Geoderma 328 (2018) 30–43

Contents lists available at ScienceDirect

Geoderma

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

No-till and cropping system diversification improve soil health and crop yield

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ARTICLE INFO

Handling Editor: M. Vepraskas

Keywords:
No-till systems
Cropping systems
Soil health

ABSTRACT

The performance of no-till (NT) in temperate regions may be enhanced through the integration of additional conservation practices such as cover cropping and crop rotations. This study assessed the long-term impacts of continuous (20+ years) NT in comparison to plow-till (PT) management on soil properties and corn (*Zea mays* L.) yields in New York. The effects of tillage were assessed in combination with different cropping systems (24 years corn monoculture vs. 12 years corn monoculture; and with or without interseeded cover crops) on three soil textures: clay loam, loamy sand and silt loam. We measured four soil biological indicators - organic matter (OM), active carbon (ActC), respiration (Resp) and protein (Prot); four soil physical indicators - available water capacity (AWC), water stable aggregation (WSA), penetration resistance (PR) and water infiltration rate (InfRate); soil chemical indicators (plant available nutrients, pH and total N), and corn yield. Soil managed under long-term NT showed the most favorable soil biological, physical and chemical conditions for plant development, with higher levels of OM, Prot, Resp, WAS, total N, P and Zn, and InfRate. Benefits of introducing a grass-legume cover crop mixture into the cropping system were evident after 4 years for OM, Prot, Resp, AWC, Fe and Zn. Cover crop effects were greater under NT than PT, and additive to the NT benefits. On the clay loam soil, the effects of a 6-year interruption of continuous corn production with a perennial grass crop were still discernable with several soil health indicators 12 years after resuming corn production under NT. The better soil conditions under NT resulted in higher corn yields in both the loamy sand and silt loam soils, but not the clay loam. Our study shows that long-term NT can be viable in temperate regions, promoting significant improvement in soil health and crop yield and that these benefits are enhanced when NT is combined with crop rotation (perennial grass) and cover crops.

1. Introduction

Plow-till (PT) management under temperate conditions is normally practiced to accelerate soil warming and water evaporation in the spring, incorporate surface materials, and temporarily improve soil physical conditions for plant establishment and growth. However, soil changes by intensive tillage may actually do long-term harm by degrading soil for crop growth and increasing environmental degradation potential (Reicosky et al., 2011; Lal, 2015). The PT can decrease soil aggregate stability and soil macroporosity, increase soil compaction in the soil subsurface (Kinoshita et al., 2017), and promote soil surface crusting after tillage (Unger, 1992). Hence, PT might decrease the depth of root growth and soil water infiltration, and increase soil erosion (Baumhardt et al., 2015). In fact, soil erosion is one of the biggest challenges of PT systems, having on-farm and off-farm impacts: reduced soil depth, impairing the land productivity, and transporting sediments thereby degrading streams and lakes (Baumhardt et al., 2015).

Intensive tillage is also damaging to soil biological properties (Martínez et al., 2016a; Kumar et al., 2017; Alhameid et al., 2017). Past studies have shown that it accelerates biological decomposition of plant biomass due to higher availability of oxygen and by exposing older physically-protected soil organic carbon (OC); reduces organic matter

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Abbreviations: NT, no-till; PT, plow-till; OM, organic matter; ActC, active carbon; Resp, respiration; Prot, protein; AWC, available water capacity; WSA, water stable aggregation; PR, penetration resistance; InfRate, water infiltration rate; N, nitrogen; OC, organic carbon; CC, cover crops; NC, no cover crops; TCM, time of corn monoculture; TN, total nitrogen; TC, total carbon

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https://doi.org/10.1016/j.geoderma.2018.04.031
Received 2 January 2018; Received in revised form 27 April 2018; Accepted 29 April 2018
0016-7061/

(OM) content in the topsoil layer (Kumar et al., 2017), increases CO_2 emissions (Melland et al., 2017) and decreases both soil ability to retain nutrients and soil physical conditions (Martínez et al., 2016a; Alhameid et al., 2017).

In the 1930's reduced tillage began to be adopted in the United States of America (USA) as an option to reduce wind and water erosion, which was generating catastrophic erosion levels during the Dust Bowl (Kassam et al., 2015). In addition to reducing soil erosion, converting soil tillage management from PT to no-tillage (NT) may also improve soil health under temperate conditions and provide additional environmental and economic benefits (Soane et al., 2012; Kassam et al., 2015; Wittwer et al., 2017). We define soil health as "the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans" (Natrual Resources Conservation Services: Soil Health, 2012). When managed with other conservation practices like cropping system diversification through the inclusion of perennial crops and cover crops, NT may increase OM content, microbial biomass, and enzyme activity (Sharma et al., 2013; Kinoshita et al., 2017). These positive effects are promoted in part by an increase in biomass produced by cover crops. In addition, a decrease in OM mineralization may occur due to the effects of NT on soil processes and an absence of residue incorporation into the soil (Dabney et al., 2001; Lal, 2004; Alvarez and Steinbach, 2009). Conservation management practices can also stimulate formation and preservation of water stable aggregates (Bottinelli et al., 2017), which improves retention and movement of water in the soil system (Dairon et al., 2017). In the long-term, NT may also increase continuity and connectivity of soil pores, which impact diffusivity and permeability of air in the soil (Martínez et al., 2016a).

Currently, NT is practiced on > 150 million hectares worldwide (Kassam et al., 2015), with highest adoption levels in South America and Oceania. In this respect, the expanse under permanent NT relative to the total cropland area is approaching 100% in Argentina, Paraguay and southern Brazil, but still around 12% in the USA and 3% in Europe (year database 2013 - Kassam et al., 2015). The limited adoption of conservation agriculture systems in temperate conditions has been linked to lower soil temperatures and higher moisture content in the spring causing delayed drilling of spring-sown crops (Soane et al., 2012). Other factors that are limiting NT adoption in temperate regions include limited use of complementary conservation practices that enhance NT benefits, (Scopel et al., 2013) and the fact that available information on NT tends to be based on short-term and monocultural field experiments, which can produce results that are not typical for commercial production environments (Soane et al., 2012).

Increases in biological diversity by introducing cover and perennial rotation crops may enhance soil health and thereby increase the viability of NT systems. Polycultures lead to agroecosystems with greater multifunctionality (Finney and Kaye, 2017). The maximization of functional diversity promotes higher crop yield under NT with crop rotation compared to monoculture under temperate (DeFelice et al., 2006) and tropical climates (Pittelkow et al., 2015). In a global meta-analysis (5463 paired yield observations from 610 studies) comparing NT and PT with and without other conservation practices, (permanent soil cover by crop residues or cover crops, and crop rotation), Pittelkow et al. (2015) showed that NT under cropping system diversification can produce equivalent or greater yields than PT. Perennial and cover cropped rotations can exploit seasonal niches and thereby increase the perenniality of crop rotations (King and Blesh, 2018). Consequently, it may promote advances in functional ecology, making the NT system viable under temperate conditions.

The measurement of soil health over time through indicators that represent soil processes can be used to assess sustainable land management (Karlen et al., 1997). It expands on traditional soil testing, which has largely focused on the measurement of chemical soil properties (i.e., soil pH and nutrient contents) to evaluate soil fertility (Karlen et al., 2003; Moebius-Clune et al., 2016). The latter approach has proven useful for increasing agricultural production, but the narrow chemical focus has been a contributor to physical and biological soil degradation (Tilman et al., 2001; Andrews and Carroll, 2001; Karlen et al., 1997). This inadequacy spurred the development of more comprehensive assessment of soil health that evaluates multiple physical, biological, and chemical soil properties with an emphasis on those that are most sensitive to land management practices and correlated to ecosystem processes (Karlen et al., 2003).

The Comprehensive Assessment of Soil Health (CASH) approach was developed for the identification of specific soil constraints in agroecosystems as it relates to land productivity and potential environmental impacts. The CASH provides standardized, field-specific information on agronomically important constraints (Fine et al., 2017) and is an integral part of a broader soil health management planning framework. It offers measurement of physical indicators (wet aggregate stability, available water capacity, and penetration resistance), biological indicators (contents of organic matter, active carbon, extractable protein, soil respiration), and chemical properties (pH and available nutrients; Moebius-Clune et al., 2016).

There is a need to quantify long-term tillage and cover/rotation cropping effects on soil health in temperate regions (Soane et al., 2012). This kind of information may provide insight into the viability of these systems and perhaps help increase NT adoption and improve ecosystem services and global food security. We hypothesized that, under temperate conditions, (i) long-term continuous NT promotes better soil health than PT; (ii) the effects of NT are enhanced with the inclusion of cover or rotation crops; and (iii) these effects can enhance crop yields.

2. Materials and methods

2.1. Study sites

This study was carried out on three controlled field trials at the Cornell University Experimental Farms located in Willsboro and Aurora, New York, USA. In Willsboro, two long-term experiments were conducted, each on widely different soil types (Table 1): a Muskellunge clay loam [fine, mixed, active, frigid Aeric Epiaqualf (Gleyic Luvisol –

Table 1
Particle size distribution for the three soils studied.

Depth	Muskellunge clay loam			Stafford loamy fine sand			Honeoye-Lima silt loam		
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
cm		---%---			---%---			---%---	
5	44.5	17.1	38.4	79.8	10.1	10.1	47.9	36.8	15.3
15	42.3	15.3	42.4	80.6	10.0	9.4	48.0	37.3	14.8
25	29.3	16.8	53.9	86.9	5.8	7.3	48.0	37.8	14.2
35	12.2	26.4	60.8	84.8	5.5	9.7	49.0	36.6	14.4
45	4.8	27.5	67.7	73.8	12.0	14.2	50.0	35.4	14.6
65	6.6	24.1	69.3	50.3	20.9	28.8	37.1	31.8	31.2
85	3.2	16.4	80.4	6.7	20.6	72.7	38.7	33.7	27.6