Journal Title: Soil Science

Volume: 174
Issue:
Month/Year: 2009
Pages: 385-394

Article Author: Yuan, Y., M.A.Locke and L.A.Gaston

Article Title: Tillage effects on soil properties and spatial variability in two Mississippi Delta watersheds

OCLC#

Staff
Daniel Wren
USDA-ARS-National Sedimentation Laborato
P.O. Box 1157
Oxford, MS 38655

Date: 9/28/2009 03:06:29 PM

Tillage Effects on Soil Properties and Spatial Variability in Two Mississippi Delta Watersheds

Yongping Yuan,[1] *Martin A. Locke,*[2] *and Lewis A. Gaston*[3]

Abstract: This study evaluated changes in soil properties several years after implementation of conservation measures. Two approximately 50-ha fields within two Mississippi Delta oxbow lake watersheds (Deep Hollow and Beasley) were laid out in 60-m grids. Soil from a tilled cotton field in Deep Hollow watershed was sampled at each node in 1996 and again in 2000 after 4 years of reduced tillage cotton (*Gossypium hirsutum*) and winter wheat (*Triticum aestivum L.*) cover crops; soil also was collected from conventional tillage cotton in Beasley Lake watershed in 1996 and again in 2006 from the same grid nodes after 4 years of reduced tillage cotton and 5 years of reduced tillage soybeans. Organic matter levels in the soil surface were higher in both watersheds after conservation tillage was implemented, likely caused by increased plant residue accumulation and limited soil mixing. Higher soil P levels in both watersheds under conservation management were attributed to less distribution in soil because of reduced tillage. Lower NO_3-N in Deep Hollow in 2000 suggested N immobilization in the soil surface. Nitrogen was not analyzed for Beasley soil samples. Soil pH values were also higher in the later samplings for both watersheds, but because lime was applied in the interim, it is difficult to ascribe an effect from tillage. Potassium, calcium, and magnesium were higher in 2000 after the 4-year reduced tillage practice in the Deep Hollow watershed. However, potassium, calcium, and magnesium were lower in 2006 than in 1996 at the Beasley Lake watershed because no fertilizer was applied to the field since 2001. Regardless of tillage system, relatively high P levels in soils from both watersheds are indicative of high native soil P levels in the Mississippi Delta soils. Similar to other studies, water-soluble P was positively correlated with Mehlich III P. Spatial relationships of P examined using kriging showed that P data were spatially dependent, and their spatial dependence was impacted by tillage practices.

Key words: Tillage, nutrients, phosphorus, nitrogen

(*Soil Sci* 2009;174: 385–394)

Tillage has long been used as a soil management tool to prepare soil for crops, control weeds, aerate the soil, and distribute nutrients; it plays an important role in soil tilth, water conservation, and soil quality. Reduced tillage (RT) is also an effective management tool to reduce erosion and help improve water quality (Andraski et al., 2003; Blevins and Frye, 1993; Daverede et al., 2003; Gaynor and Findlay, 1995; Seta et al., 1993). Numerous studies have evaluated the impact of tillage systems on soil properties (Ismail et al., 1994; Angers et al., 1997; Dick et al., 1997; Needleman et al., 1999; Rhoton 2000; Zablotowicz et al., 2000; Zibilske et al., 2002; Wright and Hons, 2005; Guzman et al., 2006; Sparrow et al., 2006; Steinbach and Alvarez, 2006). Generally, conservation tillage effects are primarily observed in the surface because reducing tillage limits distribution of plant residues and nutrients within the soil profile. Often, the result is enhanced surface organic C and microbial activity, and accumulation of immobile plant nutrients such as P. For instances, Guzman et al. (2006) studied the effect of long-term no tillage (NT) and conventional tillage (CT) continuous sorghum systems on soil properties and found that organic carbon under NT was significantly higher in the surface 7.5 cm of soil compared with that of CT; extractable P under NT was also higher than that under CT in the surface 2.5 cm of soil. Other characteristics of RT soils include higher aggregate stability, reduced pH, increased moisture, and higher bulk density (Perfect and Caron, 2002; McVay et al., 2006; Park and Smucker, 2005; Tomer et al., 2006; Buczko et al., 2006). For instance, Tomer et al. (2006) compared surface-soil properties in two small watersheds in Iowa's loess hills under continuous corn with contrasting tillage histories; their results indicate that long-term RT increased water retention capacity, aggregate stability, and bulk density. Crop nutritional needs must be managed closely in conservation tillage soils because nutrients may be less available because of immobilization by organic C, limited distribution in the case of immobile nutrients, or enhanced leaching by preferential flow (Ismail et al., 1994; Needleman et al., 1999; Steinbach and Alvarez, 2006; Wright and Hons, 2005).

Large-scale studies on how tillage systems impact soil properties, distribution of nutrients, and soil organic matter continue to be an interest to US farmers and policy makers. In 2004, the US Department of Agriculture (USDA) began implementing the Conservation Effect Assessment Project (CEAP). The principle focus of the CEAP project is to produce an assessment of environmental benefits derived from implementing USDA conservation programs (Mausbach and Dedrick, 2004). Conservation tillage is one of the CEAP-emphasized (or targeted) cropland conservation practices (www.nrcs.usda.gov/technical/nri/ceap). The Mississippi Delta (flood plain of Mississippi River) is an important agricultural region of the United States, and conservation tillage is slowly being adopted in this region, but relatively limited information is available concerning the effects of tillage on these soils (Snipes et al., 2004). Thus, the objective of this study was to measure differences in soil characteristics that could be attributed to conservation practices in Mississippi Delta alluvial soils.

MATERIALS AND METHODS

Description of Soil Sampling Sites

Study sites included portions of Deep Hollow Lake watershed (Leflore County, Mississippi) and Beasley Lake

---

[1] USEPA/ORD/NERL/ESD/Landscape Ecology Branch, Las Vegas, NV. Dr. Yuan is corresponding author. E-mail: yuan.yongping@epa.gov
[2] USDA-ARS–National Sedimentation Laboratory, Water Quality & Ecology Research Unit, Oxford, MS.
[3] Dept. of Agronomy & Environmental Management, LSU AgCenter, Baton Rouge, LA.

Received November 19, 2008.
Accepted for publication April 27, 2009.

ISSN: 0038-075X
DOI: 10.1097/SS.0b013e3181ac679c

watershed (Sunflower County, Mississippi). Both watersheds were a component of the Mississippi Delta Management Systems Evaluation Area project (MDMSEA), which sought to develop and assess alternative innovative farming systems for improved water quality and ecology in the Mississippi Delta (Locke, 2004). In 2004, Beasley Lake watershed also was selected as one of 14 Agricultural Research Service (ARS)–CEAP benchmark watersheds to assess environmental benefits derived from implementing USDA conservation programs (Locke et al., 2008).

Deep Hollow Lake (former channel of the Yazoo River) watershed is about 240 ha. As part of the MDMSEA project, 50 ha of the watershed were selected for collecting soil samples (Gaston et al., 2001). The sampling area was in continuous cotton production under CT through 1995, when it was converted to RT. During the CT period, tillage operations consisted of cut stalk and one chisel operation in the fall, followed by 2 to 3 disking operations in the spring and 2 to 4 cultivations during the growth season for weed control. After it was converted to RT, the only tillage activities involved bed preparation in the spring before planting. Herbicides were applied to control weeds during the cotton-growing season. Beginning in the winter of 1995, a winter wheat (*Triticum aestivum* L.) cover crop was planted for soil erosion control. Fertilizers were applied each year for crop production. Agricultural management practices are listed in Table 1. Dundee (fine-silty, mixed, active, thermic Typic Endoaqualf), Forestdale (fine, smectitic, thermic Typic Endoaqualf), and Dowling (very fine, smectitic, nonacid, thermic Vertic Endoaquept) are the major soil series in the 50-ha sampling area.

Beasley Lake (former channel of the Sunflower River) watershed is about 915 ha. In 1996, as part of the MDMSEA project, 50 ha were selected for collecting soil samples. The sampling area was originally in continuous cotton production under CT management. From 1998 to 2001, the area was gradually converted to RT for soil erosion control. The entire area was in RT soybean production from 2002 until soil sampling in 2006. Herbicides were applied to control weeds during the growing season. After the spring of 2001, no more fertilizer was applied in the sampling area. Agricultural management practices are listed in Table 2. Dundee (fine silty, mixed, active, thermic Typic Endoaqualf), Forestdale (fine, smectitic, thermic Typic Endoaqualf), Dowling (very fine, smectitic, nonacid, thermic Vertic Endoaquept), and Alligator (very fine, smectitic, thermic Chromic Dystraquert) are the major soil series in the sampling area.

Soil Sampling

Soil sampling locations and procedures are outlined in Gaston et al. (2001), but briefly, plots were established by laying out 60 × 60–m square grids in the 50-ha areas, and coordinates of each grid were recorded by a global positioning system (Pathfinder ProXR, Timble Navigation, Ltd, Sunnyvale, CA) so that the grid could be reestablished in subsequent years. Each grid node was the center of a 2 × 2–m sampling spot from which soil samples were taken. Soil samples were

TABLE 1. Agricultural Management Practices for Deep Hollow Watershed Sampling Area

Date	Action	Materials	Amount
April 1, 1996	Burn down		
April 29, 1996	Fertilize, knifed in	N	32.3 kg ha^{-1}
May 3, 1996	Do-all and plant	Cotton	
Fall 1996	Cut stalks subsoil with rows hip up rows		
Fall 1996	Plant	Wheat cover crop	
March 3, 1997	Burn down		
May 13, 1997	Fertilize, knifed in	N	87.9 kg ha^{-1}
May 14, 1997	Do-all and plant	Cotton	
May 18, 1997	Fertilize, sidedress	N	10.8 kg ha^{-1}
October 14, 1997	Fertilizer, spreader	K	162.8 kg ha^{-1}
Fall 1997	Subsoil with rows disk, hip up rows		
November 7, 1997	Plant	Wheat cover crop	
March 10, 1998	Burn down		
April 9, 1998	Fertilize, knifed in	N	37.0 kg ha^{-1}
May 5, 1998	Do-all and plant	Cotton	
June 16, 1998	Fertilize, sidedress	N	9.0 kg ha^{-1}
October 6, 1998	Fertilizer, spreader	P	21.9 kg ha^{-1}
October 6, 1998	Fertilizer, spreader	Lime	1120 kg ha^{-1}
October 6, 1998	Fertilizer, spreader	K	100.9 kg ha^{-1}
Fall 1998	Subsoil with rows		
October 14, 1998	Plant	Wheat cover crop	
April 1, 1999	Burn down		
April 30, 1999	Fertilize, knifed in	N	32.7 kg ha^{-1}
May 9, 1999	Do-all and plant	Cotton	
June 25, 1999	Fertilizer, sidedress	N	10.2 kg ha^{-1}
October 18, 1999	Plant	Wheat cover crop	

Two agricultural fields XP3 and XP10 were included in the sampling area.

TABLE 2. Agricultural Management Practices for the Beasley Watershed Sampling Area

Date	Action	Materials	Amount
Spring 1996	Cut stalks, subsoil, hipped up twice, disk, rowed		
April 1, 1996	Broadcast nitrogen	N	78.4 kg ha^{-1}
April 12, 1996–May 17, 1996	Do all and plant	Cotton	
	Cultivate 6 times		
Fall 1996	Cut stalks, subsoil, hipped up		
Spring 1997	Disk 2 times, hipped up		
March 1997	Fertilizer	N	78.4 kg ha^{-1}
		K	139.4 kg ha^{-1}
March 20, 1997	Rehip, do-all and rowed		
April 11, 1997	Plant	Cotton	
May 27, 1997	Fertilizer, knifed in	N	67.2 kg ha^{-1}
	Cultivated 4 times		
March 31, 1998	Subsoil, disk, rowed up		
April 1, 1998	Fertilizer, terragator	K	29.1 kg ha^{-1}
		P	29.1 kg ha^{-1}
		Zn	500 ppm
May 9, 1998	Plant	Cotton	
	Cultivated 2 times		
Fall 1998	Hipped up		
Spring 1999	Rehipped, subsoiled		
April 26, 1999	Fertilizer, surface application	Lime	2240 kg ha^{-1}
		N	67.2 kg ha^{-1}
April 30, 1999	Do all and plant	Cotton	
	Cultivated 2 times		
May 20, 1999	Fertilizer, sidedressed	N	112 kg ha^{-1}
		P	112 kg ha^{-1}
		K	112 kg ha^{-1}
Fall 1999	Hipped up		
Spring 2000	Disked, rowed up, do all		
April 29, 2000	Fertilizer before planting	K	185.9 kg ha^{-1}
April 30, 2000	Plant	Cotton	
	Cultivated twice		
March 24, 2001	Burndown		
April 5, 2001	Fertilizer	K	185.9 kg ha^{-1}
April 13, 2001	Planted no till	Cotton	
May 20, 2001	Fertilizer liquid injected	N	128.8 kg ha^{-1}
September 21, 2001	Harvest		

Three agricultural fields ZC19, ZC20, and ZC22 were included in the sampling area.

Since 2002, the study area was reduced tillage soybeans with subsoiling as the only tillage operation.

collected from the upper 5 cm in both watersheds in April of 1996 before full establishment of RT and again in (i) April 2000 after 4 years of RT cotton in Deep Hollow watershed and (ii) March 2006 after 5 years of RT soybeans in Beasley Lake watershed.

Soil Analyses

Soil samples were air dried, grounded, and sieved to 2 mm. Samples collected from the Deep Hollow Lake watershed were sent to the University of Arkansas Soil Testing Laboratory for routine soil testing. Elements analyzed included soil organic matter (SOM) measured through loss on ignition (Combs and Nathan, 1998), pH (Carroll et al., 2005a; Donahue, 1983), nutrients as Mehlich III phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and zinc (Zn) measured through Mehlich III method (Carroll et al., 2005b; Mehlich, 1984) and nitrate (NO_3-N) (Carroll et al., 2005c; Donahue, 1992). Samples collected from the Beasley Lake watershed were sent to the Mississippi State University Soil Testing Laboratory for routine soil testing. Elements analyzed included SOM (Combs and Nathan, 1998), pH (Carroll et al., 2005a; Donahue, 1983), Lancaster P, K, Ca, Mg, and Zn (Cox, 2001), Mehlich III P (Carroll et al., 2005b; Mehlich, 1984), and water-soluble P (Sikora et al., 2004). Nitrate was not analyzed for the Beasley Lake watershed samples, and water-soluble P was not analyzed for the 1996 Deep Hollow watershed samples.

Statistical Analyses

Kolmogorov-Smirnov tests were performed first to look at the distribution of samples of all soil properties using Statistical Analysis System. Then, sample means and variances for data from 1996, 2000, and 2006 were summarized in terms of the

TABLE 3. Means and S.D. of Soil Property Data (Deep Hollow Watershed)

Soil Parameter	Mean		S.D.		Statistical Testing Results ($P < 0.1$)
	1996	2000	1996	2000	
OM, %	1.1	1.3	0.2	0.3	Significantly higher
pH	5.7	6.7	0.5	0.5	Significantly higher
Mehlich III P, ppm	49.5	54.9	19.9	28.1	Significantly higher
Water-soluble P, ppm	1.1	2.8	0.7	3.4	Significantly higher
NO_3-N, ppm	39.5	12.0	34.3	5.5	Significantly lower
K, ppm	355.4	364.0	72.3	77.3	Not significant
Ca, ppm	1339.4	1894.2	491.2	729.0	Significantly higher
Mg, ppm	244.0	259.2	128.1	137.5	Not significant
Zn, ppm	5.3	5.3	2..3	2.7	No changes

tillage effects. *t* Tests were performed to determine significant mean differences, and the 0.1 probability level was chosen as a significant level (Ott, 1993). Linear regression was used to evaluate the relationship between water-soluble P and Mehlich III P and to determine if tillage system had an impact on the relationship. Finally, spatial variations of Mehlich III P and water-soluble P were quantified using the semivariogram (Burrough and Mcdonnell, 1998; Isaaks and Srivastava, 1989) and also used to evaluate whether tillage systems had an impact on their spatial distributions. Through applying script Kriging 1.1 for Spatial Analyst (Boeringa, 2004) in ArcView 3.3, experimental semivariograms were calculated from observations, and semivariogram models were then fit to the variance points using the Levenberg-Marquardt Method (Press et al., 1986) of nonlinear least square approximation. Five different semivariogram models were examined: linear, spherical, circular, exponential, and Gaussian model. The decision on the semivariogram model used was made based on the best fit to the experimental semivariogram, judged by the root mean square error. The ordinary Kriging was applied to create the representative grids of the P.

RESULTS AND DISCUSSION

Simple Statistics

Organic Matter

The mean of SOM in the 0- to 5-cm depth was significantly greater in 2000 after 4 years of RT practices in Deep Hollow watershed (Table 3). Actual SOM values were higher in 2000 than in 1996 at a majority of the sampling locations, although there were a few locations where the SOM values remained unchanged or decreased (Fig. 1). Higher SOM also was measured for RT soil in a companion study in Deep Hollow watershed (Locke et al., 2001). The comparison between 1996 and 2006 of actual SOM values for Beasley Lake watershed demonstrated a trend similar to that of Deep Hollow watershed (Fig. 2), and the mean SOM also was significantly greater in 2006 than in 1996 at the confidence level of 90% (Table 4). The higher SOM content with less tillage also is consistent with studies at other locations (Ismail et al., 1994; Locke and Bryson, 1997; Wright and Hons, 2005; Guzman et al., 2006).

The 1996 average SOM for the Deep Hollow sampling area and the Beasley sampling area were the same (Tables 3 and 4). However, the mean SOM content at the Deep Hollow sampling area after 4 years of RT (Table 3) was higher than the mean of the SOM at the Beasley sampling area after a longer period of RT and NT practices (Table 4). The winter wheat cover crop planted annually in Deep Hollow watershed since the winter of 1996 may have resulted in the greater incremental increase of SOM than was observed at Beasley (Figs. 1 and 2). It should be noted that although surface soil textures varied from loamy to clayey at both locations, Deep Hollow soil was generally of a coarser texture (lower clay

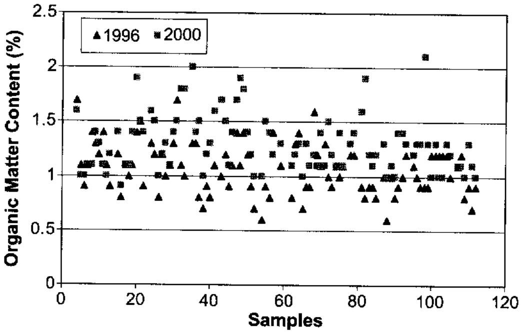

FIG. 1. Comparison of soil organic matter between 1996 and 2000 in Deep Hollow watershed.

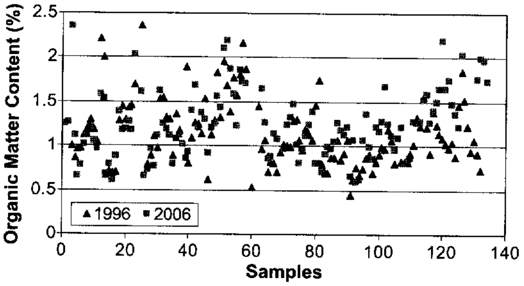

FIG. 2. Comparison of soil organic matter between 1996 and 2006 in Beasley Lake watershed.

TABLE 4. Means and S.D. of Soil Property Data (Beasley Lake Watershed)

Soil Parameter	Mean		S.D.		Statistical Testing Results ($P < 0.1$)
	1996	2006	1996	2006	
OM, %	1.1	1.2	0.4	0.4	Significantly higher
pH	5.8	6.3	0.6	0.6	Significantly higher
Mehlich III P, ppm	35.7	40.1	13.8	19.0	Significantly higher
Lancaster P, ppm	48.2	48.8	28.3	28.6	Not significant
Water-soluble P, ppm	1.2	1.8	0.8	1.0	Significantly higher
K, ppm	275.7	183.4	81.0	74.7	Significantly lower
Ca, ppm	2257.5	2029.0	558.8	564.9	Significantly lower
Mg, ppm	406.1	396.9	164.2	180.9	Not significant
Zn, ppm	2.4	1.4	1.1	1.0	Significantly lower

NO_3-N was not analyzed for the Beasley Lake watershed.

content and a higher sand content) than Beasley (Gaston et al., 2001). Studies have shown positive relationships between SOM and clay content and negative relationships between SOM and sand content (Collins and Kuehl, 2000). This was not the phenomenon observed in this study because of the winter cover crop.

Soil pH

Higher surface soil pH values were observed in 2000 than in 1996 for Deep Hollow Lake watershed. Lime applied in the fall of 1998 (1120 kg ha^{-1}) likely have contributed to the higher soil pH levels measured in 2000 (Table 1). Similarly, higher surface soil pH values were observed in 2006 than in 1996 in Beasley Lake watershed, possibly resulting from a lime application (2240 kg ha^{-1}) in the spring of 1999 (Table 2). Ismail et al. (1994) observed higher soil pH values in NT fields than CT fields, where lime was applied 6 years before soil sampling. In that study, the lime was not distributed in the subsurface to the extent that would have occurred under CT.

Nitrate

The mean NO_3-N level in Deep Hollow watershed soils was significantly lower in 2000 after 4 years of RT practices (Table 3). In 1996, NO_3-N ranged from 0 to 160 ppm, but NO_3-N levels were generally below 20 ppm in 2000 (Fig. 3). During the 4-year period from 1996 to 2000, N fertilizer was applied every year (Table 1). Lower soil NO_3-N in 2000 may be caused by an increase in N immobilization caused by increased surface plant residues and enhanced organic matter associated with RT and cover crop management. Other studies also found that the mean NO_3-N concentrations in no-till fields were significantly less than that in conventional tilled fields because tillage enhanced N mineralization (Soon et al., 2001; Grandy, et al., 2006; Nelson et al., 2006). Nitrogen levels in the surface and groundwater were well below the US drinking water maximum contamination level of 10 mg L^{-1} NO_3-N (Knight and Welch, 2004; Dabney et al., 2004) set by the USEPA (1990) in the Mississippi Delta area.

Potassium, Calcium, Magnesium, and Zinc

Minimal disturbance of the soil and enhanced plant residues and surface SOM can lead to the accumulation of relatively immobile nutrients such as K, Ca, and Mg in the soil surface (Ismail et al., 1994; Guzman et al., 2006). In the Deep Hollow watershed, extractable K, Ca, and Mg (0- to 5-cm soil depth) were greater in 2000 than in 1996, similar to extractable P (Table 3). Potassium fertilizer was applied twice, in the fall of 1997 and 1998 (Table 1). The higher K in 2000 than in 1996, therefore, may be a combination of tillage and cover crop management and the application of K fertilizer. Lime applied in the fall of 1998 (1120 kg ha^{-1}) may also have contributed to the higher Ca levels measured in 2000 (Table 1). In Beasley watershed, however, extractable K, Ca, and Mg were lower in 2006 than in 1996 (Table 4). Although conservation tillage systems accumulate nutrients such as K, Ca, and Mg, no more fertilizer was applied after the spring of 2001 (Table 2), and nutrient demands during the ensuing period likely depleted available nutrient reserves. In addition, about 168 kg ha^{-1} K was applied at Beasley in 1995, which also accounted for higher K in 1996 than in 2006. Zinc remained unchanged from 1996 to 2000 in the Deep Hollow watershed, and no Zn fertilizer was added to the sampling area. Zinc was significantly lower in 2006 than in 1996 in Beasley watershed, although Zn was applied in the spring of 1998.

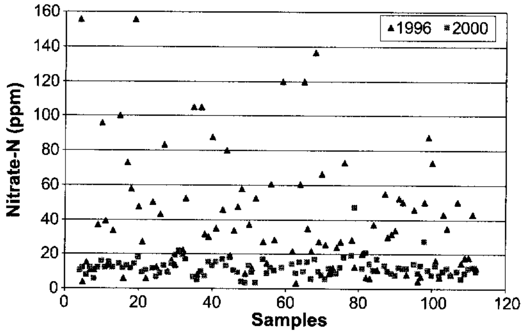

FIG. 3. Comparison of NO3-N between 1996 and 2000 in Deep Hollow watershed.

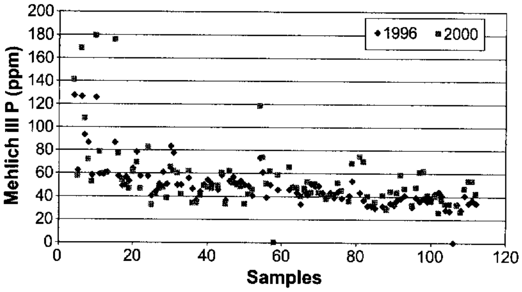

FIG. 4. Comparison of Mehlich III P between 1996 and 2000 in Deep Hollow watershed.

Phosphorus

Although the Lancaster soil extractant is the method used for soil test recommendations in Mississippi (Mississippi State University Extension Service, 2007; Cox, 2001), Mehlich III soil extractant was used in this study because it is commonly used and results are more widely applicable (Sumner, 2000). Reduced tillage resulted in a greater mean Mehlich III P of the soil in both Deep Hollow and Beasley watersheds, and the differences were significant in both sampling areas (Tables 3 and 4). Other studies also showed higher soil P associated with RT compared with CT (Ismail et al., 1994; Guzman et al., 2006; Tomer et al., 2006). Actual *P* values from sampling locations generally were higher in the second sampling for both watersheds; Fig. 4 shows this phenomenon for Deep Hollow as an illustration (similar observation in Beasley study area). In Deep Hollow watershed, P fertilizer was surface applied once (fall of 1998, 21.9 kg ha^{-1}) (Table 1) since the 1996 sampling. The higher Mehlich III P values in 2000 may have been partially caused by the 1998 P application and the increase in P availability caused by the increase in pH, but some factors to be considered include loss of P availability over time (2 years), limited redistribution of P in the subsurface because of RT would have increased P levels, crop uptake over two growing seasons would reduce P levels, increased incorporation of P into organic matter that may have resulted from the RT, and cover crop management would also reduce P levels. In Beasley Lake watershed, P was applied twice (1998 and 1999) during the period from 1996 to 2006 (Table 2), so it is unlikely that the P fertilizer applications contributed to the higher Mehlich III P levels measured

TABLE 5. Linear Regression Between Mehlich III P and Water-Soluble P

	Water-Soluble P			
	Beasley		Deep Hollow	
Linear Regression	1996	2006	1996	2000
Mehlich III P	Y = 0.03X + 0.2 $r^2 = 0.3$ <0.0001	Y = 0.04X + 0.2 $r^2 = 0.6$ <0.0001	Y = 0.02X $r^2 = 0.5$ <0.0001	Y = 0.06X + 0.4 $r^2 = 0.6$ <0.0001

in 2006. Factors similar to those cited for Deep Hollow may have played a role.

Environmental Implications of Soil P Levels and Tillage

According to University of Arkansas Soil Testing Laboratory soil test recommendations, Mehlich III P in Deep Hollow (Fig. 4) exceeded levels (>36 ppm) where row and forage crop yields would not likely respond to P fertilization (Espinoza et al., 2006). Similarly, Mehlich III P and Lancaster P in Beasley watershed (Figures not shown) exceeded critical levels, where a response to fertilizer would not be expected (Mississippi State University Extension Service, 2007). Phosphorus levels observed in surface runoff and groundwater from these two watersheds frequently exceeded critical levels established by the USEPA (Dabney et al., 2004; Knight and Welch, 2004). The soil P levels (Mehlich III and Lancaster) observed in these studies may reflect the high native P levels in these alluvial soils because soil P remained high, although it was removed annually in harvested crops (about 7 kg P is removed for a soybean production of 1680 kg ha^{-1}). Positive correlations of extractable soil P and P loss in surface runoff have been demonstrated in many studies (Sharpley, 1995; Pote et al., 1996, 1999; Pautler and Sims, 2000; Fang et al., 2002; Daverede et al., 2003), but relationships were site specific and influenced by management practice. Generally, P loss to surface runoff increased as the level of extractable P increased, but with diminishing P losses at higher extractable P levels (Daverede et al., 2003).

Water-soluble P was extracted from soil samples to gain a better understanding of the connection between Mehlich III and the risk of P loss to runoff in Mississippi Delta soils that have relatively high native P levels. Water-soluble P tends to have a positive correlation with Mehlich III P (McDowell et al., 2001; Maguire and Sims, 2002; Fuhrman et al., 2005; Bond et al., 2006). This trend also was observed with the Beasley and Deep Hollow data (Tables 3 and 4). Linear regression analysis of water-soluble P with Mehlich III P for soil samples from Deep Hollow and Beasley resulted in significant positive linear relationships (Table 5). Although all linear relationships showed that water-soluble P increased as Mehlich III P increased (Table 5), the slopes and intercepts differed. Deep Hollow 2000 had the greatest slope and intercept, followed by the 2006 sampling at Beasley and, the 1996 sampling at Deep Hollow had the smallest slope and intercept. Reduced tillage not only resulted in a greater extractable P, but also changed the relationship of water-soluble P to extractable P. It is not clear how tillage practice impacted this linear relationship and how this linear relationship would impact the P in runoff. It appeared from this study that RT retained more Mehlich III P in soil, and more Mehlich III P resulted in higher levels of water-soluble P that crops require. Based on Havlin et al. (1999), average water-soluble P in soil is about 0.05 ppm, and the water-soluble P concentration required by most plants varies from 0.003 to 0.3 ppm, depending on the crop species and production level. The water-soluble P in Deep Hollow watershed (1.1 and 2.8 ppm, respectively, for 1996 and 2000) and Beasley watershed (1.2 and 1.8 ppm, respectively, for 1996 and 2006) fell above that range in both sampling years. The mean water-soluble P during the second sampling was significantly greater than that obtained in the first sampling, similar to Mehlich III P (Tables 3 and 4) in both watersheds. Actual P values from sampling locations generally increased in the second sampling (Figs. 5, 6). These data lend credence to the argument that native P levels in Mississippi Delta soils are relatively high, and that farmers should not be advised to apply P to these soils (Figs. 5, 6), particularly because adding fertilizer to crops that do not need it only increases potential P loss.

Spatial Variability of Phosphorus

Average semivariances of experimental data were plotted at a separation interval of 60 m (Gaston et al., 2001). Fig. 7 shows

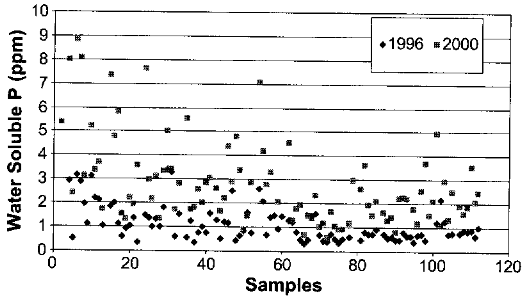

FIG. 5. Comparison of water-soluble P between 1996 and 2000 in Deep Hollow watershed.

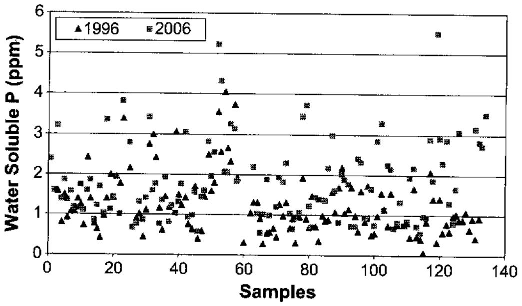

FIG. 6. Comparison of water-soluble P between 1996 and 2006 in Beasley Lake watershed

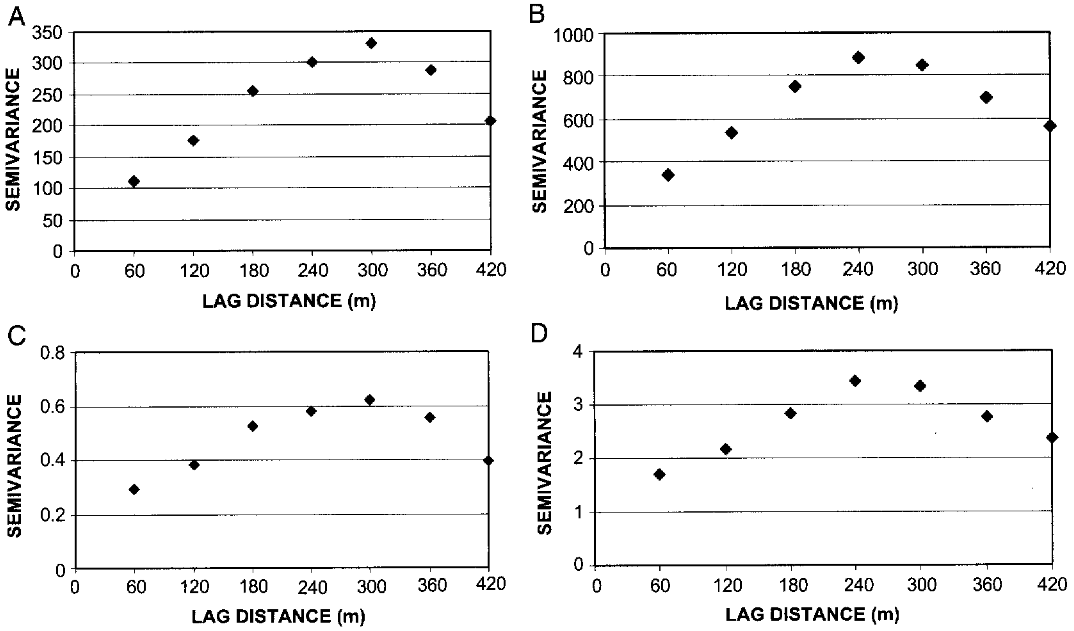

FIG. 7. Experimental semivariograms for (A) Mehlich III P for 1996 data, (B) Mehlich III P for 2000 data, (C) water-soluble P for 1996 data, and (D) water-soluble P for 2000 data at Deep Hollow.

experimental semivariograms of Mehlich III P (data from 1996 and 2000) and water-soluble P (data from 1996 and 2000) for Deep Hollow. In general, the data showed spatial dependence, that is, if there is spatial dependence, P measurements within a certain distance from a sampling point (a range) are considered to be related. At locations farther than that distance, the values are independent. Mehlich III P from 2000 presented similar spatial structures as that from 1996 (Fig. 7), as did the water-soluble P. In addition, the water-soluble P in 1996 presented similar spatial structures as that corresponding to Mehlich III P in 1996, and the water-soluble P in 2000 presented similar spatial structures as that corresponding to Mehlich III P in 2000. The range of Mehlich III P and water-soluble P in 2000 was shorter than in 1996, possibly caused by the RT practices that have less soil disturbance than CT (Fig. 7). Semivariance plots for Beasley Lake watershed data demonstrated similar phenomena to that of Deep Hollow watershed (Fig. 8). Water-soluble P had spatial structure similar to Mehlich III P (Figs. 8A, B). In addition, the range in 2006 data (not shown) was shorter than in 1996. Experimental semivariances for Beasley data can be best described using the exponential model as fitted in Fig. 8.

Block-kriging maps of Mehlich III P and water-soluble P generated from semivariances at both locations (Figs. 9–11) showed data distribution and variation over the study areas. For Deep Hollow, the distribution and spatial variation of Mehlich III P in 2000 (Fig. 9B) resembled that in 1996 (Fig. 9A) and the water-soluble P in 2000 (Fig. 9D) resembled that in 1996 (Fig. 9C) because of RT. In addition, water-soluble P in 1996 (Fig. 9C) generally corresponded with Mehlich III P in 1996 (Fig. 9A), and water-soluble P in 2000 (Fig. 9D) generally corresponded with Mehlich III P in 2000 (Fig. 9B). Although the distribution and spatial variation of Mehlich III P in 2006 (Fig. 10B) somewhat resembled that in 1996 (Fig. 10A), more variations during the second sampling were observed at Beasley than at Deep Hollow. This may be caused by more tillage operations that occurred from the first sampling at Beasley than at Deep Hollow (Tables 1 and 2). More variations were observed for water-soluble P, and water-soluble P from 2006 (Fig. 11B) did not resemble that from 1996 (Fig. 11A). Distribution of

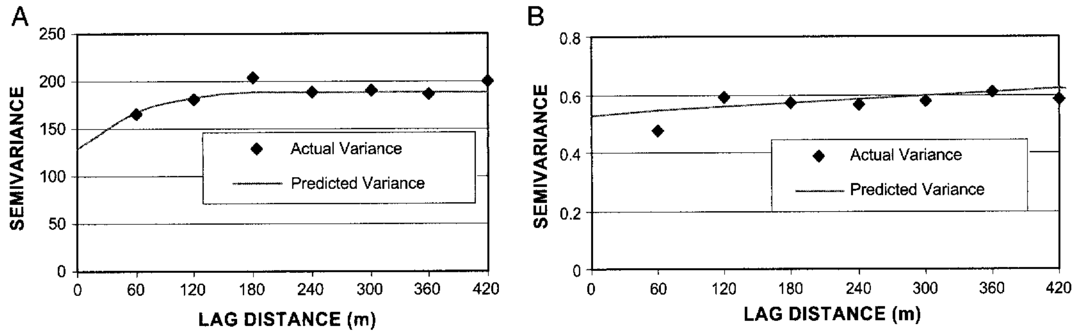

FIG. 8. Semivariograms for (A) Mehlich III P for 1996 data and (B) water-soluble P for 1996 data at Beasley.

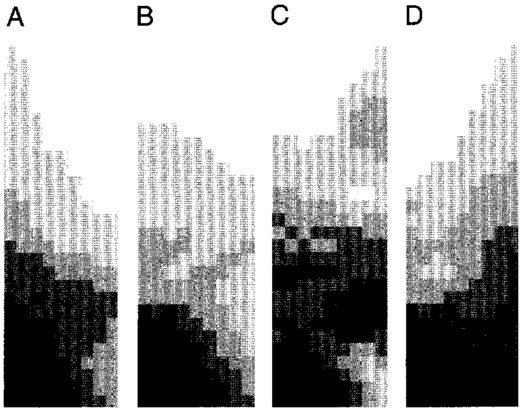

FIG. 9. Block-kriging estimates of (A) Mehlich III P for 1996 data, (B) Mehlich III P for 2000 data, (C) water-soluble P for 1996 data, and (D) water-soluble P for 2000 data at Deep Hollow. Darker colors correspond to higher values.

water-soluble P in 2006 was more random than in 1996. As more tillage operations caused more nutrient variation, more rainfall and runoff events could result in a more random distribution of water-soluble P.

SUMMARY AND CONCLUSIONS

Analysis of data collected from two Mississippi Delta watersheds before and after conservation tillage implementation showed that soils in these Mississippi Delta watersheds followed typical patterns in the surface region, including enhanced organic matter, lower availability of NO_3-N, and an accumulation of nutrients such as P, K, Ca, and Mg after conservation tillage was implemented. Data collected from three periods, 1996, 2000, and 2006, consistently showed high soil P levels in these soils, although relatively low P fertilizer was applied. This indicates that these alluvial soils have relatively high native soil P levels, and farmers may be cautioned against adding fertilizer P to help lower the environmental risk of loss to surface water and groundwater. Reduced tillage is especially important in this area because of high sediment loss associated with CT systems (Knight and Welch, 2004). Increased SOM caused by RT or cover crop (Deep Hollow) may enhance retention of P in these soils. However, strong P sorption to soil clay and organic matter also renders it vulnerable to loss associated with runoff sediment.

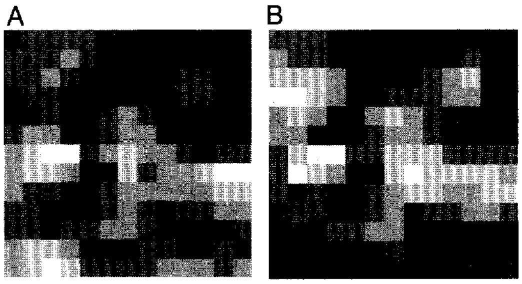

FIG. 10. Block-kriging estimates of (A) Mehlich III P for 1996 data and (B) Mehlich III P for 2006 data at Beasley. Darker colors correspond to higher values.

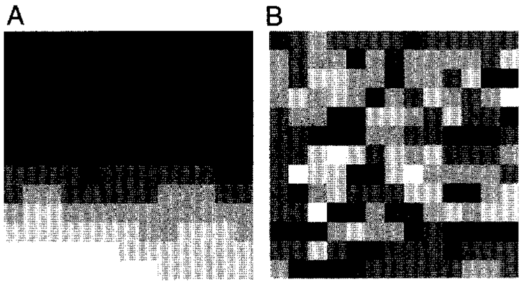

FIG. 11. Block-kriging estimates of (A) water-soluble P for 1996 data (B) water-soluble P for 2006 data at Beasley. Darker colors correspond to higher values.

It was found that water-soluble P is linearly correlated with Mehlich III P. Spatial analysis showed that P data were spatially dependent and tillage practices impacted their spatial dependence.

REFERENCES

Andraski, T. W., L. G. Bundy, and K. C. Kilian. 2003. Manure history and long-term tillage effects on soil properties and phosphorus losses in runoff. J. Environ. Qual. 32(5):1782–1789.

Angers, D. A., M. A. Bolinder, M. R. Carter, E. G. Gregorich, R. P. Voroney, C. F. Drury, B. C. Liang, R. R. Simard, R. G. Donald, R. P. Beyaert, and J. Martel. 1997. Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. Soil Tillage Res. 41(3):191–201.

Boeringa, M. 2004. Kriging 1.1. Interpolator extension for Arcview 3.2. Hydrology Department of Amsterdam Water Supply. Amsterdam, Netherlands. Available from http://arcscripts.esri.com/details.asp?dbid=10079 (verified July 25, 2007).

Bond, C. R., R. O. Maguire, and J. L. Havlin. 2006. Change in soluble phosphorus in soils following fertilization is dependent on initial Mehlich-3 phosphorus. J. Environ. Qual. 35(5):1818–1824.

Burrough, P. A., and R. A. Mcdonnell. 1998. Principles of Geographical Information Systems: Spatial Information Systems and Geostatistics. Oxford University Press, New York, NY.

Blevins, R. L., and W. W. Frye. 1993. Conservation tillage: An ecological approach to soil management. Adv. Agron. 63(2):593–596.

Buczko, U., O. Bens, and R. F. Huttl. 2006. Tillage effects on hydraulic properties and macroporosity in silty and sandy soils. Soil Sci. Soc. Am. J. 70(6):1998–2007.

Carroll, S. D., C. G. Herron, and D. C. Lafex. 2005a. Determination of soil pH. University of Arkansas Soil Testing and Research Laboratory. Marianna, AR. Available at http://www.uark.edu/depts/soiltest/Methods/Soil%20pH.htm. Accessed on August 21, 2007.

Carroll, S. D., C. G. Herron, and D. C. Lafex. 2005b. Mehich 3 Soil Extraction-Analysis for K, Ca, Na, Mg, Fe, Mn, Cu, Zn, B, S, P. University of Arkansas Soil Testing and Research Laboratory. Marianna, AR. Available at http://www.uark.edu/depts/soiltest/Methods/MEHLICH%203%20SOIL1_10.htm Accessed on August 21, 2007.

Carroll, S. D., C. G. Herron, and D. C. Lafex. 2005c. Nitrate-Nitrogen. University of Arkansas Soil Testing and Research Laboratory. Marianna, AR. Available at http://www.uark.edu/depts/soiltest/Methods/Nitrate.htm. Accessed on August 21, 2007.

Collins, M. E., and R. J. Kuehl. 2000. Organic matter accumulation and organic soils. *In* Wetland Soils: Genesis, Hydrology, Landscapes, and Classification. J. L. Richardson and M. J Vepraskas (eds.). CRP Press, New York, NY. pp. 137–162.

Combs, S. M., and M. V. Nathan. 1998. Soil Organic Matter. Recommended Chemical Soil Test Procedures for the North Central Region. Missouri Agricultural Experiment Station SB 1001. Columbia, MO. pp. 53–58.

Cox, M. S. 2001. The Lancaster soil test method as an alternative to the Mehlich 3 soil test method. Soil Sci. 166(7):484–489.

Dabney, S. M., J. D. Schreiber, S. Smith, and S. S. Knight. 2004. Groundwater nutrients in the Beasley Lake watershed of the Mississippi delta management systems evaluation area: American Chemical Society symposium series 877. *In* Water Quality Assessments in the Mississippi Delta. M. T. Nett, M. A. Locke, and D. A. Pennington (eds.). Oxford University Press, New York, NY. pp. 75–90.

Daverede, I. C., A. N. Kravchenko, R. G. Hoeft, E. D. Nafziger, D. G. Bullock, J. J. Warren, and L. C. Gonzini. 2003. Phosphorus runoff: Effect of tillage and soil phosphorus levels. J. Environ. Qual. 32(4):1436–1444.

Dick, W. A., W. M. Edwards, and E. L. McCoy. 1997. Continuous application of no-tillage to Ohio Soils: Changes in crop yields and organic matter–related soil properties. *In* Soil Organic Matter in Temperate Agroecosystems. E. A. Paul, K. Paustian, E. T. Elliott, and C. V. Cole (eds.). CRC Press, New York, NY.

Donahue, S. J. 1983. Determination of Soil Water pH. Reference Soil Test Methods for the Southern Region of the United States. Southern Cooperative Series Bulletin 289. University of Georgia College of Agriculture Experiment Station. Athens, GA. pp. 1–4.

Donahue, S. J. 1992. Determination of Nitrate-Nitrogen by Specific-Ion Electrode. Reference Soil Media Diagnostics for the Southern Region of the United States. Southern Cooperative Bulletin 347. University of Georgia College of Agriculture Experiment Station. Athens, GA. pp. 25–27.

Espinoza, L., N. Slaton, and M. Mozaffari. 2006. Understanding the Numbers on Your Soil Test Report. Cooperative Extension Service, University of Arkansas. Marianna, AR. Available from http://www.uark.edu/depts/soiltest/ (verified August 21, 2007).

Fang, F., P. L. Brezonik, D. J. Mulla, and L. K. Hatch. 2002. Estimating runoff phosphorus losses from calcareous soils in the Minnesota River basin. J. Environ. Qual. 31(6):1918–1929.

Fuhrman, J. K., H. Zhang, J. L. Schroder, and R. L. Davis. 2005. Water-soluble phosphorus as affected by soil to extractant ratios, extraction times, and electrolyte. Commun. Soil Sci. Plant Anal. 36(7):925–935.

Gaynor, J. D., and W. I. Findlay. 1995. Soil and phosphorus loss from conservation and conventional tillage in corn production. J. Environ. Qual. 24(4):734–741.

Gaston, L. A., M. A. Locke, R. M. Zablotowicz, and K. N. Reddy. 2001. Spatial variability of soil properties and weed populations in the Mississippi Delta. Soil Sci. Soc. Am. J. 65(2):449–459.

Grandy, A. S., T. D. Loecke, S. Parr, and G. P. Robertson. 2006. Long-term trends in nitrous oxide emissions, soil nitrogen, and crop yields of till and no-till cropping systems. J. Environ. Qual. 35(6):1487–1495.

Guzman, J. G., C. B. Godsey, G. M. Pierzynski, D. A. Whitney, and R. E. Lamond. 2006. Effects of tillage and nitrogen management on soil chemical and physical properties after 23 years of continuous sorghum. Soil Tillage Res. 91:199–206.

Havlin, J. L., J. D. Beaton, S. L. Tisdale, and W. L. Nelson. 1999. Soil Fertility and Fertilizers: An Introduction to Nutrient Management, 6th Ed. Prentice Hall, Upper Saddle River, NJ.

Isaaks, E. H., and R. M. Srivastava. 1989. An Introduction to Applied Geostatistics. Oxford University Press, New York, NY.

Ismail, L., R. L. Blevins, and W. W. Frye. 1994. Long-term no-tillage effects on soil properties and continuous corn yields. Soil Sci. Soc. Am. J. 58(1):193–198.

Knight, S. S., and T. D. Welch. 2004. Evaluation of watershed management practices on oxbow lake ecology and water quality. American chemical society symposium series 877. *In* Water Quality Assessments in the Mississippi Delta. M. T. Nett, M. A. Locke, and D. A. Pennington (eds.). Oxford University Press, New York, NY. pp. 119–133.

Locke, M. A. 2004. Mississippi Delta management systems evaluation area: Overview of water quality issues on a watershed scale. American Chemical Society symposium series 877. *In* Water Quality Assessments in the Mississippi Delta. M. T. Nett, M. A. Locke, and D. A. Pennington (eds.). Oxford University Press, New York, NY. pp. 1–15.

Locke, M. A., and C. T. Bryson. 1997. Herbicide-soil interactions in reduced tillage and plant residue management systems. Weed Sci. 45:307–320.

Locke, M. A., W. J. Staddon, R. M. Zablotowicz, and S. M. Dabney. 2001. Nutrient distribution in reduced tillage and conventional tillage cotton soils. *In* The Mississippi Delta Management Systems Evaluation Areas Project, 1995–1999. R. A. Rebich and S. S. Knight (eds.). Mississippi Agricultural and Forestry Experiment Station Information Bulletin 377:144–148.

Locke, M. A., S. S. Knight, S. Smith Jr., R. F. Cullum, R. M. Zablotowicz, Y. Yuan, and R. L. Bingner. 2008. Environmental quality research in the Beasley Lake watershed, 1995 to 2007: Succession from conventional to conservation practices. J. Soil Water Conserv. 63(6):430–442.

Maguire, R. O., and J. T. Sims. 2002. Measuring agronomic and environmental soil phosphorus saturation and predicting phosphorus leaching with Mehlich 3. Soil Sci. Soc. Am. J. 66(6):2033–2039.

Mausbach, M. J., and A. R. Dedrick. 2004. The length we go: Measuring environmental benefits of conservation practices. J. Soil Water Conserv. 59(5):97A–103A.

McDowell, R., A. Sharpley, P. Brookes, and P. Poulton. 2001. Relationship between soil test phosphorus and phosphorus release to solution. Soil Sci. 166(2):137–149.

McVay, K. A., J. A. Budde, K. Fabrizzi, M. M. Mikha, C. W. Rice, A. J. Schlegel, D. E. Peterson, D. W. Sweeney, and C. Thompson. 2006. Management effects on soil physical properties in long-term tillage studies in Kansas. Soil Sci. Soc. Am. J. 70(2):434–438.

Mehlich, A. 1984. Mehlich 3 soil extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15(12):1409–1416.

Mississippi State University Extension Service, 2007. Soils: Soil Testing. Available from http://msucares.com/crops/soils/mgsoitestin.html (verified September 2, 2007).

Needleman, B. A., M. M. Wander, G. A. Bollero, C. W. Boast, G. K. Sims, and D. G. Bullock. 1999. Interaction of tillage and soil texture: Biologically active soil organic matter in Illinois. Soil Sci. Soc. Am. J. 63(5):1326–1334.

Nelson, M. A., S. M. Griffith, and J. J. Steiner. 2006. Tillage effects on nitrogen dynamics and grass seed crop production in Western Oregon, USA. Soil Sci. Soc. Am. J. 70:825–831.

Ott, R. L. 1993. An Introduction to Statistical Methods and Data Analysis. Duxbury Press, Pacific Grove, CA.

Park, E., and A. J. M. Smucker. 2005. Saturated hydraulic conductivity and porosity within macroaggregates modified by tillage. Soil Sci. Soc. Am. J. 69(1):38–45.

Pautler, M. C., J. T. Sims. 2000. Relationships between soil test phosphorus, soluble phosphorus and phosphorus saturation in Delaware soils. Soil Sci. Soc. Am. J. 64(2):765–773.

Perfect, E., and J. Caron. 2002. Spectral analysis of tillage-induced differences in soil spatial variability. Soil Sci. Soc. Am. J. 66(5):1587–1595.

Press, W., B. Flannery, S. Teukolsky, and W. Vetterling. 1986. Numerical Recipes—The Art of Scientific Computing. Cambridge University Press, Cambridge, UK, pp. 523–528.

Pote, D. H., T. C. Daniel, A. N. Sharpley, P. A. Moore Jr., D. R. Edwards, and D. J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Sci. Soc. Am. J. 60(3):855–859.

Pote, D. H., T. C. Daniel, D. J. Nichols, A. N. Sharpley, P. A. Moore Jr., D. M. Miller, and D. R. Edwards. 1999. Relationship between phosphorus levels in three Ultisols and phosphorus concentrations in runoff. J. Environ. Qual. 28(1):170–175.

Rhoton, F. E. 2000. Influence of time on soil response to no-till practices. Soil Sci. Soc. Am. J. 64:700–709.

Seta, A. K., R. L Blevins, W. W. Frye, and B. J. Barfield. 1993. Reducing soil erosion and agricultural chemical losses with conservation tillage. J. Environ. Qual. 22(4):661–665.

Sharpley, A. N. 1995. Dependence of runoff phosphorus on extractable soil phosphorus level. J. Environ. Qual. 24(5):920–926.

Sikora, F. J., P. S. Howe, L. E. Hill, D. C. Reid, and D. E. Harover. 2004. Comparison of colorimetric and ICP determination of phosphorus in Mehlich-3 extracts. Commun. Soil Sci. Plant Anal. 36(7):875–887.

Snipes, C. E., L. P. Evans, and D. H. Poston. 2004. Agricultural practices of the Mississippi delta. American chemical society symposium series 877. *In* Water Quality Assessments in the Mississippi Delta. M. T. Nett, M. A. Locke, and D. A. Pennington (eds.). Oxford University Press, New York, NY. pp. 1–15.

Soon, Y. K., G. W. Clayton, and W. A. Rice. 2001. Tillage and previous crop effects on dynamics of nitrogen in a wheat-soil system. Agron. J. 93(4): 842–849.

Sparrow, S. D., C. E. Lewis, and C. W. Knight. 2006. Soil quality response to tillage and crop residue removal under subarctic conditions. Soil Tillage Res. 91(1):15–21.

Steinbach, H. S. and R. Alvarez. 2006. Changes in soil organic carbon contents and nitrous oxide emissions after introduction of no-till in Pampean agroecosystems. J. Environ. Qual. 35(1):3–13.

Sumner, E. M. 2000. Handbook of Soil Science. CRC Press, New York, NY.

Tomer, M. D., C. A. Cambardella, D. E. James, and T. B. Moorman. 2006. Surface-soil properties and water contents across two watersheds with contrasting tillage histories. Soil Sci. Soc. Am. J. 70(2): 620–630.

U. S. Environmental Protection Agency. 1990. Maximum Contaminant Levels (Subpart B of 141, National Primary Drinking Water Regulations). In U. S. Code of Federal Regulations, Title 40, Parts 100–149:559-563. U. S. GPO, Washington, DC.

Wright, A. L. and F. M. Hons. 2005. Soil carbon and nitrogen storage in aggregates from different tillage and crop regimes. Soil Sci. Soc. Am. J. 69(1):141–147.

Zablotowicz, R. M., M. A. Locke, L. A. Gaston, and C. T. Bryson. 2000. Interactions of tillage and soil depth on fluometuron degradation in a Dundee silt loam soil. Soil Tillage Res. 57(1):61–68.

Zibilske, L. M., J. M. Bradford, and J. R. Smart. 2002. Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. Soil Tillage Res. 66(1):153–163.

Tra

Yo

Abstract:
content is
chemical pr
this article,
selected as t
laser grain-s
variability o
transiogram.
spatial distri
random. Ho
hibited obvi
horizontally.
transition pr
create condi
zations were
well as mean
major textur
were underes
were well re
measured da
reduced, wh
measured da
which were n
accuracy of p
suitable meth
The results m

Key words: S
geostatistics,

(*Soil Sci* 200

Clay is
composi
physical, ch
science, mu
formed. In s
has a signifi
decompositi
organism. In

---

[1]Department o
Sciences Colle
China. Dr. Hua
[2]School of Res
Land and Envir

Received Octob
Accepted for pu
Copyright © 20
ISSN: 0038-075
DOI: 10.1097/S