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Effects of reduced tillage and fertilizer application method on plant growth, yield, and soil health in organic bell pepper production

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ABSTRACT

Concerns over soil erosion and nitrate leaching have generated interest in cover crop-based reduced tillage systems. A 2-year field study was conducted in Ames, IA in 2013–14 and 2014–15 to compare cover crop-based no tillage (NT) and strip tillage (ST) with conventional tillage (CT) in production of organic bell pepper (*Capsicum annuum* L.). Two fertility treatments – preplant fertilizer only, or application split between preplant and post-planting fertigation – which applied the same amount of total N (90 kg ha^{-1}), were also evaluated. The experimental design was a split plot randomized complete block design with tillage as the whole plot (NT, ST, or CT) and fertility as the subplot treatment (preplant or split). A mixture of cereal rye and hairy vetch was seeded in September 2013 and September 2014 in all plots. The cover crop was terminated in mid-May using tillage in CT plots and in early June using a roller-crimper in NT and ST plots. Data were collected on plant growth, yield, soil temperature and moisture, weed suppression, nitrate leaching, and microbial biomass and diversity. Marketable yields were equal among tillage treatments in 2014, but higher for CT in 2015, with no difference between NT and ST. Preplant fertility increased yield in 2014, but yields were lower in the preplant fertility treatment in 2015. Leaf N concentration was higher in CT than NT and ST, but plant height, stem diameter, and dry weight were similar across all treatments. Soil temperature was generally highest for CT and higher in ST than NT in one out of three instances. Soil moisture was unaffected by tillage in 2014, but was higher under NT and ST from June to late-August in 2015. The rolled cover crop mulch in NT and ST plots effectively suppressed annual weeds during period between planting and the first weeding event, reducing weed biomass and density compared to CT. Nitrate-N concentration in leachate was reduced under NT and ST only during early sampling dates in 2014. Soil microbial biomass and diversity were similar among tillage treatments on most sampling dates, but consistently higher in the 0–7.5-cm than the 7.5–15-cm soil profile. Results indicate the potential for NT and ST yields to be comparable to CT, but temperature and nitrogen may limit yield under some circumstances. Though observed only periodically in this study, benefits of cover crops and reduced tillage to soil health and water quality make organic NT and ST systems promising in addressing current environmental concerns in agriculture.

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1. Introduction

Cover crops are widely used by organic farmers. According to the 2014 Organic Survey in the 2012 Census of Agriculture, 8400 out of the 12,595 certified organic farms used green or animal manures (USDA-NASS, 2015). Cover crops have been shown to provide many benefits to soil health and water quality. Soil benefits include reduced soil erosion (Kaspar et al., 2001), increased soil organic matter (Reicosky and Forcella, 1998), and symbiotically fixed nitrogen (N) from legume cover crops. Winter annual cover crops planted after a cash crop can scavenge nutrients and reduce nitrate leaching by up to 80% (Dabney et al., 2001; Staver and Brinsfield, 1998).

However, cover crops are typically incorporated into the soil using tillage before planting the following cash crop, thereby leaving soil vulnerable to erosion during the growing season (Magdoff and van Es, 2009). A non-tillage method for terminating cover crops in organic systems is rolling them flat with a roller-crimper during a particular stage of growth. Cover crops commonly used in this system are cereal rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth), which can be effectively killed when rolled at anthesis for cereal rye (Ashford and Reeves, 2003)

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and early pod stage for hairy vetch (Mischler et al., 2010). If sufficient biomass is produced, the rolled cover crop mulch can provide season-long annual weed suppression (Silva, 2014; Smith et al., 2011) for a cash crop planted through the mulch using no-till (NT) methods. This system enables NT production of organic crops by replacing the need for herbicide with weed-suppressive cover crop residue.

While several studies of organic NT vegetable production have shown NT can produce equal or superior yields compared to conventional tillage (CT) (Creamer et al., 1996; Delate et al., 2008; Delate et al., 2012; Lounsbury and Weil , 2014; Vollmer et al., 2010), others found that NT reduced yield (Delate et al., 2003; Díaz-Pérez et al., 2008; Leavitt et al., 2011). Yield reductions in these systems may be explained by reduced soil temperature and nitrogen availability (Delate et al., 2003; Griffith et al., 1988; Leavitt et al., 2011). Strip tillage (ST) is a hybrid of NT and CT, where tillage is restricted to a narrow band centered on the crop row. In a cover crop-based system, the rolled mulch is retained between strips, thus providing many of the benefits of NT within that region. Strip tillage can provide soil temperatures equal to those of CT (Licht and Al-Kaisi, 2005), but not necessarily if CT treatment includes plastic mulch (Tillman et al., 2015). Thomas et al. (2001) reported that yields of ripe processing tomato fruit were equal in CT and ST, but reduced under NT. Based on these findings, we hypothesize that ST may produce a higher yield than NT, in part due to increased soil temperature.

While warmer soil in strips may play a role in increasing N availability through more rapid mineralization of soil organic matter (MacDonald et al., 1995), the rolled cover crop mulch in both NT and ST systems poses challenges for N management. First, the high carbon-to-nitrogen (C:N) ratio of mature rolled cereal cover crops may significantly increase immobilization of N through at least the first six weeks after planting, compared to a CT system (Wells et al., 2013). A biculture of a cereal and a legume cover crop may lower the C:N ratio, and thus the immobilization potential (Ranells and Wagger, 1996), without reducing the weed suppressive capacity of the residue (Burgos and Talbert, 1996). Second, the physical obstruction of the cover crop mulch prevents mechanical sidedressing of granular fertilizers. Schellenberg et al. (2009) found that hand-applying a sidedress application of organic fertilizer increased yield of NT broccoli in a rolled cover crop system, but this practice would be impractical on large commercial scale. We hypothesize that fertigation could be a better method of delivering nitrogen to the crop in presence of surface mulch in NT systems.

While yield is of primary interest to growers, maintenance of soil health is essential to agricultural sustainability. Long-term NT crop production has been shown to improve soil health (Karlen et al., 2013), although improvements in soil health can be difficult to quantify during the relatively short duration of most field experiments. Indicators of soil health, such as microbial biomass and diversity, are considered more sensitive to management and thus useful tools in shorter timeframes (Bending, 2004; Schloter et al., 2003). Numerous studies have found that NT can increase microbial biomass in surface soil (Alvarez et al., 1995; Carter and Rennie, 1982; Doran, 1987), while not affecting or reducing microbial biomass of deeper regions in soil. This may have to do with the concentration of carbon (C) substrates (plant residues) on the soil surface, and more consistent soil moisture due to surface residue in NT systems (Doran, 1980). There may also be differential microbial responses in the tilled in-row (IR) region and untilled between-row (BR) region in ST. Overstreet and Hoyt (2008) found greater microbial biomass in the BR region than the IR region in an ST system after 10 years of management.

While total microbial biomass is a useful metric to assess microbial health of the soil, it does not account for diversity or activity of those organisms. Community-level physiological profiling (CLPP) uses sole-source-C substrate utilization as a measure to assess relative functional diversity of culturable soil microorganisms in soils from different treatments (Zak et al., 1994). Two such measures are substrate richness (S), which indicates the number of unique substrates oxidized by soil microbes, and average well color development (AWCD), which reflects both substrate richness and the respiratory activity of those communities. Govaerts et al. (2007) found that an NT system with retained plant residues increased AWCD compared to CT or NT with residues removed. Increased microbial diversity is also associated with suppression of plant pathogens and increased terrestrial resilience during periods of abiotic stress (Brussaard et al., 2007), which will be an increasingly important feature of agroecosystems as weather patterns become more volatile due to climate change.

In addition to agriculture's effect on soil health, impact on water quality is also coming under increasingly public scrutiny. A hypoxic zone in the Gulf of Mexico has been increasing in size since the 1960s (Diaz and Rosenberg, 2008), and nitrate and phosphorus lost from agricultural fields are major contributors (Burkart and James, 1999). Many states, including Iowa (Iowa State University, 2015), have enacted strategies aimed at reducing nutrient loading of the Mississippi River watershed from agricultural land, with a primary focus on nitrate. Cover crops (Constantin et al., 2010; Feyereisen et al., 2006), reduced tillage (Dinnes et al., 2002), and orgnic management (Cambardella et al., 2015) can be effective tools to reduce nutrient pollution coming from farm fields via leaching and erosion. However, the effect of NT has varied, with Constantin et al. (2010) finding only a small difference between NT and CT, and Oorts et al. (2007) finding no difference at all. Few studies have quantified the effects of organic NT and ST systems, which integrate cover crops with reduced tillage, on nitrate leaching.

In this study, we sought to obtain a holistic understanding of how different degrees of reduced tillage affect yield and growth of bell pepper plants, soil health as indicated by microbial biomass and diversity, and the nitrate concentration in leachate. Bell peppers are widely grown in the United States and according to the 2012 Census of Agriculture, over 844,681 t of field-grown bell peppers were harvested from 22,257 ha in the U.S. (Correll and Thornsbury, 2013). We were particularly interested in whether ST would 1) increase soil temperature and nitrogen availability, 2) increase yield, and 3) not adversely affect soil health, as compared to NT. To this end, we conducted a two-year field study to compare organically managed CT, NT, and ST systems and two fertilization regimes in production of bell pepper.

2. Materials and methods

2.1. Site description

The study was carried at the Iowa State University Horticulture Research Station in Ames, IA, in 2013–14 and 2014–15. The soil types for the first year of the study were Clarion and Nicollet loams (fine-loamy, mixed, superactive, mesic Typic Hapludolls) with 2.5% organic matter. The site was previously planted to demonstration plots of oilseed radish (*Raphanus sativus* L.), yellow mustard (*Sinapis alba* L.), and cereal rye (*S. cereal* L.), after which it was fallow for 3 months before cover crops were established for this study in Sept. 2013. Due to the need to establish the cover crop for the second growing season before completion of pepper harvest in the first year, the plot location was changed in 2015. The soil type at the 2014–15 site was Lester loam (fine-loamy, mixed, superactive, mesic Mollic Hapludalf) with 2.5% organic matter. The prior crop was organically managed alfalfa, which was terminated four weeks prior to cover crop establishment.