The use of cover crops in row crop systems has been reported to improve ecosystem services provided by the row crop systems including enhanced carbon (C) sequestration, reduced erosion, increased nutrient supply, increased weed suppression, and reduced losses of agrochemicals (Snapp et al., 2005; Bhardwaj et al., 2011). It has been demonstrated that cover crops increase the concentration of soil C and nitrogen (N) (Dabney et al., 2001; Fageria et al., 2005), influence soil physical conditions and water retention (Drury et al., 2003; Papadopoulos et al., 2006), and reduce bulk density and increase porosity (Ess et al., 1998).

Use of leguminous cover crops can be particularly advantageous. Benefits of using legumes include increased microbial biomass (Jokela et al., 2009), and increased N mineralization rates (Dinesh et al., 2001). In addition, legumes possess the ability to absorb low available nutrients in the soil profile, which after legume biomass incorporation increase nutrient concentration in the soil surface layer (Fageria et al., 2005). A meta-analysis of the response of corn yield to cover crops was provided by Miguez and Bollero (2005), who analyzed the results from 36 peer-reviewed publications and concluded that legume cover crops increase corn yield by 37%, compared to the no-cover crop control. Red clover (*Trifolium pratense* L.) is among the most commonly used legume cover crops in the northeastern United States (Singer and Cox, 1998), and has been shown to provide up to 85 kg N ha^{-1} for a subsequent crop (Vyn et al., 1999).

Despite all their benefits, adoption of cover crops by farmers remains low, and only a very small percentage of the U.S. cropland is planted with cover crops (Dabney et al., 2001). One of the reasons for the low adoption rate is that cover crop establishment, growth, and subsequent nutrient supply to a cash crop are spatially and temporally variable (Boyer et al., 1996; Harmoney et al., 2001; Guretzky et al., 2004). High spatial and temporal variability increases management challenges of cover crop-based systems.

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Legumes in particular are known to have high spatial variability in N-fixation patterns in addition to variable biomass production (Boyer et al., 1996; Nykanen et al., 2008; Hauggaard-Nielsen et al., 2010). Soil properties may contribute to this variability by influencing cover crop growth and biomass production (Boyer et al., 1996; Hauggaard-Nielsen et al., 2010).

Topography plays an important role in the spatial distribution of soil particles (erosion/deposition), organic matter, nutrients, and hydrologic conditions throughout the landscape and has been shown to be correlated with a variety of soil properties, including soil water content (Moore et al., 1993; Kang et al., 2003; Zhu and Lin, 2011), soil C content (Gregorich et al., 1998; Ritchie et al., 2007), and soil temperature and microclimate conditions (Kang et al., 2003; Bennie et al., 2008). The effect of topography on performance of row crops has been studied extensively and found to be substantial across diverse cropping systems in the U.S., including row crops in the Midwest (Halvorson and Doll, 1991; Kravchenko and Bullock, 2000; Jiang and Thelen, 2004; Huang et al., 2008). Considerably less attention has been devoted to the effects of topography on performance of cover crops. In particular, studies from Harmoney et al. (2001) and Guretzky et al. (2004), showed a significant effect of landscape position on legume diversity and legume dry matter composition. Since spatial and temporal variability play an important role in cover crop performance, a better understanding of the effect of topography would contribute to more effective cover crop implementation, allowing producers to tailor recommendations to site-specific features of their fields.

Field sites used for agricultural experiments have been traditionally placed on flat land with homogeneous soil properties. This allows researchers to minimize variability in crop growth and performance conditions external to the study and to maximize detection of the effects of the agricultural management treatments considered in the study. However, such experimental settings also limit the ability of traditional field research experiments to address the role of topography and edaphic factors on variability in crop performance as well as the role of interactions between the studied agricultural management practices and other factors affecting crop growth. Such interactions can potentially change the practical outcomes of the research findings, e.g. when one management practice can outperform another under some but not other soil/terrain settings. This is particularly relevant to commercial agriculture that uses large fields with diverse topographic and soil conditions which make crop production highly spatially variable. The concern about the role of management vs. terrain interactions is especially valid for managements involving cover crop use. In commercial cropping systems it may be difficult to see the positive effect of cover crops on row-crop yields because variations in soil/terrain settings could mask the cover crop effects. We hypothesize that in the systems with cover crops, the main row crop yield will be affected by topography both directly, through topography's role in water redistribution and spatial patterns of soil properties, and indirectly, through the contribution that topography makes to spatial patterns in biomass inputs by cover crops. While general effects of topography on plant growth cannot be doubted, the magnitudes, temporal patterns, and synchronies between these direct and indirect topographical influences on main row crops in cover crop based systems have not been addressed before.

To assess direct and indirect effects of topography on row crop yields we will use Path Analysis (PA), a procedure that allows testing direct and indirect relationships ("paths") between topography, red clover and corn yield (Hoyle, 1995). With PA we can study the contribution of cover crop biomass to the main crop while accounting for confounding effects of topographic attributes (Gajewski et al., 2006). We propose the implementation of PA under the Bayesian framework. Such implementation can be particularly advantageous for inferential purposes in studies with multiple factors within a hierarchical structure. Data from agricultural studies, such as ours, that are conducted across multiple topographically diverse fields with different management practices in multiple years can be challenging to analyze using traditional linear model based statistical approaches, while Bayesian approach can provide multiple numerical and estimation advantages. Ability of Bayesian approach to handle data that are not normally distributed constitutes its additional benefit (Gelman et al., 2004; Gajewski et al., 2006).

Table 1
List of the fields used in the study, along with years when the fields were sampled, their agricultural management treatments (reduced input and organic), field sizes, and the numbers of samples collected per field.

Field	Years	Treatment	Area (ha)	Samples
301	2008 and 2011	Reduced	5.8	20*/6
38	2008 and 2011	Organic	7.4	56*/6
79-S	2008 and 2011	Reduced	5.7	12*/6
97	2008	Organic	5.4	42
93	2009	Organic	5.6	56
87	2009	Reduced	4.9	57
52	2009	Reduced	5.9	61
79-N	2009	Organic	5.7	64
91	2011	Organic	3.3	3
822	2011	Reduced	1.4	3

* Number of samples collected in 2008/Number of samples collected in 2011. Cover crop effect on corn growth and yield as influenced by topography.

2. Objectives

The main goal of our study is to examine the influence of cover crops on growth and yield of the following row-crop, i.e., corn, on a scale of a typical agricultural field. Since topography could affect growth and production of both cover and main crop, topography becomes a potentially confounding factor that may mask the contribution of the cover crop effects, thus we aim at separating the partial effect of topography from the effect of the cover crop. The specific objectives of the study are (1) to determine the relative significance of direct and indirect effects of red clover biomass and topographic attributes on corn biomass and yield using hierarchical PA under a Bayesian framework; and (2) to quantify the effect of red clover biomass on corn biomass and yield at different landscape positions.

3. Materials and methods

3.1. Study site

The study was carried out at the Long Term Ecological Research (LTER) Scale-up experiment at Kellogg Biological Station (KBS) located in southwest Michigan at 42° 24′N, 85° 24′W. Annual rainfall averages 890 mm/y and mean annual temperature is 9.7 °C. The dominant soil series are the Kalamazoo (fine-loamy, mixed, mesic Typic Hapludalfs) and Oshtemo (coarse-loamy, mixed, mesic Typic Hapludalfs) (Crum and Collins, 1995). The Scale-up experiment is an RCB design established in 2006 with three treatments corresponding to three main cropping systems. Each treatment system is replicated three times in independent experimental fields ranging in size from 1.4 to 7.4 ha (Table 1). In this study we examined two of the Scale-up's treatments, namely, the system with reduced chemical inputs (reduced) and the organic system with zero chemical inputs (organic). The reduced chemical input system receives banded herbicide and starter N fertilizer only at planting time for wheat and corn, for a 50% reduction in chemical inputs compared to the conventional management. Tillage practices in both systems include chisel plow and post-planting row cultivation, additionally the organic treatment is rotary-hoed to control weeds. A detailed