ONE-TIME TILLAGE OF NO-TILL CROP LAND: FIVE YEARS POST-TILLAGE

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Abstract

Field research was conducted at two eastern Nebraska locations to test the hypotheses that one-time tillage of no till (NT) land results in increased grain yield, reduced stratification of available soil phosphorus but reduced wet aggregate stability, and increased soil organic carbon (SOC), without a long term effect on the soil microbial community. Research was conducted in long-term NT fields under rainfed corn [*Zea mays* (L.)] or sorghum [*Sorghum bicolor* (L.) Moench.] rotated with soybeans [*Glycine max* (L.) Merr.]. Tillage treatments were applied in the fall and included continuous NT, tandem disk (disk), chisel with 4" wide twisted shanks, moldboard plow (MP), and mini-moldboard plow (MMP). Bray-1 P was redistributed with tillage but tillage effects on stratification persisted for 5 years at one location only. Tillage did not have a long term effect on water stable soil aggregates. Cumulative emission of CO_2 during the weeks following one-time tillage was similar for MP, MMP, and NT. Stocks of SOC were not changed relative to NT at 2 and 5 years after one-time tillage. Tillage effects on microbial community structure persisted for 5 years at the 0- to 5-cm depth at one location only, with greater biomass of arbuscular mycorrhizae (AM), actinomycetes, and bacteria, but not fungi. Tillage resulted in reduce root colonization by AM but increased P uptake. One-time MP and MMP tillage resulted in a small but inconsistent increase in grain yield. One-time MP or MMP tillage of NT can be done in eastern Nebraska with a small yield increase and without detrimental or positive effects on soil properties.

Abbreviations

AMF, arbuscular mycorrhizal fungi; ARDC, Agricultural Research and Development Center; Ch8 or Ch12, chisel plowing with 4" wide twisted shanks at either 8 or 12" depth; FAME, fatty acid methyl ester; MMP, mini-moldboard plow; MP, moldboard plow; NT, continuous no-till; RMF, Rogers Memorial Farm; SOC, soil organic carbon.

Introduction

Continuous NT is beneficial relative to tillage with fewer field operations, reduced erosion, and surface soil improvement. An accumulation of P in the surface soil over years of NT may result in increased P runoff (Sharpley and Smith, 1994). The gains in SOC in NT compared with conventional tillage are greatest near the surface, but are often negative at lower depths (Doran, 1987) with the gains in SOC primarily during the first 10 years of NT (Paustian et al., 1997).

The objective of this study was to determine the effects on one-time tillage of NT land on grain yield, P distribution, SOC, water stable soil aggregates, and soil microbial communities over 5 years after one-time tillage. One-time tillage of NT fields was expected to reduce available P stratification (Sharpley, 2003), surface soil aggregate stability, and water infiltration rate. An immediate increase in CO_2 flux from soil was expected following tillage due to CO_2 release from soil aggregates and, later, with increased microbial activity.

Approach

Field research was conducted in eastern Nebraska with rainfed NT systems at Rogers Memorial Farm (RMF) (40^o50'44", 96^o28'18", 1270' altitude) and the Agricultural Research and Development Center (ARDC) (41^o10'48", 96 ^{o} 28'40", 1200' altitude). The upland loess soils were deep and well or moderately well drained with moderately slow permeability. Mean annual precipitation was 29".

The tillage treatments at RMF were: (i) moldboard plowing to 8" depth (MP); (ii) chisel plowing with 4" wide twisted shanks at either 8 or 12" depth (Ch8 or Ch12); (iii) disk; and (iv) continuous NT as the control (Table 1). At ARDC, tillage treatments were: (i) MP; (ii) Ch12; (iii) disk; (iv) mini-moldboard plowing to 8" depth but with less soil inversion than with MP (MMP); and (v) NT. Tillage was conducted in the fall when the bare soil temperature at 4" depth was 46 and 34^oF for RMF and ARDC, respectively. The plots were 80' long and either 15 or 20'wide. There were four replications.

Soil samples were taken in 4 increments to 12" depth to determine stratification of soil properties at ~0.5, 2 and 5 years after tillage. A portable gas exchange system (LI-6200 Portable Photosynthesis System, LiCor, Lincoln NE) was used to measure CO^2 flux during the minutes, hours and days after tillage. Total SOC and particulate SOC were determined for 5 depth increments to 12" depth shortly after the first planting and ~2 years after tillage, and total SOM was measured again at 5 years after tillage. Quantity of SOC was determined on an equivalent mass basis of 400 kg soil m^{-2} (~12" depth). The percentage of soil in water stable aggregates was determined at 2 and 5 years after tillage from soil samples collected between the rows avoiding wheel tracks. Water infiltration rates were measured with simulated rainfall of constant intensity using Cornell sprinkle infiltrometers (Ogden et al., 1997). Grain yield was determined from the harvest of 20' of the center two rows.

Microbial analysis involved extraction of total fatty acid methyl esters (FAME) from the soil by mild alkaline methanolysis and separation of FAMEs by capillary gas chromatography (Wortmann et al., 2008). FAMEs specific to microbial groups were used to estimate tillage effects on bacteria, actinomycetes, AM, and saprophytic fungi biomass in the soil. Microbial biomass was determined on an equivalent mass basis of 400 kg soil m^{-2} (~12" depth). Tillage effects on root colonization by AM were also determined in years 1 and 2 as indicated by the concentration of FAME C16:1cis11 (nmol g^{-1} root) (Garcia et al., 2007).

Results and Discussion

Stratification of soil properties. Soil properties were stratified with NT, especially Bray-1 P (Table 1) (Garcia et al., 2007). Stratification was reduced with MP tillage at RMF, but not with disk tillage. Some of the reduction in Bray-1 P with MP tillage in the 0-2" depth in 2005 was because only 4.5% of total P was Bray-1 extractible compared to 14.1% with NT. Much of the stratification had returned by 2008 for MP tillage although NT stratification had increased as well. Soil test P levels were low at ARDC, and although some stratification occurred with NT and available P was redistributed with MP, tillage effects on Bray-1 P were not significant in 2008. At both locations, however, plant P uptake at V6 was affected by tillage, and uptake was generally least with NT and most with MP tillage (Garcia et al., 2007). The effect on plant P uptake was less in R6 and less in the second year after tillage with the cereal crops compared with soybean in year 1.

Soil organic C. Total and particulate SOC concentration with NT was 33 and 412% more in the 0 to 1” depth compared with the 4 to 8” depth (Quincke et al., 2007a). Cumulative CO_2 emission was 3 and 2 times as great with MP compared with NT at 5 minutes and 4 hours after tillage, respectively. At 6 and 30 days after tillage, however, cumulative CO_2 emission was similar for NT and MP, but 64% higher with disk and chisel tillage at RMF. Cumulative emissions were low compared with some other studies as the one-time tillage was done in late fall with low soil and air temperature compared with in summer.

One-time MP and MMP tillage effectively redistributed total and labile SOC (Quincke et al., 2007a). Total and labile SOC concentrations were reduced by 24 to 88% in the 0 to 1” depth and increased by 13 to 381% for the 2 to 4” depth for the various tillage operations. Moldboard plowing caused the greatest redistribution of SOC. On an equivalent soil mass basis, tillage did not cause significant losses of total or labile SOC in the 0 to 12” depth between tillage and planting of the next crop or by 2 and 5 year after tillage using the equivalent mass approach (Fig. 1) (Quincke et al., 2007a; Wortmann et al., 2010). The mean amount of SOC across the two sites was 30.9 t/ac. We did not measure SOC below 12” and it is unlikely that the one-time tillage had significant effect on deep SOC. Stratification of SOC in long-term NT soil could be reduced most effectively by means of one-time MP tillage without increased loss or gain of SOC.

Soil microbial communities. One-time tillage of NT resulted in reduced colonization of AM colonization on crop roots at R6 (Garcia et al., 2007) (Table 2). The effect was more pronounced on soybean in year 1 compared with the cereal crops in year 2. Colonization was much less for sorghum compared with corn roots. Plant P uptake was not directly related to AM colonization except for soybean at R6 at ARDC where the correlation was negative, an unexplained result since Bray-1 P was low at this site compared with RMF. Tillage treatments apparently had other effects on plant P uptake that overcame the effects of reduced AM colonization. Another effect of one-time tillage was much increased root P concentration with MP compared with NT, more so at R6 than at V6 (Table 3). Root P concentration was negatively correlated with AM colonization at R6 for corn and sorghum, and for soybean at ARDC.

Soil microbial biomass was greater in the 0 to 2” soil depth compared with the >2” depth, especially for saprophytic fungi and bacteria (Wortmann et al., 2008; Wortmann et al., 2010). One-time tillage resulted in reduced microbial biomass in the 0 to 2” depth of surface soil. The reduction in biomass of bacteria, actinomycetes, and AM persisted until year 5 for MP at ARDC but the MP effects were no longer significant at RMF and with MMP at ARCD (Table 4).

The reduction of AM colonization of crop roots and of AM biomass with one-time tillage may have been due to disruption of the hyphal network reducing AM inoculum and because of high P concentration in roots and root exudates which is known to impede AM colonization (Mengue et al., 1978; Olsson et al., 1997). Given limited recovery of the AM during the 5 yr following tillage (Wortmann et al., 2010), it appears likely that both mechanisms decreased AM colonization. The persistent effect of MP for 5 years at ARDC on bacteria and actinomycetes is unexplained but may have been due to reduced particulate SOC in the surface soil.

Soil physical properties. Approximately 83% of the soil was in water stable aggregates > 0.002" in diameter at 2 years after one-time tillage (Quincke et al., 2007b). At the time there was no tillage effect on soil aggregates except for 11% less in micro-aggregates (0.002 to 0.01") with disking in the 0-2" soil depth compared with NT and MP. In year 5, there was no one-time tillage effect on soil aggregation at either location (Wortmann et al., 2010). Bulk density was not affected by one-time tillage at 2 and 5 years after tillage.

Soil hydraulic properties at 2 years after one-time tillage were inconsistently affected with sorptivity decreased and runoff increased at RMP with MP compared to NT (Quincke et al., 2007b). At ARDC, the reverse effect occurred with a higher rate of infiltration with MP and MMP tillage compared with NT. At RMF, traffic was confined to the same rows for several years previously while at ARDC traffic was less confined and corn stalks were grazed. Observations were made outside of recent traffic tracks. Equipment and cattle traffic history may account for the inconsistency in the results.

Grain yield. On average, grain yield over 5 years following one-time tillage was 4.8 and 7.9% more with MP and MMP compared with NT but effects were inconsistent and significant in only two site-years (Table 5) (Quincke et al, 2007b; Wortmann et al., 2010). Disk and chisel tillage did not result in increased yield. Grain sorghum yield in 2005 was greater with MP compared with one-time disk tillage and soybean yield at ARDC was greater with MMP compared with NT in 2008. One-time tillage effects were not significant at RMF for soybean in 2004, 2006, and 2008, and for sorghum in 2007; the respective mean yields were 63, 44, 38, and 74 bu/ac. One-time tillage effects were not significant at ARDC for soybean in 2004 and 2006, and for corn in 2005 and 2007; the respective mean yields were 52, 39, 111, and 150 bu/ac. The increase in yield was great enough to make one-time MP and MMP tillage profitable with typical price:cost ratios.

Summary

One-time tillage of continuous no-till land had little negative or positive effects except for an inconsistent but general increase in grain yield. Stratification of soil properties 5 years after tillage was only slightly less with MP at RMF, which was the more stratified location, and similar at the ARDC compared to NT. Water stable soil aggregates were not much affected. Water infiltration rate was increased with MP and MMP at the location with less controlled traffic but decreased by MP at RMF. Tillage treatments had no effect on SOC mass in the 0 to 12" depth. One-time MP tillage reduced microbial biomass but there was no evidence that this decrease adversely affected productivity or other soil properties. One-time tillage of NT can generally be done without a negative effect on long-term yield or on the soil properties measured.

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Table 1. The effect of one-time tillage of no-till land on soil Bray-1 P at Rogers Memorial Farm (RMF) in eastern Nebraska (from Garcia et al., 2007).

Soil depth, in	***Disk***	***MP***	No-till
		2005	
0-2	45.0ab	20.0cd	59.7a
2-4	22.7bc	26.7c	12.0bc
4-8	8.0cd	13.3cd	7.3cd
8-12	4.7d	5.3d	6.0d
		2008	
0-2	56.3a	40.1b	71.5a
2-4	19.0c	12.9cd	21.2c
4-8	6.2cd	7.9cd	8.2cd
8-12	4.8cd	4.1d	5.5cd

Letters denote differences between tillage treatments (P = 0.05) within years.

Table 2. One-time tillage effect of no-till land on arbuscular mycorrhizae colonization (as indicated by C16:1cis11 concentration, nmol g^{-1} root) of crop roots at R6, one and two years after tillage, at the Rogers Memorial Farm (RMF) and the Agricultural Research and Development Center (ARDC) in eastern Nebraska.

	Soybean 2004	***Corn 2005***	***Soybean 2004***	***Sorghum 2005***
	ARDC		**RMF**	
Chisel tillage, 12”	477	500	857	63
Disk	350	361	901	140
Moldboard plow	362	501	515	19
No-till	1319	987	1108	228
LSD (0.05)	371	207	180	116

Table 3. One-time tillage effect of no-till on root P concentration (%) of soybean in 2004 and corn and sorghum in 2005 at R6 at the Agricultural Research and Development Center (ARDC) and Rogers Memorial Farm (RMF) in eastern Nebraska.

	Soybean 2004	***Corn 2005***	***Soybean 2004***	***Sorghum 2005***
	ARDC		**RMF**	
Moldboard plow	0.053a	0.296a	0.165a	0.224a
No-till	0.039b	0.158b	0.095b	0.114b

Letters denote differences between tillage treatments (P = 0.05) within crops and locations.

Table 4. Percent change in biomass of microbial groups with one-time tillage relative to continuous no-till, at years 1, 2, or 5 after tillage at Rogers Memorial Farm (RMF) and the Agricultural Research and Development Center (ARDC) in eastern Nebraska (From: Wortmann et al., 2008, 2010).

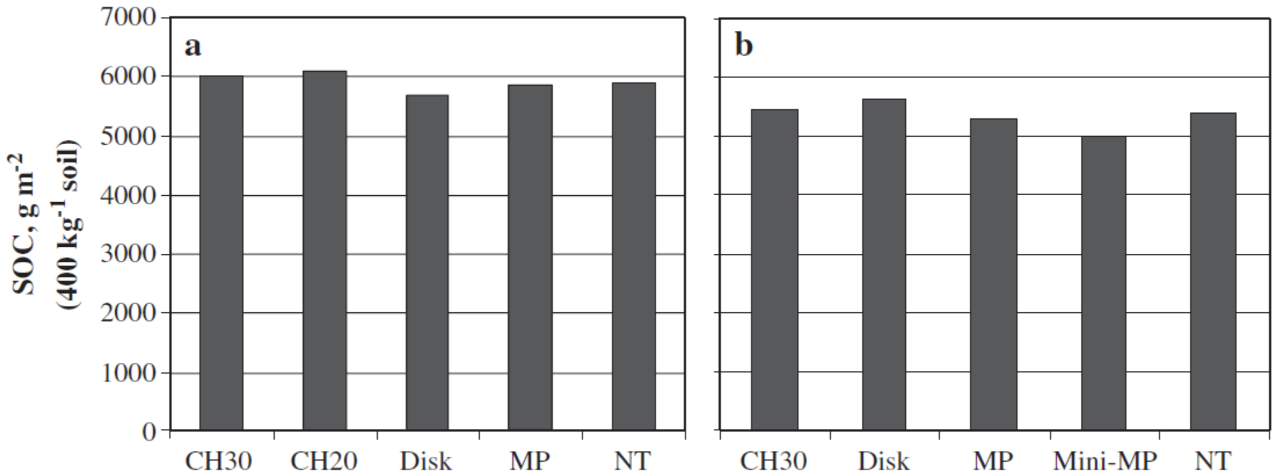
Soil depth	***MP†, RMF***			***MP, ARDC***			***MMP, ARDC***		
	2004	**2005**	**2008‡**	**2004**	**2005**	**2008**	**2004**	**2005**	**2008**
				Bacteria					
0–2”	–33.1***	–30.9***	-15.0	–34.2***	–25.5***	-27.2**	–15.3***	–6.2	-8.7
2–8”	+9.1	+2.7		+7.6	+6.9		–2.1	–5.1	
				Actinomycetes					
0–2”	–18.5**	–25.4***	-8.2	–27.1***	–19.7**	-17.5**	–15.4***	–10.8	-9.1*
2–8”	+25.0*	+4.0		+4.2	+11.6		+1.2	+1.1	
				Fungi					
0–2”	–61.0***	–6.0	0.4	–28.3**	–23.2**	-34.0	+2.7	+2.4	-15.8
2–8”	+34.0	+55.8		+143.6**	+35.0		+20.5	–1.7	
				Arbuscular mycorrhyzae					
0–2”	–52.2***	–56.3***	-16	–34.5**	–43.3***	-26.9**	–7.9	–28.3**	-12.2
2–8”	+16.1	+1.9		–1.0	–13.1		–15.1	–9.1	

†MP and MMP, one-time tillage with moldboard plow and mini-moldboard plow.
‡The 2008 results are for the 0 to 4” soil depth.
*, **, *** Significant difference at P = 0.05, 0.01, and 0.001, respectively, compared with no-till. No symbol denotes no significant difference.

Table 5. The effect of one-time tillage of no-till land and compost application on grain yield (Mg ha^{-1}) at Rogers Memorial Farm (RMF) and the Agricultural Research and Development Center (ARDC) in eastern Nebraska (from: Quincke et al, 2008; Wortmann et al., 2010).

Tillage treatment	***Sorghum RMF, 2005***	***Soybean ARDC, 2008***
NT†	129 ab	35.2 b
Disk	123 b	38.3 ab
CH30	133 ab	
MMP		41.4a
CH20	131 ab	37.7 ab
MP	143 a	38.7 ab

Figure 1. Stocks of soil organic carbon (SOC) based on an equivalent soil mass of 400 kg m^{-2}, representing approximately the 0 to 12" soil depth, at ~2 years after one-time tillage of no-till land at a) Rogers Memorial Farm [LSD(0.05) = 413]; and b) Agricultural Research and Development Center [LSD(0.05) = 967] in eastern Nebraska. The tillage effects were not significant; 1000 g m^{-2} = 0.47 t/ac SOC (from: Quincke et al., 2007a).



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