Soil health changes from grassland to row crop conversion in the Northern Great Plains

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Figure 1, Test plots for a grassland conversion study with converted grassland on the left and native grassland on the right.

> In the Northern Great Plains, vast amounts of native grassland have given way to crops, mostly small grains and corn, over the past half century. It is less clear, however, what short-term effects occur to the soil from grassland conversion. Research was conducted to assess the short-term effects of converting land that is considered long-term grassland to small-grain production through either conventional tillage or no-till practices using various indicators of soil health and to demonstrate how tools such as the Comprehensive Assessment for Soil Health (CASH) was used to document soil health indicator decline immediately upon conversion from grassland to small grains.

The Northern Great Plains (NGP) landscape is a mosaic of land uses. The NGP comprises 24% of the farmland and nearly 30% of range and pastureland in the United States (USDA, 2018). As a land use priority, grasslands and row crop acreage are often at odds. Indeed, temperate grasslands are commonly thought of as one of the most threatened biomes globally—risking the loss of an extremely biodiverse ecosystem and habitat to numerous threatened and endangered species (Hoekstra et al., **2004**).

Grassland displacement for crop production has occurred rapidly over the last half century where an estimated 60% of all native mixed-grass prairie in South Dakota, North Dakota, and Montana have been converted to cropland (Higgins et al., 2002). Between 2008 and 2012, nearly 7.4 million acres of previously uncultivated land was transitioned to cropland nationwide (Lark et al., 2015). Of these 7.4 million acres, 77% was converted from grasslands, located largely in the NGP. Recent research found that as much as 5% of the entire NGP grassland was being converted to cropland each year during this same time period (Wright & Wimberly, 2013). While this trend has slowed somewhat since the period of this study, it still remains a critical issue (Gage et al., 2016).

Land use change is a dynamic process across the NGP—driven by economic forces often underwritten by governmental policies. Programs such as the Sodbuster Provision and the Conservation Reserve Program (CRP), authorized within farm bills, significantly influence the extent of land that is brought into or out of production in any given time period. However, funding for CRP has steadily decreased as Cotton and Acosta-Martínez (2018) noted that CRP enrollment has dropped from a high of 35 million acres in 1995 to 23.5 million acres in 2017 with further decreases expected through 2022. Moreover, a significant portion of this land is returning into production agriculture. It is likely that this land use change has significant environmental impacts, and it is unclear what the impacts are to either soil health or ecosystem functioning as a whole.

The vast majority of grassland conversion across the NGP is for the purposes of growing wheat, corn, and soybeans (Gage et al., 2016; Lark et al., 2015). The method in which this land is converted is likely to have significant impacts on various soil functions. We know that the land manager is the ultimate determinant of soil quality and health; however, very little data exists highlighting the short-term effects of land conversion or tools that can be used by land managers to document this change.

For land managers to understand the impacts resulting from land conversion, simple, comprehensive tools are necessary to provide context to management decisions. One potential tool is the Comprehensive Soil Assessment Tool (CASH), which offers a suite of standard nutrient analyses along with physical and biological tests that represent critical soil functions (Moebius-Clune et al., 2016). The framework can be used to identify physical, chemical, or biological constraints due to management decisions. However, for it to be useful to land managers, it must be responsive on short time scales.

The objectives of this study were to use the CASH to assess the short-term effects of converting land that is considered long-term grassland—similar to that in a CRP contract—to small-grain production. Specifically, this experiment was designed to investigate if, and how, soil health declines are measurable immediately following grassland conversion to row crops using either tillage or no-till practices and if the CASH is a viable tool to document changes in critical soil function.

Experiment Design

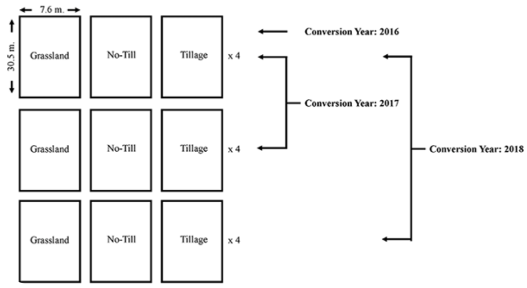

Figure 2, *Plot layout depicting sequential conversion of grassland to row crops by either tillage or no-till methods for each year*

(2016–2018) of the study period. 1 m = 3.28 ft.

A field experiment was conducted at the Cottonwood Field Station in western South Dakota. The research was conducted on a silty clay loam soil with a sand, silt, and clay content of 18, 49 and 33%, respectively (Kettler et al., 2001) and a slope of 0–2%. Grassland conversion took place using either conventional tillage (CT) or no-till (NT) practices. Plots were established in a sequential manner across three growing seasons between 2016 and 2018 (Figures 1 and 2). In each growing season, a new set of conversion plots was established and maintained along with the previous years' conversions. Therefore, the resulting dataset includes three years of "one year after conversion data," two years of "two years after conversion data," and one year of "three years after conversion" data. Precipitation and temperature for the study period were measured on-site (Figure 3). The established three-year crop rotation was hard red spring wheat (HRS, cultivar Surpass) in Year 1, followed by sorghum (cultivar KS-585) in Year 2, and then HRS in Year 3. Nitrogen was applied for both HRS and sorghum at planting as a mid-row band to both CT and NT as 28% urea ammonium nitrate at a rate of 120 lb N/acre, and phosphorus, sulfur, and zinc were applied with the seed as a starter application of 10-25-0-5-0.5 at a rate of 2.7 gal/ac.

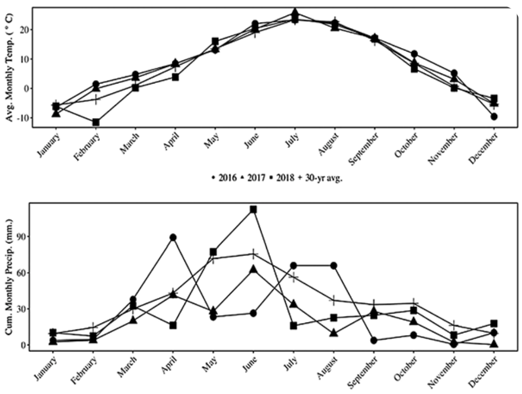

Figure 3, *Temperature and precipitation trends for the three-*

year study period (2016–2018) and 30-year climatological average for the study site. 1 °C = 33.8 °F. 1 mm = 0.04 inches.

The CASH approach was selected to assess soil health during grassland conversion. The focus of the current study is based on seven soil tests that can be broken down into physical, biological, and chemical indicators. Soil samples were collected in the fall following harvest of all crops. All soil replicates were based on a composite of 8 to 12 samples taken from a depth of 0 to 6 inches according to Moebius-Clune et al. (2016). Among soil parameters measured to assess soil health changes were the soil physical properties wet aggregate stability (WAS) and available water-holding capacity (AWC); the soil biological properties soil organic matter (SOM), permanganate oxidizable carbon (POX-C), autoclaved citrate extractable protein (ACE-Protein), and soil respiration (Figure 4); and the soil chemical property soil pH. Data were analyzed statistically using R (R Core Development Team, 2014). Significance was determined at P ≤.05 (unless otherwise stated) with means separation determined using the Tukey method. Linear correlations were determined using Pearson's correlation coefficient.

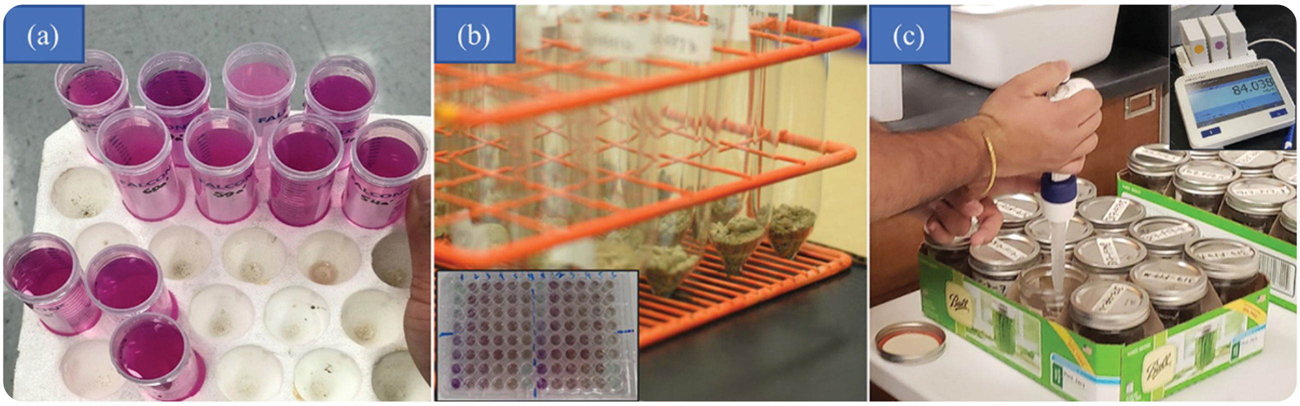

Figure 4, *Laboratory methods for (a) permanganate oxidizable carbon (POX-C), (b) ACE-Protein, and (c) soil respiration.*

Weather Trends

Temperatures during the study period did not vary significantly from long-term trends. However, all three years of the study were below the long-term average for precipitation—particularly in 2017. The yearly, cumulative growing-season precipitation was 77, 61, and 83% of the long-term average for 2016, 2017, and 2018, respectively (Figure 3).

Physical Indicators

Available water-holding capacity was not statistically different between the grassland control and either conversion method (Table 1). In the driest year for the study (2017), there were virtually no differences in AWC between the tillage practices. As precipitation increased, however, tillage had a greater influence, and larger differences were observed (Table 2). Nunes et al. (2018) and van Es and Karlen (2019) also failed to measure significant effects of tillage management, which is mostly influenced by inherent soil differences (texture and mineralogy) and less by management effects.

Tillage	AWC	WAS	SOM[§]	ACE-Protein	POX-C	Respiration	pH
	g H_2O/g	——%——		mg protein-N/g soil	mg C/kg soil	mg CO_2/kg soil	
Control	0.29	51.7a[a]	3.7	4.78ab	541.8	0.59a	6.55
NT	0.29	48.1ab	3.7	4.84a	519.2	0.53ab	6.36
CT	0.30	41.8b	3.5	4.31b	500.6	0.49b	6.44
SE[b]	0.01	5.2	0.4	0.75	69.2	0.06	0.26
p-value	.55	.02	.14	.03	.28	.02	.07

Note. AWC, available water-holding capacity; WAS, wet aggregate stability; SOM, soil organic matter; ACE-Protein, autoclaved citrate extractable protein; POX-C, permanganate oxidizable carbon.
[a]Different letters following means denote statistically different values based on Tukey's HSD test.
[b]SE, standard error of the mean.

Table 1. *Mean percent difference of the tillage effect from native grassland control across all site-years (n = 72) of the trial sampled at a depth of 0–6 inches.*

Conversion year	Tillage	AWC (g H_2O/g)	WAS (%)	SOM (%)	ACE-Protein (mg protein-N/g soil)	POX-C (mg C/kg soil)	Respiration (mg CO_2/kg soil)	pH
2016	Control	0.3	59.4	3.9	4.75	571.3	0.65a[a]	6.37
	NT	0.3	50.6	3.9	5.22	569.5	0.51ab	6.03
	CT	0.30	42.5	3.7	4.46	589.8	0.45b	6.23
	SE[b]	0.01	4.9	0.1	0.33	40.3	0.04	0.15
	p-value	.79	.10	.52	.24	.88	.008	.24
2017	Control	0.28	52.9	4.4	6.38a	647.3a	0.73	6.28a
	NT	0.28	55.6	4.2	5.72ab	603.8ab	0.65	6.12b
	CT	0.28	51.3	4.0	5.38b	543.3b	0.70	6.20ab
	SE	0.01	3.6	0.2	0.20	29.2	0.06	0.05
	p-value	.89	.44	.21	.02	.04	.42	.05
2018	Control	0.30a	42.8	2.9	3.23	406.8	0.39	7.0
	NT	0.32ab	38.2	3.1	3.57	384.4	0.44	6.93
	CT	0.33b	31.5	2.9	3.09	368.7	0.32	6.89
	SE	0.01	3.2	0.1	0.18	23.5	0.04	0.11
	p-value	.02	.09	.62	.21	.36	.14	.58

Note. AWC, available water-holding capacity; WAS, wet aggregate stability; SOM, soil organic matter; ACE-Protein, autoclaved citrate extractable protein; and POX-C, permanganate oxidizable carbon.
[a]Different letters following means denote statistically different values based on Tukey's HSD test.
[b]SE, standard error of the group mean.

Table 2. *Least squared means of measured soil health variables after the first growing season following conversion from grassland sampled at a depth of 0–6 inches.*

In contrast, WAS, a measure of the soil's ability to resist erosion and aggregate degradation, was strongly influenced by tillage. Wet aggregate stability decreased through both conversion methods, but to a greater extent in the CT plots, decreasing by 7 and 19% for NT and CT, respectively (Table 1). In a study of various management practices at long-term research stations across three different regions in North

Carolina and New York, van Es and Karlen (2019) and Nunes et al. (2018) also found strong WAS effects among management practices and negative relations with tillage intensity. Coming out of long-term grassland, it is likely that aggregation was more evenly distributed in the current study and thus susceptible to more invasive tillage practices (Rezaei et al., 2006).\

Biological Indicators

Soil organic matter (SOM) was on average always lower than the grassland control; however, no statistical differences were observed for any year of the study (Tables 3 and 2). Similarly, Grandy and Robertson (2006) found that total carbon changes were not detectable following tillage of uncultivated land. Permanganate oxidizable carbon is considered to be a more sensitive indicator to track such changes over various time periods. Similar to SOM, POX-C showed a downward trend with increasing tillage activity; however, overall, no statistical differences were found (Table 1). The decrease was most drastic during the driest year, 2017 (Table 3). Culman et al. (2012) found POX-C to be strongly correlated to other measures of soil carbon but also found that the sensitivity of POX-C to detect changes due to tillage was less robust than sensitivity to timing of sampling. Despite a general trend towards decreased POX-C with tillage, the current study found similar statistical results (Table 1). Some of this retained carbon is likely to be in the form of POX-C, which is considered to be a more labile fraction of SOM but maintains a strong correlation with SOM (Table 4).

Conversion year (field position)	SOM	ACE-Protein	POX-C	Respiration
	%	mg protein-N/g soil	mg C/kg soil	mg CO_2/kg soil
2016 Control (east)	3.76a[a]	4.06a	482.00a	0.43
2017 Control (central)	3.31ab	3.55ab	451.10ab	0.43
2018 Control (west)	2.94b	3.23b	406.75b	0.39
p-value	.09	.06	.05	.27

Note. SOM, soil organic matter; ACE-Protein, autoclaved citrate extractable protein; and POX-C, permanganate oxidizable carbon.
[a]Different letters following means denote statistically different values based on Tukey's HSD test.

Table 3. *Means for biologically active soil health variables from grassland control samples.*

	SOM	POX-C	ACE-Protein	Respiration
SOM	1.00			
POX-C	0.83	1.00		
ACE-Protein	0.89	0.84	1.00	
Respiration	0.89	0.68	0.79	1.00

Note. SOM, soil organic matter; ACE-Protein, autoclaved citrate extractable protein; and POX-C, permanganate oxidizable carbon.

Table 4. *Pearson correlation coefficient matrix for the biologically active portions of the Comprehensive Assessment for Soil Health (CASH). All correlations have significance level of p<.001.*

Comparatively, total ACE-Protein trended slightly lower in this study when compared with larger regional studies. Fine et al. (2017) found an average ACE-Protein of 5.5 mg protein-N/g soil across a range of soils from the Midwestern United States while our study had an average of 4.78, 4.85, and 4.31 mg protein-N/g soil for the grassland, NT, and CT treatments, respectively (Table 1). With a Pearson correlation of 0.89 and 0.84, ACE-Protein correlated strongly with SOM and POX-C, respectively (Table 4). Statistically, NT was greater than the CT while neither conversion treatment differed from the grassland (Table 1). These results suggest that tillage served to decrease the overall organic N pool.

Finally, the general decreasing trend observed in many variables with CT was similar for respiration. Respiration was significantly lower in the CT plots versus the grassland while NT was not statistically different (Table 1). In general, there were still fairly strong correlations between soil respiration and other biological indicators (Table 4). Franzluebbers et al. (2018) found a strong correlation between the flush of CO_2 and net N mineralization. In combination with the decrease of ACE-Protein and POX-C through CT, these results indicate that N availability may be limited to a greater extent in grasslands converted to small grains through intensive tillage.

Chemical Indicators

In contrast to other indicators, pH showed less variability across the field (Table 3). No-till plots had lower pH overall (average of 6.36 vs. 6.55 and 6.44 for the grassland and CT plots, respectively), which was exacerbated during the driest year of the study (Table 3). This pattern is well documented and typically ascribed to the ammonium-based fertilizers being left on the soil surface with NT; hence, a strong pH stratification (Reeves & Liebig, 2016).

Utility and Sensitivity of Soil Health Indicators

The different CASH indicators varied in their response to the treatment effects. However, when taken as a suite of indicators, these protocols can be used to measure soil health in relation to management effects. Strong correlation among indicators, particularly POX-C, ACE-Protein, and SOM, suggests that these measures are sensitive to short-term fluctuations in both carbon- and nitrogen-cycling processes to a varying extent; however, sufficient variability still exists within treatments both among and between years (Cooper et al., 2020). Traditional chemical approaches are effective in increasing agricultural production but fail to identify soil degradation. When combined, the CASH indicators serve as proxies for defining critical physical, biological and chemical properties important to agricultural production and correlated to ecosystem processes. These indicators can serve as benchmarks for targeted studies to determine mechanistic effects of ecological functioning following invasive interventions such as grassland conversion. Overall, our results suggest that the potential for soil health degradation during grassland conversion to row crops is likely to be more severe in dry years. However, these results only address the immediate consequences following conversion and do not address the potential ramifications over a longer time period.

Conclusion

Overall, it is evident that soil health potentially declines rapidly upon conversion from grassland to small grains. In general, the decline was greater under conventional tillage than no-tillage, and these effects occurred within the first year of conversion. This is an intuitive result given the well-documented effects of tillage on a number of different soil health indicators; however, this study provides new data documenting how quickly these changes begin to occur. Moreover, the CASH provides an intuitive framework for monitoring the effects of land use change and can be used by land managers to identify potential soil constraints and formulate potential interventions. These results suggest that several important soil health indicators—notably, wet aggregate stability, ACE-Protein, and soil respiration—are sensitive in the short term to conversion to row crops from grassland based on tillage method. The current study demonstrates how these measures serve as a set of interconnected and reinforcing indicators providing a basis for documenting soil degradation through tillage. Further study is required to establish more robust correlations among the tested soil properties and environmental outcomes.

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