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Impacts of Conservation Tillage Systems on Long-Term Crop Yields

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Abstract: The 20 year study was conducted in Southern Illinois (USA) on land similar to that being removed from Conservation Reserve Programme (CRP) to evaluate the effects of conservation tillage systems on maize and soybean yields and for the maintenance and restoration of soil productivity of previously eroded soils. The effects of tillage on soil loss from erosion and Soil Organic Carbon (SOC) change were determined. The No-Till (NT) system had significantly less soil loss from erosion and maintained more SOC than the Mouldboard Plough (MP) and Chisel Plough (CP) tillage systems. The 10 year average maize yields were slightly higher for MP than NT and CP systems as a result of a significantly higher maize yield in the first year. The 10 year average NT soybean yield was slightly higher than for the MP and CP tillage systems. Crop yields for 10 years maize and 10 years soybean appear to show long-term productivity of NT compared favorably with that of MP and CP tillage systems.

Key words: Conservation tillage, erosion, crop growth, plant population, maize, soil organic carbon, soybean

INTRODUCTION

Conservation tillage can resulted in an increased in crop yield compared with that of a MP tillage system. Lawrence *et al.* (1994) showed in a 4 year study in a semi-arid environment in Australia that NT had a higher crop yield than did reduced till fallow or conventional till fallow. Wilhelm *et al.* (1986) observed a positive linear response between yields of maize and soybean and amount of residue applied to a NT system. Lueschen *et al.* (1991), in a maize-soybean rotation in Minnesota, found an increase of 6.30 Mg ha^{-1} in yield of the NT system above the MP system in a dry year. Kapusta *et al.* (1996) studied the effects of tillage systems for 20 years and found, despite the lower plant population in NT, equal maize yield in NT, reduced till and conventional tillage. Olson *et al.* (2004) studied the effects of conservation tillage systems on short term maize and soybean yields to determine if the soil productivity of previously eroded soils could be restored. NT systems appeared to improve the productivity after 3 years when compared with that of the MP and CP tillage systems.

Change in frequency and intensity of tillage practices altered the bulk density and SOC in the soil profile. Mann (1986) reported that the reduction in SOC content (by volume) of soils having an initial content of between 2 to 5% (absolute) was 20% less after cultivation. Mann (1986) found that changes in SOC content were most pronounced during the first 20 years of cultivation. Also, changes in SOC storage were more variable in the upper 15 cm of soil than in the upper 30 cm. Kitur *et al.* (1994) evaluated the effects of MP, CP and NT on SOC content (by weight) and found the content was lowest for MP and highest for NT. The treatment differences in SOC were attributed to the effects of incorporation of the majority of plant residues below the 0-5 cm layer in the MP and CP treatments. Effects of tillage on SOC were not significant in the 5 to 15 cm layer. Ismail *et al.* (1994) observed a decrease in SOC (by volume) in the 0 to 30 cm silt loam layer of soil during the first 5 years, no change in the next 5 years and an increase in SOC in the last 10 years in both NT and MP in comparison with sod plots.

The impact of tillage and cover crops on SOC sequestration (net increase) or loss has been the focus of many studies since this management techniques were thought to contribute to atmospheric C loss or sequestration. SOC sequestration or retention has been show to retain more SOC with decreasing disturbance or enhanced rotation diversity (West and Post, 2002). Fronning *et al.* (2008) found that the winter rye cover crop did not did not significantly affect total SOC compared to untreated and did not overcome C losses associated with tillage and harvesting corn stover for cellulose based biofuel production.

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The crop yields with different tillage systems vary from year to year due to the fluctuations in weather. NT maize yields are lower in the early years which could be due to lower SOC and nitrogen mineralization and higher immobilization of fertilizer nitrogen, than those of conventional tillage (House *et al*., 1984; Rice and Smith, 1984). Rice *et al*. (1986) and Kapusta *et al*. (1996) also reported no differences in maize yield with NT and conventional tillage over time. NT maize yielded more in drier than normal years, whereas maize yields with MP were higher in the wetter than normal years in the moderately well-drained soils in Ohio (Eckert, 1984).

Maintaining crop residue on the soil surface (Dickey *et al*., 1985; Alberts and Neibling, 1994) can reduce the severity of erosion. At planting, with CP residue cover is 30% and much higher with NT due to minimum soil disturbance (Lal *et al*., 1994). Lueschen *et al*. (1991) for a maize-soybean rotation in Minnesota, observed 69 to 82, 49 and 10% of soybean residue cover on the soil surface after maize planting in NT, CP and MP plow system plots, respectively.

In the United States, the Food Security Act of 1985, the 1990, 1995, 2001 and 2006 Farm bills and the Illinois T by 2000 programme have resulted in millions of hectares of erodible land previously in row crops being put into the CRP for 15-25 years. Any conversion of CRP land back to maize and soybean production could require the use of conservation tillage systems such as NT to meet soil erosion control standards. Evaluations of yield response of these conservation tillage systems over time are needed to assess returning this land to crop production.

Shorter term tillage studies (Kitur *et al*., 1994; Olson *et al*., 2004) were extended to 20 years with the objective of evaluating long-term tillage systems (NT, CP and MP) effects on soil loss from erosion, SOC change and maize and soybean yields and the maintenance and restoration of soil productivity of previously eroded soils in Southern Illinois. The study was extended to show that NT system can be used instead of MP or CP systems to reduce soil loss from erosion, to reduce SOC loss and to maintain long-term crop yields.

MATERIALS AND METHODS

A tillage experiment was started on April 12, 1989, at the Dixon Springs Agricultural Research Center in Southern Illinois. The soil at the study site was a moderately eroded phase of Grantsburg silt loam (Albic Luvisol) (fine-silty, mixed, active, mesic Oxyaquic Fragiudalf) with an average depth of 64 cm to a root-restricting fragipan. The area with an average slope of 6% had been in tall fescue (*Festuca arundinacea* L.) hayland for more than 15 years prior to the start of this experiment. Three tillage treatments, NT, CP and MP, were established on April 27, 1989. Starting with maize in 1989, maize and soybean were grown in alternate years. The experimental design was two complete Latin squares and each square having three rows and three columns (Cochran and Cox, 1957) that allowed for randomization of the tillage treatments (NT, CP and MP) both by row (block) and by column. This replication was used to control random variability in both directions. Each treatment was randomized 6 times in 18 plots with a size of 9×12 m. The columns were separated with 6 m buffer strips of sod.

The implements used in each tillage system and depth of tillage were as follows: NT (John Deere no-till planter with wavy coulters), CP (straight-shanked chisel plowed to 15 cm with disking to 5 cm) and MP (moldboard plowed to 15 cm with disking to 5 cm). In the spring of each year the MP and CP plots were mouldboard and chisel ploughed followed by 2 disking and planting. In odd years maize was planted at the seeding rate of 64,000 seeds ha^{-1} with fertilizers of 218 kg ha^{-1} N, 55 kg ha^{-1} P and 232 kg ha^{-1} K. In even years soybean were planted at 432,000 seeds ha^{-1} with no fertilizer. Chemical weed control practices were used during the study. Crop yield results were published after 14 years (Olson *et al*., 2004) and extended to 20 years to evaluated long-term tillage systems (NT, CP and MP) effects on soil loss from erosion, SOC change and maize and soybean yield differences after 6 additional years and the maintenance and restoration of soil productivity of previously eroded soils in Southern Illinois.

Soil samples were collected in July of 1989 (first crop year and year the first tillage treatment was applied), August of 2000, in July of 2003 and July of 2007 at depths of 0 to 5, 5 to 15, 15 to 30, 30 to 45, 45 to 60 and 60 to 75 cm for SOC determination. The sampling depth was limited due to the presence of a root restricting fragipan at a 75 cm depth. Earlier soil sampling found only trace amounts of SOC present below the 75 cm depth, probably from previous grass roots penetrating the fragipan along the prism faces. Four soil cores, one from near each of the four corners of the plot (1.5 m from adjacent, above or below plot and 1.5 m from border strip), were obtained for each depth and composited by crumbling and mixing. The samples were air-dried and pulverized to pass through a 2 mm sieve prior to analysis for sand, silt and clay contents (Soil Survey Staff, 1984). The SOC was determined after removal of un-decomposed plant residue using the Walkley-Black procedure (Soil Survey Staff, 1984). Field moist core bulk density was determined (Soil Survey Staff, 1984) using a Model 2000 soil core sampler manufactured by Soil Moisture Equipment Corp.

The percentage surface residue was determined after planting by the line-transect method (Hill *et al*., 1989). Plant population for the center 0.001 ha of each plot was determined by counting at 25 days after planting. The crop yield and plant population data from 1989 to 2008 were collected as part of this study. The soil loss rates were determined using RUSLE2 and USLE (Walker and Pope, 1983).

Statistical analysis for all parameters were performed using the procedures from Statistical Analysis System (SAS) computer software. Analysis of variance and least square means of selected variables (in the case of crop yield and SOC) were performed by General Linear Model (GLM) procedures.

RESULTS

The NT system maintained a significantly higher amount of residue on the soil surface as compared with that of the CP and MP systems at planting during each selected year (Table 1). Crop residue on the soil surface was higher with maize as earlier crop, compared with that of soybean because of higher residue production from maize and lower rate of decomposition of maize residue (Eckert, 1984) than soybean residue. On Grantsburg soil with 5-7% slopes, the estimated annual soil loss, measured with USLE and RUSLE2, was 9, 21 and 29 Mg ha^{-1} with the NT, CP and MP systems, respectively (Table 1) (Walker and Pope, 1983). The higher the percentage of crop residue (Table 1) on the soil surface with the NT system protected the soil from erosion keeping it near the tolerance level of 8.4 Mg ha^{-1} year^{-1} (Walker and Pope, 1983). The rill erosion was observed with the MP and CP systems due in part to less residue on soil surface compared with that of the NT system.

The SOC (kg layer^{-1} or kg layer^{-1} thickness $\times 1 \times 1$ m) of tillage treatments on Grantsburg soil was measured in crop years 1, 12, 15 and 19 (Table 2). The plots had previously been in sod for at least 15 years prior to the establishment of the tillage plots and the SOC content was determined 3 months after the initial tillage and maize planting, the 12th year, the 15th year and the 19th year. The SOC was measured on a gravimetric basis and converted to a volumetric basis using the bulk density of each soil layer in each tillage treatment. In July of 1989 there was no significant differences in the SOC content of the combined 0-75 cm layer which included both the

Table 1: Effect of different tillage treatments on plant residue after planting and soil loss at Dixon springs

Tillage	Residue present from previous crop (% cover) 1996	1997	1998	1999	2005	2006	2007	Soil loss† --(Mg ha^{-1}	SOC year^{-1})---
NT	91a*	75a	95a	73a	85a	90a	78a	9c	0.15c
CP	21b	18b	29b	21b	18b	28b	24b	21b	0.32b
MP	6c	6c	17c	5c	5c	10c	8c	29a	0.44a

*For each year, means with in a same column followed by same letter(s) are not significantly different at the p = 0.05 probability level. †Soil loss is calculated by Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Eq. 2 (RUSLE2)

Table 2: SOC (kg layer^{-1} or kg per layer thickness $\times 1 \times 1$ m) of the Grantsburg in 1st, 12th, 15th and 19th years of tillage treatments

Treatments	Depth (cm)	July 1989	August 2000	August 2003	July 2007	SOC change in 18 years^{-1} (%)
		--------------------(kg layer^{-1} or layer thickness $\times 1 \times 1$ m)--------------------				
NT	0-5	1.20a*	1.21a	1.53a	1.06a	-0.14b -11
	5-15	1.62a	1.47a	1.44b	1.33a	-0.29b -18
	15-30	0.78a	0.97a	0.95a	0.94a	-0.16b +20
	30-45	0.52a	0.46a	0.44a	0.46a	-0.06a -11
	45-60	0.28a	0.33a	0.20b	0.25b	-0.03a -11
	60-75	0.26a	0.26a	0.20b	0.23b	-0.03a -12
Combined	0-75	4.66a	4.70a	4.74a	4.27a	-0.39b -8
CP	0-5	1.09ab	1.07a	1.03b	0.74b	-0.35a -32
	5-15	1.69a	1.43a	1.48a	1.07b	-0.62a -37
	15-30	0.95a	0.96a	1.00a	0.63b	-0.32a -34
	30-45	0.48a	0.32b	0.44a	0.38b	-0.10a -26
	45-60	0.30a	0.39a	0.29a	0.37a	+0.07a +23
	60-75	0.28a	0.20ab	0.29b	0.27ab	-0.01a -4
Combined	0-75	4.79a	4.37a	4.54a	3.49b	-1.30a -27
MP	0-5	1.03b	0.76b	0.66c	0.65b	-0.38a -37
	5-15	1.67a	1.23b	1.22b	1.07b	-0.60a -36
	15-30	0.94a	0.92a	0.96a	0.66b	-0.28a -42
	30-45	0.50a	0.45a	0.40a	0.44a	-0.06a -12
	45-60	0.26a	0.26b	0.37a	0.36a	+0.10a +36
	60-75	0.28a	0.15b	0.26b	0.33a	-0.05a -19
Combined	0-75	4.78a	3.77b	3.87b	3.52b	-1.26a -26

*Mean of six replications with the same letter(s) and in the same year and depth with a different tillage treatment are not significantly different at p = 0.05

topsoil and subsoil layers above a root restricting fragipan. However, the mouldboard ploughing in the spring did lower the SOC of the 0-5 cm layer as a result of aeration, inversion and burying of this layer or the layer being mixed with the 5-15 cm layer by the ploughing. In addition, the soil erosion rates were significantly higher for the CP and MP plots which would have contributed to the higher SOC loss relative to the NT plots (Table 1).

During the 18 years, 8% of the SOC in the NT plots was lost, 27% was lost from the CP plots and 26% was lost from the MP plots. All of the soil layers between 0 and 75 cm of the NT plots lost SOC except the 15-30 cm subsurface layer, all of the soil layers of CP plots all lost SOC except the 45-60 cm subsoil layer and all of the MP plots lost SOC in all layers except the 45-60 cm subsoil layer. These three increases in SOC exceptions were most likely a result of the natural variability of these soil layers which probably masked any changes as a result of tillage treatments. By July of 2007 the NT system retained or maintained significantly more SOC in the 0-5 and 5-15 cm layers as a result of reduced tillage equipment mixing and aerating these surface layers and reduced soil loss from erosion. The 15-30 and 30-45 cm subsurface layers of the NT lost less SOC than the same layers in the CP and MP plots. The NT plots did loss more SOC in the 45-60 and 60-75 cm subsoil layers than CP and MP plots perhaps as a result of the presence of fewer decomposed maize and soybean roots at these depths during the last 18 years of maize-soybean production.

Table 3: Rainfall data during the growing season from 1989-2008 at Dixon springs in Southern Illinois

	Rainfall (cm)						
Years	April	May	June	July	August	September	Growing season
1989	6.1	4.1	14.3	12.8	10.0	4.6	51.9
1990	14.5	28.2	4.4	6.4	10.5	8.8	72.8
1991	12.5	8.9	1.8	3.7	4.0	12.4	43.3
1992	6.1	6.7	7.6	13.4	3.9	19.1	56.8
1993	12.3	13.0	17.8	13.4	10.9	19.4	86.8
1994	16.2	1.5	10.2	6.0	9.8	7.0	50.7
1995	17.7	22.0	15.2	7.3	8.2	4.8	75.2
1996	14.8	14.2	9.0	13.1	1.4	14.8	67.3
1997	9.5	14.9	14.5	5.8	7.5	4.0	56.2
1998	15.3	6.5	19.3	10.3	11.8	2.5	65.7
1999	10.3	6.8	16.8	10.0	2.3	1.5	47.7
2000	6.2	15.8	15.1	6.8	3.8	8.3	56.0
2001	6.0	8.4	9.3	15.9	9.8	9.3	58.7
2002	19.0	24.7	3.1	5.1	7.2	18.8	77.9
2003	12.4	32.2	11.9	4.0	13.5	12.6	86.6
2004	6.5	13.5	5.4	8.1	4.8	0.0	38.3
2005	10.0	4.7	6.5	10.8	18.2	6.8	57.0
2006	7.5	10.2	7.0	21.3	7.7	21.3	75.0
2007	8.2	7.3	7.1	9.9	4.5	7.4	44.4
2008	11.6	6.6	5.8	11.6	7.0	3.2	45.8
1989-2008							
Average	11.1	12.6	10.1	9.8	7.9	9.3	60.8
30 year							
Average	11.9	12.9	10.3	9.4	9.0	8.2	61.7

Rainfall data (30 year average growing season rainfall by month for the Southeastern Illinois, USA) and 1989-2008 growing seasons are shown in Table 3. The 30 year average cumulative rainfall during April-September in Southeastern Illinois was 61.7 cm. During the study, six of the years (1991, 1994, 1999, 2004, 2007 and 2008) could be characterized as dry years with a growing season rainfall of 43.3, 50.7, 47.7, 38.3, 44.4 and 45.8 cm, respectively.

From 1989 to 2008, the MP system had higher plant populations than the other tillage systems in 6 of 20 years (Table 4). The NT system had higher plant population than the other tillage systems in 5 of 20 years while CP only had 1 of 20 years with higher plant populations than the other tillage systems. The other 8 years were similar. In 1989, 1996, 1998, 2002 and 2006 the NT had a lowest plant population (Table 4) compared with the other tillage systems which was probably due to insufficient soil-seed contact, lower germination and greater soil strength in the NT system (Kitur *et al*., 1994). During 1990, 1996, 2002 and 2006 the high April and May rainfalls (Table 3) contributed towards lower plant population with the NT system compared with that of the MP system (Table 4). Higher plant population with the MP system than with the NT and CP systems during 1995 was also observed (Table 4). Better seed-soil contact with the MP system could have increased the germination compared with that of the NT system during 1996, 2002 and 2006. On the other hand, in 1994 and 2000 the plant population was higher with the NT treatment compared with that of the MP treatments, which could have been

Table 4: Effect of different tillage treatments on the maize and soybean populations during 1989-2008 at Dixon springs

	Plant population (plants ha^{-1})										
Crops	1989	1991	1993	1995	1997	1999	2001	2003	2005	2007	10 year average
Maize											
NT	55300b*	57900a	51400a	58800ab	46900a	69200a	64500a	59500a	70500b	68800a	59400a
CP	59200ab	47400b	54100a	55700b	51900a	64200ab	56500b	61300a	76000a	68500a	58600a
MP	62900a	52200ab	52600a	62200a	51900a	62700b	65900a	60000a	69500b	68300a	60200a
Crops	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	10 year average
Soybean											
NT	191000b*	344000a	303000a	263000b	271000b	422000a	293000b	240000a	320000a	310000b	295000a
CP	247000a	335000a	229000b	277000b	273000b	398000a	393000a	228000a	363000b	390000a	312000a
MP	249000a	343000a	181000c	309000a	294000a	405000a	420000a	255000a	388000c	360000ab	316000a

*For each crop, means with in a same year followed by same letter(s) are not significantly different at the p = 0.05 probability level

Table 5: Effect of different tillage treatments on maize and soybean yields during 1989-2008 at Dixon springs

	Crop yield ($Mg\ ha^{-1}$)										
Tillage	1989	1991	1993	1995	1997	1999	2001	2003	2005	2007	10 year average
Maize											
NT	8.99b*	6.57a	11.79a	11.60a	9.87a	8.12a	9.73b	6.67a	11.4a	6.46a	9.17a
CP	9.99b	6.10a	11.61a	11.55a	9.32a	6.78b	9.60b	7.33a	11.8a	6.80a	9.12a
MP	11.26a	6.60a	10.98a	10.37a	9.59a	6.98b	10.34a	7.82a	11.4a	7.33a	9.34a
Tillage	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	10 year average
Soybean											
NT	2.37a*	3.74a	2.87a	2.63a	2.63a	2.32a	2.37a	0a	3.17ab	2.84a	2.47a
CP	2.62a	3.46a	1.81b	2.27a	2.63a	2.38a	2.07b	0a	3.37a	2.84a	2.27a
MP	2.62a	3.65a	1.49b	2.43a	2.75a	2.32a	1.98b	0a	3.10b	3.04a	2.34a

*For each crop, means with in a same year followed by same letter(s) are not significantly different at the p = 0.05 probability level

due to relatively greater water availability in the NT system compared with MP tillage system at planting. Ten year average plant population (Table 4) for maize and soybean were not statistically different from NT and MP systems.

In 2004, the driest year, the soybean yields were zero for all treatments (Table 5) since all plant available water above the fragipan was extracted from all treatments including the NT system. In 1994, another year of low rainfall, the soybean yields were low for all treatments, but NT yield (Table 5) was substantially higher than CP and MP yields. In 1999, the NT maize yield of NT system was significantly higher than CP and MP. The 20 year average rainfall for the April through September period was 61.7 cm which is equal to the 30 year average (Table 3). Years 1990, 1993, 1995, 2002, 2003 and 2006 were considered wet years.

From 1989 to 2008, tillage affected crop yields in only 1989, 1994, 1999, 2001, 2002 and 2006 (Table 5). In 1994 and 2002 the NT system produced significantly higher soybean yield than with the CP and MP systems due to better plant population in 1994. Since 1994 was a dry year and 2002 had a dry June to August period, the NT system could have provided more soil water to soybean at planting and later in the season compared with that of the other tillage systems. This enhanced soil water storage could have resulted in an improvement in nutrient availability and played an important role in higher soybean yields in 1994 and higher soybean yields in 2002 with the NT system as compared to MP and CP systems. Higher crop yield with the NT system than MP system in a dry year (not a drought) was also noted by Lueschen *et al.* (1991). Although the differences in soybean yield in 1996 were not significant by tillage treatment, the NT system had 7 and 15% higher yield than the MP and CP systems, respectively. In 2002 the NT soybean yield (Table 5) was significantly higher than MP when the plant population (Table 4) was significantly lower. Year 2002 was considered a wet year; however, the combination of a dry period (between June and August of 2002) and the high plant population in MP resulted in less water available per plant. In 2004 there was no measurable soybean yields on any of the tillage treatments. Growing season rainfall totaled 38.3 cm which is 27 cm below normal. In addition, the fall 2003, winter and spring of 2004 had below average rainfall and the 15 cm water storage capacity of the Grantsburg moderately eroded soils was not full on April 1 which caused the soybean yield to be zero on all treatments.

DISCUSSION

The NT system had significantly less soil loss from erosion and less SOC loss as a result of less carbon rich sediment being transported off the NT plots than from the CP and MP system plots. During the 18 years, a net 8% of the SOC in the NT plots was lost, a net 27% was lost from the CP plots and a net 26% was lost from the MP plots.

The 10 year average maize yield and the 10 year soybean yields were not affected by tillage (Table 5). Ten year average MP soybean yield was 5 and 8% higher than NT and CP systems. The MP maize yields were 3 and 2% higher than for CP and NT systems as a result of significantly higher yields with MP system when planted into sod. At the beginning of the experiment, the MP system produced 21 and 11% higher yield compared with that of the NT and CP systems during 1989. The NT yields were lower in the early years of study but improved with the passage of time. The NT performance relative to MP and CP (Table 5) was better during dry years (1999) or years with extended dry periods than wet years (Table 3), which was observed by Eckert (1984). The only year that CP treatment had the highest yield was 2006 when compared to other tillage systems. The rainfall that year was higher than average (75 cm).

The NT crop yields were lower during the 3 early years (1989 to 1991) of the study but the NT system yielded as well as the MP system during the last 17 years of study. NT yields lower than MP system in wet years (except 2002 with a dry period from June to August) but were higher in relatively dry year (Table 5). The higher yields with the NT system in dry years (1994, 1999 and 2002) was probably due to the conservation of more soil water than the MP system (Table 3). Chisel plow yields were lower in wet years and higher in dry years as compared to MP system (Table 5).

Based on 20 years of crop yield measurements (10 years maize and 10 years soybean), the NT system appears to have resulted in similar long-term productivity and system had significantly less soil loss from erosion and less SOC loss (-8%) when compared with that of the CP and MP systems (-27 and -26%, respectively). However, none of the tillage treatments (NT, CP or MP) sequestered SOC but the NT system maintained more SOC after 18 years that the other treatments. The results of this study would not be applicable to poorly drained and slightly eroded soils on nearly level landscapes with subsoils favorable for crop rooting. However, study results should apply to similar root-restricting, sloping and moderately eroded soils in Illinois, Indiana, Missouri and Kentucky.

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