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Research Letter

Intensive Tillage Converting Grassland to Cropland Immediately Reduces Soil Microbial Community Size and Organic Carbon

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Core Ideas

- Decreased CRP funding is resulting in US grassland being tilled.
- Intensive tillage of grassland rapidly decreases soil health indicators.
- One month after tilling grassland surface microbial biomass (0–10 cm) decreased 52%.
- Soil organic C decreased by 20% in the top 30 cm after one growing season.
- Alternative grassland conversion methods are needed to sustain soil health.

Abstract: Intensive tillage of grassland has negative long-term effects on soil health, but little data exist to understand how quickly this decline occurs. We sampled a commercial field in the semiarid Southern Plains of the United States before and after tilling grassland and compared the results to adjacent row crop and perennial grass fields. Within the first month of tillage, we detected losses of 52% of microbial biomass C (505 to 241 mg kg^{-1} soil), 33% of organic C (11.6 to 7.78 g kg^{-1} soil), 30% of total N (1.09 to 0.760 g kg^{-1} soil) and 64 to 70% of β-glucosidase and phosphodiesterase activities. The rapid decreases in these soil health indicators demonstrate that tillage management decisions are crucial for maintaining soil health if perennial grasses are converted to row cropping.

Perennial grasslands combine four soil health principles—minimization of disturbance, maximization of soil cover, increasing of biodiversity, and maximization of a living root system—and are therefore vital to soil health in the US Southern Plains (USDA–NRCS, 2018). Reintroduction of perennial grasslands, primarily under government-funded conservation initiatives such as the Conservation Reserve Program (CRP), were initially designed to mitigate soil erosion, but their large-scale benefit to soil health has recently been recognized (Li et al., 2017, 2018). Funding reductions, however, have decreased CRP enrollment in the United States from a peak of 14.2 million ha in 1995 to 9.5 million ha in 2017, with an additional 5.7 million ha set to expire between 2018 and 2022 (USDA–FSA, 2017a, 2017b). Many of these grasslands are being returned to row crop production through intensive tillage that causes long-term decreases in soil organic C (SOC), microbial biomass, and biodiversity (Schimel et al., 1985; Calderón et al., 2000; Acosta-Martínez and Cotton, 2017). However, little is known about the rate at which this occurs in the short term.

After a fortuitous interaction with a producer, we were able to collect soil samples within a commercial field that had perennial grasses for over 10 yr just before intensive tillage was used to convert it to row cropping during spring 2017. We then sampled throughout the growing season to quantify short-term changes in a number of soil health indicators. Adjacent row crop and perennial grass sites were sampled at the same time to serve as controls. Since this grower was not converting any other grassland areas, we could not replicate this one-time unique opportunity, but by combining before-and-after sampling with adjacent controls, we were able to increase our understanding of how rapidly the soil microbiome and overall soil health can be changed by a major disturbance such as tillage of long-term perennial grasslands. For this evaluation, we measured microbial biomass C (MBC), community composition

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Abbreviations: CRP, Conservation Reserve Program; EL, ester-linked; FAME, fatty acid methyl ester; MBC, microbial biomass carbon; SOC, soil organic carbon; TN, total nitrogen.

via ester-linked fatty acid analysis (EL-FAME), SOC, total N (TN), and enzyme activities. We believe this information will stimulate new strategies regarding conversion of grassland to row crops that will maintain soil health benefits obtained through public investment in conservation programs, including CRP.

Materials and Methods

Site Description and Soil Sampling

The US Southern Plains in Texas is a warm, semiarid region (470 mm precipitation annually) with mostly sandy soils primarily under tilled cotton (*Gossypium hirsutum* L.) production. The 33.5-ha conversion site is located in Lamb County, 11 km east of Littlefield, TX, and had been under perennial grasses for over 10 yr and grazed by cattle just before conversion. This site was tilled four times before planting using an in-furrow switch breaking plow for initial deep tillage (>45 cm) followed by a tandem disking two times to break up large clods; then rows (102 cm spacing) were plowed to a depth of ~25 cm. The site was planted with cotton during May 2017, which failed due to a lack of precipitation. It was then replanted with corn (*Zea mays* L.) during June 2017, which was harvested during November 2017. The long-term crop control (30.4-ha) site has been managed using reduced tillage, with cotton as the primary crop and winter cover crops and corn planted secondarily. The grassland control (14.1 ha) has been under CRP since 1986. Both the converted grassland and row crop control sites are dryland and have an Olton loam soil (fine, mixed, superactive, thermic Aridic Paleustolls), with an average of 49% sand, 30% clay, and 21% silt (0–30 cm). The perennial grassland control has a Portales loam (fine-loamy, mixed, superactive, thermic Aridic Calciustolls), with 64% sand, 23% clay, and 13% silt. All sites were within 500 m and were sampled (0–10 and 10–30 cm) monthly from March 2017 (T0, before tillage) through November 2017 (T8). Each time, four samples were taken along a 100-m transect, with each sample consisting of a composite from three nearby locations.

Soil Health Indicators

Soil organic C and TN were determined by automated dry combustion using a Leco TruSpec CN by Ward Laboratories, Inc. Soil microbial measurements used as indicators of soil health are well established and have been used in our other studies of agroecosystems in this region (e.g., Cotton et al., 2013; Acosta-Martínez and Cotton, 2017). Microbial biomass C was determined using the chloroform fumigation-extraction method (Brookes et al., 1985; Vance et al., 1987). We used EL-FAME (Schutter and Dick, 2002) to characterize soil microbial community composition with Microbial ID, Inc., PLFA naming software. Two enzyme activities were evaluated to provide information on C (β-glucosidase) and P (phosphodiesterase) cycling (Tabatabai, 1994). Results are presented as means for four field subreplicates at each site and sampling time.

Results and Discussion

Initial Soil Health Indicator Response to Tillage

Comparisons of T0 and T1 within the surface 10 cm show that MBC was reduced by 52% (from 505 to 241 mg kg^{-1} soil), SOC was reduced by 33% (from 11.6 to 7.78 g kg^{-1} soil), and TN was reduced by 30% (from 1.09 to 0.760 g kg^{-1} soil) within 1 mo after tillage (Table 1). To further illustrate the magnitude of changes due to intensive tillage, ratios of indicator values from the converted site and adjacent grassland control were calculated. These showed that prior to tillage, MBC, SOC, and TN were higher in the converted site compared with the grassland control, likely because of higher silt

Table 1. Soil health indicators and converted to grassland ratios, as well as adjacent cropland reference values, before and after intensive tillage.

Time (months)	Organic C			Total N			Microbial biomass C			Ratio converted/grass		
	Converted	Control		Converted	Controls		Converted	Controls		Organic C	Total N	Microbial biomass C
	Grass → Crop	Grass	Crop	Grass → Crop	Grass	Crop	Grass → Crop	Grass	Crop			
	——— g kg^{-1} soil ———			——— g kg^{-1} soil ———			——— mg kg^{-1} soil ———					
					Soil depth 0–10 cm							
					Initial, before conversion tillage							
0	11.6 (0.48)†	9.63 (0.32)	6.43 (0.14)	1.09 (0.042)	0.881 (0.004)	0.702 (0.031)	505 (31)	359 (28)	240 (23)	1.21	1.23	1.40
					Postconversion							
1	7.78 (0.10)	9.97 (0.24)	6.96 (0.26)	0.760 (0.036)	0.814 (0.039)	0.718 (0.028)	241 (11)	333 (26)	220 (35)	0.78	0.93	0.72
2	7.77 (0.10)	9.79 (0.36)	6.81 (0.30)	0.716 (0.019)	0.951 (0.027)	0.693 (0.026)	196 (7.3)	552 (40)	360 (14)	0.79	0.77	0.35
3	7.47 (0.35)	9.52 (0.20)	6.54 (0.30)	0.704 (0.039)	0.894 (0.025)	0.696 (0.023)	257 (14)	654 (36)	391 (21)	0.79	0.79	0.39
8	7.28 (0.26)	9.57 (0.14)	6.80 (0.41)	0.667 (0.027)	0.874 (0.015)	0.672 (0.019)	294 (3.6)	469 (35)	199 (10)	0.76	0.76	0.63
					Soil depth 10–30 cm							
					Initial, before conversion tillage							
0	6.76 (0.07)	4.99 (0.16)	5.88 (0.05)	0.661 (0.004)	0.504 (0.018)	0.623 (0.028)	251 (6.9)	198 (13)	156 (4.4)	1.36	1.31	1.27
					Postconversion							
1	6.84 (0.06)	5.02 (0.26)	5.87 (0.16)	0.696 (0.024)	0.500 (0.010)	0.609 (0.050)	242 (14)	165 (7.0)	120 (10)	1.36	1.39	1.47
2	6.25 (0.18)	5.56 (0.16)	5.95 (0.32)	0.659 (0.026)	0.552 (0.016)	0.605 (0.024)	235 (7.0)	371 (22)	212 (21)	1.12	1.19	0.63
3	6.58 (0.14)	5.21 (0.16)	6.17 (0.12)	0.653 (0.016)	0.532 (0.009)	0.657 (0.020)	240 (21)	459 (11)	346 (6.2)	1.26	1.23	0.52
8	6.17 (0.12)	5.29 (0.10)	5.83 (0.14)	0.645 (0.013)	0.500 (0.022)	0.587 (0.007)	191 (35)	196 (11)	138 (8.1)	1.17	1.29	0.97

† Mean and standard error (in parenthesis) of four field subreplicates.

and clay content (51 vs. 36%), which has been found to be a strong positive predictor of SOC in grasslands in this region (Li et al., 2017). After tillage, however, these ratios dropped significantly, with ratios for the three indicators ranging from 1.21 to 1.40 before tillage to 0.72 to 0.93 1 mo after tillage. In other words, for example, before tillage the converted site had 40% more MBC than the grassland control, but 1 mo after tillage there was 38% less MBC in the converted site. When compared with the crop control site under the same soil type, SOC, TN, and MBC were still higher in the converted site after tillage. At the lower depth (10–30 cm), neither the values of the indicators nor the ratios with the controls were changed, indicating minimal soil layer mixing or increased soil O_2 effects at that depth.

Total FAMEs (0 to 10 cm) decreased significantly from 317 to 124 nmol g^{-1} soil after conversion, with decreases of 57, 40, and 8 nmol g^{-1} soil (40–60%) in saprophytic fungi, bacteria, and arbuscular mycorrhizal fungi markers, respectively (Fig. 1). The fungal/bacterial ratio changed slightly from 1.47 to 1.26. Little change was seen in FAME content at the 10- to 30-cm depth within 1 mo (data not shown). Significant decreases were found in β-glucosidase (70%) and phosphodiesterase (64%) activities following intensive tillage, reducing the potential nutrient cycling capacity of the soil (Fig. 2).

Growing Season Changes in Soil Health Indicators

Soil organic C and TN dropped fractionally throughout the rest of the growing season (T1 to T8) within the surface 10 cm (0.5 and 0.1 g kg^{-1} soil, respectively), for a total loss of 4.32 g kg^{-1} SOC and 0.423 g kg^{-1} TN (Table 1). Ratios for those properties confirmed the large initial loss, followed by much smaller losses throughout the growing season. Within the 10- to 30-cm depth, relatively small SOC and TN losses were seen after one growing season.

Microbial biomass C and total FAME within the surface 10 cm showed the same general trend of a large initial loss followed by smaller decreases when compared with either crop or grass controls regardless of seasonal precipitation-driven fluctuations (Fig. 1). The fungal/bacterial ratio showed an overall decrease from 1.47 to 0.94, suggesting the soil microbial community had relatively less fungal biomass. Enzyme activities remained relatively stable in soil after the large initial drop due to intensive tillage (Fig. 2).

Soil Health Implications of Grassland Conversion

Every property measured in the surface 10 cm showed the strong negative effects four tillage events used to convert perennial grassland to cropland had on soil health Not only was SOC rapidly degraded, but losses of soil microbial biomass, especially fungi, mean that the soil's capacity to form chemically diverse and stable soil organic matter was also decreased (Kallenbach et al., 2016). Using data from the cropland control under the same soil type as a baseline, the grassland conversion resulted in a 90% loss of the SOC gained from a 10-yr public investment in CRP during the first growing season. While it will always be difficult to maintain soil health under annual crops at the same level as perennial grasses, the trends documented in this study emphasize the importance of management decisions regarding the methods used for perennial grassland conversion.

In practical terms, losses of SOC in the semiarid Texas High Plains decrease infiltration and soil water holding capacity, limiting cotton yield as a significant amount of soil water used by plants during the summer is stored during the higher precipitation spring season. Furthermore, this region

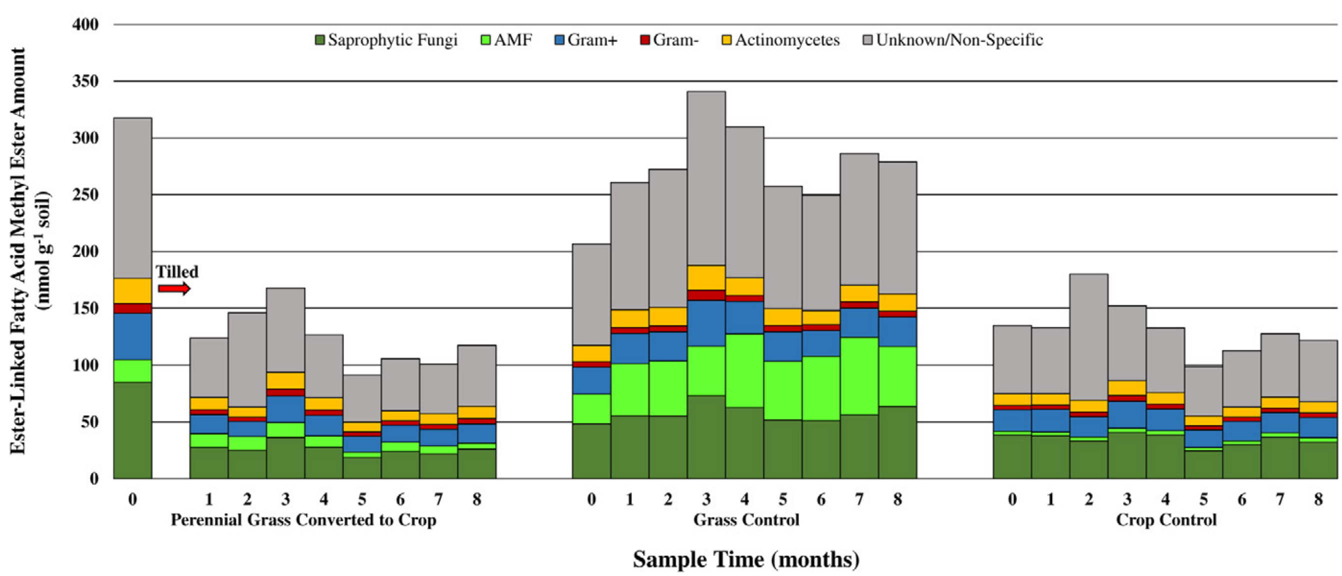

Fig. 1. Soil ester-linked fatty acid methyl ester (FAME) content (0–10 cm) before and after grassland conversion tillage compared with controls. The FAME indicators presented are sums of the following: saprophytic fungi (i18:0, 18:1ω5c, 18:1ω6c, 18:1ω7c, 18:1ω9c, 18:2ω6c, 18:3ω6c, 18:3ω6c), arbuscular mycorrhizal fungi (AMF, 16:1ω5c), Gram-positive bacteria (i14:0, a14:0, i15:0, a15:0, i16:0, a16:0, i17:0, a17:0, i19:0, a19:0), Gram-negative bacteria (i17:0 3OH, cy17:0ω6c, cy19:0ω7c), and actinomycetes (10Me16:0, 10Me17:0, 10Me17:1ω7c, 10Me18:0, 10Me18:1ω7c, 10Me19:1ω7c).

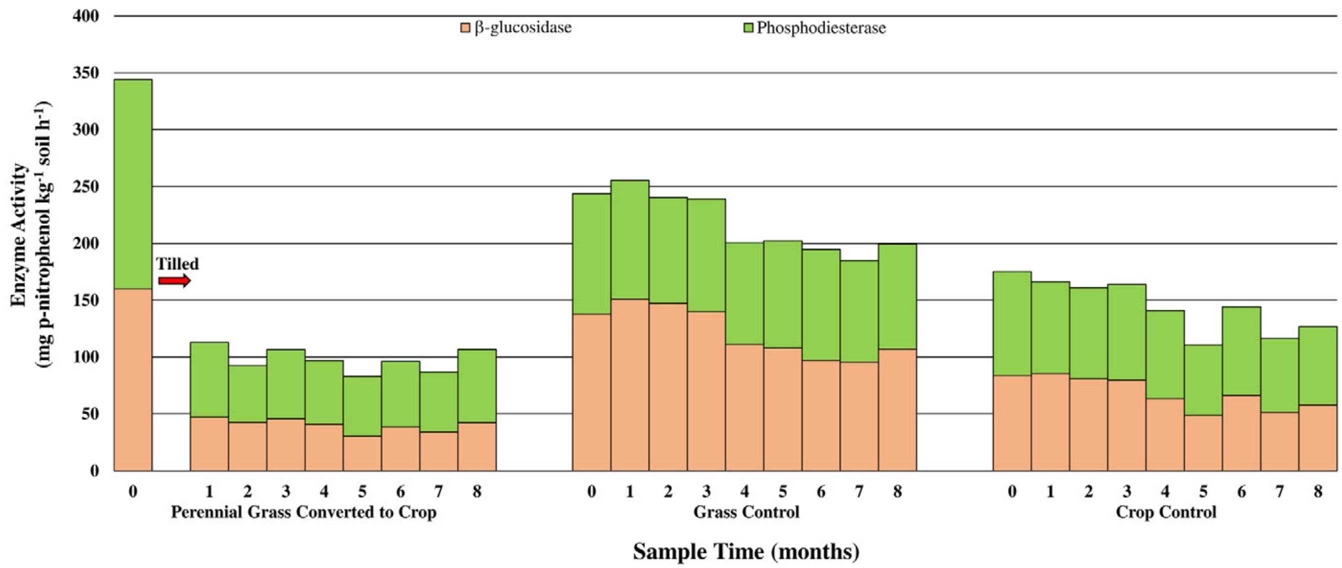

Fig. 2. Soil enzyme activities (0–10 cm) β-glucosidase (C cycling) and phosphodiesterase (P cycling) before and after grassland conversion tillage compared with controls.

has some of the highest aeolian erosion rates in the United States, so this type of intensive tillage conversion of grassland to cropland will create more dust sources, especially with more than 620,000 ha of CRP contracts being set to expire in Texas from 2018 to 2022 (Lee et al., 2012; USDA–FSA, 2017b). Therefore, when discussing soil health on a regional scale in terms of agricultural production, conservative management practices such cover crops, reduced tillage, and/or organic amendments will always be essential; however, another opportunity to improve and maintain soil health over large land areas would be to identify more innovative ways to return grassland to row cropping without intensive tillage.

Conclusions

This study documents the rapid negative impact on soil health indicators due to intensive tillage often used to convert a perennial grassland to cropland. Considering the large amount of land scheduled to come out of CRP contracts within the next four years, there is a tremendous opportunity for research and development of innovative agronomic practices that can have a more positive effect on both large-scale soil health and agricultural production. Assuming soil health benefits of a public investment in CRP is a priority, these results show that the initial conversion process is more important than any subsequent cropping or soil management practices that can be implemented by land managers.

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