Agriculture, Ecosystems and Environment 239 (2017) 219–227

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Balancing multiple objectives in organic feed and forage cropping systems

Meagan E. Schipanski[a,*], Mary E. Barbercheck[b], Ebony G. Murrell[b], Jayson Harper[c], Denise M. Finney[d,e], Jason P. Kaye[d], David A. Mortensen[f], Richard G. Smith[h]

[a] Department of Soil and Crop Sciences, Colorado State University, Fort Collins, 1170 Campus Delivery, CO 80523-1170, USA
[b] Dept of Entomology, The Pennsylvania State University,University Park, PA, USA
[c] Dept of Agricultural Economics, Sociology, and Education, The Pennsylvania State University,University Park, PA, USA
[d] Dept of Ecosystem Science and Management, The Pennsylvania State University,University Park, PA, USA
[e] Dept of Biology, Ursinus College, Collegeville, PA, USA
[f] Dept of Plant Science, The Pennsylvania State University,University Park, PA, USA
[h] Dept of Natural Resources and the Environment, University of New Hampshire, Durham, NH, USA

ARTICLE INFO

Article history:
Received 8 September 2016
Received in revised form 8 January 2017
Accepted 15 January 2017
Available online xxx

Keywords:
Cropping systems
Multifunctionality
Soil quality
Perennial crops
Weed management
Tillage
Arthropod natural enemies

ABSTRACT

Balancing weed suppression, beneficial insect conservation, soil quality and profitability is challenging in organic cropping systems due to reliance on soil disturbance for weed control. We hypothesized that the benefits of tillage can be retained while mitigating adverse impacts on soil quality by alternating tillage with practices that can build soil organic matter. We conducted a four-year experiment in central Pennsylvania, USA, to compare four organic feed and forage cropping systems, each differing in tillage, manure management, and cropping strategies. Each system was designed to address baseline soil quality and weed pressure conditions arising from practices implemented during the previous three-year transition period. To assess cumulative system effects, we established a soybean (*Glycine max*) uniformity trial across all systems in year four. Systems that were in perennial forage for 2 years outperformed annual crop-based systems in weed control and beneficial insect conservation, while maintaining overall profitability over the four-year study period. Soybean yields during the uniformity trial were more than 30% greater in systems that had included perennial forages than in systems with only annual crops. Labile soil carbon pools, an indicator of soil quality, were maintained over time in all systems. Our results indicate that soil quality, weed management, beneficial insect conservation, and profitability can be maintained in organic systems when periodic tillage is coupled with perennial forage crops in rotation.

1. Introduction

Organic management systems have the potential to improve multiple ecosystem services over conventional management systems due to reduced reliance on external inputs and increased reliance on biological processes (Cavigelli et al., 2013). However, balancing pest management, soil quality and profitability can be challenging because tillage is often used for weed and pest management, incorporation of animal and green manures, and preparation of seedbeds. Soil disturbance via tillage can also negatively impact key processes that are the foundation of effective organic management. For example, organic production relies on soil-based processes to support pest and disease management (Bond and Grundy, 2001; van Bruggen and Termorskuizen, 2003), nutrient cycling (Drinkwater and Snapp, 2007), and reduce environmental impacts (Tuomisto et al., 2012). Research is necessary to balance the trade-offs between the benefits and disservices of soil tillage to optimize production, profitability and the ecological processes that support organic production.

Over the past decade, there has been growing interest in reduced-till organic management systems (Mirsky et al., 2012; Légère et al., 2013). The development of cover crop termination techniques using a roller-crimper has improved the viability of no-till planting organic crops; however, many organic systems still include inversion tillage within a multi-year rotation (Mirsky et al., 2012). We lack an understanding of the frequency of tillage required to maintain weed control, particularly of perennial weeds,

* Corresponding author.
E-mail address: meagan.schipanski@colostate.edu (M.E. Schipanski).

http://dx.doi.org/10.1016/j.agee.2017.01.019
0167-8809/

in organic systems. In addition, we lack an understanding of how tillage frequency impacts soil organic matter and beneficial arthropods under different crop rotations and levels of manure input.

Understanding the role that tillage frequency and intensity play in soil quality is an area of interest that extends beyond organic management systems. For example, the increase in herbicide-resistant weeds is leading some no-till producers to return to periodic tillage as a management tool (Price et al., 2011). Periodic tillage may have short-term negative impacts on labile carbon and microbial pools that do not persist beyond a few years (Franzluebbers et al., 1999), but longer-term modeling studies suggest that the effects of periodic tillage can accumulate to negatively affect total soil carbon over time with reduced impacts found for shallow cultivation and non-inversion tillage (Conant et al., 2007). Similarly, a recent meta-analysis indicates that reducing the intensity of tillage in organic systems can improve soil C stocks (Cooper et al., 2016).

In addition to tillage frequency, crop rotations can also exert a strong influence on weed density, beneficial arthropods, and soil quality. For example, Cardina et al. (2009) found that more diverse, corn-oat-hay rotations had lower weed density compared with continuous corn under no-till management. While less-disturbed cropping systems often have greater insect predator populations, beneficial insect species also respond to previous cash or winter cover crops (Holland and Luff, 2000; Thorbeck and Bilde, 2004; Lundgren and Fergen 2010). Integrating perennial crops, which typically have larger root systems than annuals, into rotations can also contribute to soil quality improvements in addition to reducing tillage frequency (Zan et al., 2001).

Organic cropping systems managed with tillage can also maintain or build local soil organic matter, a central component of soil quality, through additions of carbon-rich manure or composts as well as increased use of cover crops (Teasdale et al., 2007). Increasing carbon inputs can offset the stimulatory effect of tillage on soil organic matter decomposition. Therefore, balancing soil quality, beneficial arthropod conservation, and weed control may be achieved through a reduction of tillage frequency and intensity coupled with diversified crop rotations and the use of organic soil amendments.

Cropping systems experiments are an important tool for understanding how management strategies influence overall system performance over time. For example, long-term cropping systems studies have highlighted the relative effects of conventional, organic, no-till, reduced input, and conservation tillage systems on a broad suite of agroecosystem functions (Mäder et al., 2002; Syswerda and Robertson, 2014). Within organic management systems, cropping systems studies have allowed us to understand the relative effect of input strategies and crop rotations on yield and profitability (Teasdale et al., 2007; Caldwell et al., 2014) and to identify key drivers of critical ecosystem processes (Finney et al., 2015).

One of the challenges with systems experiments is how to allow them to evolve over time using adaptive management strategies. Implementing changes in long-term systems experiments can make it difficult to interpret whether changes are an effect of the newly imposed management system or the previous management legacy. We implemented a novel approach of layering a new experiment across a previous cropping systems experiment that intentionally utilized the soil quality and weed community

Table 1
The previous and current experiment management strategies for 4 organic feed and forage cropping systems, including the cumulative number of inversion and secondary tillage events and the 4-year cropping sequence for each system initiated in 2007 (Start 1) and 2008 (Start 2) near Rock Springs, PA.

				System 1	**System 2**	**System 3**	**System 4**
Previous experiment management				Reduced tillage	Full tillage	Reduced tillage	Full tillage
Management strategy				*Perennial crops with high disturbance initially to reduce perennial weed pressure*	*Perennial and annual forages with reduced disturbance to rebuild soil quality*	*Annual crops with disturbance, including high intensity tilled fallow, to reduce perennial weed pressure*	*Annual crops with low disturbance to rebuild soil quality*
Inversion tillage events in Yrs 1-3[a]				3	2	2	1
Secondary tillage events in Yrs 1-3[b]				8	7	8	8
Year	**Start 1**	**Start 2**	**Season**	**Cropping Sequence**			
0	2007	2008	Fa	Rye & hairy vetch	Rye & hairy vetch	Rye & hairy vetch	Rye & hairy vetch
1	2008	2009	Wi				
			Sp	Mustard			
			Su	Buckwheat	Sudangrass* (60/50)[c]	Tilled fallow	Buckwheat
			Fa	Oats	Fallow	Rye*	Rye & hairy vetch
2	2009	2010	Wi	Fallow			
			Sp	Alfalfa*	Alfalfa/orchardgrass*		
			Su				
			Fa			Triticale & hairy vetch	Rye
3	2010	2011	Wi				
			Sp				
			Su			Corn* (114/123)	Corn* (299/258)
			Fa			Fallow	Fallow
4	2011	2012	Wi				
			Sp				
			Su	Soybean*	Soybean*	Soybean*	Soybean*

Adapted from Finney et al. (2015).
*Crops marked with an asterisk (*) were harvested as cash crops.
[a]Shaded areas represent rotation phases managed without tillage and un-shaded regions represent crop phases managed with inversion tillage for crop establishment or manure incorporation prior to crop establishment.
[b]Secondary tillage events include non-inversion soil disturbance events such as field cultivation, tine weeding or discing.
[c]Manure application rates (Mg/ha) are presented in parentheses for Start 1 and Start 2, respectively.