CAN DIVERSIFIED CROP ROTATION REDUCE NO-TILL INDUCED STRATIFICATION OF PHOSPHORUS AND POTASSIUM?

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ABSTRACT

The increasing adoption of No-till as a conservation practice has been beneficial for agricultural land. However, given the lack of mechanical disturbance, nutrients such as phosphorus (P) and potassium (K), may tend to accumulate at the soil surface (stratification) and affect both crop nutrition and water quality (P in particular). This study investigated the stratification ratio of P and K after 63 years of No-till and evaluated the role of crop diversification in minimizing P and K-stratification. Treatments included three tillage systems (no-till, chisel, moldboard plow) and three crop rotations (continuous corn, corn-soybean, corn-forage-forage) and two contrasting soil types (Sites: Hoytville and Wooster, OH). Our results showed that No-till increased both P and K in the surface (0 to 4 inches). P stratification ratios were affected by tillage and crop rotation, but the effect of crop rotation was site dependent; at Hoytville, adding soybean to the rotation decreased P-stratification by approximately 50% within No-till system. Potassium stratification showed no interaction between tillage and crop rotation. Overall, continuous corn under No-till showed the highest P-stratification ratio (6.47). Although inconsistent, crop rotation can reduce No-till induced stratification, future studies may need to evaluate synergistic practices that can further improve the effect of crop rotation.

INTRODUCTION

No-till induced stratification is very common in conservation systems. Given the lack of mechanical disturbance, nutrients tend to accumulate in the upper (0-10 cm) and decrease in lower depths (Dick, 1983; Essington & Howard, 2000). Nutrients like phosphorus (P) and potassium (K) with relatively low mobility in soil, stratify even more, causing negative effects on crop and water quality (particularly for P) (Smith et al., 2017). However, the adoption of no-till has provided numerous benefits to soil health: reducing erosion, increased accumulation of organic matter and improving overall farm resilience (Hariharan et al., 2017, Deiss et al., 2021, de Camargo et al., 2025). Therefore, tillage appears to be a too-risky alternative to reduce stratification. As roots extend vertically within the soil profile, crop diversification could play a key role in minimizing nutrient stratification by promoting more uniform nutrient redistribution throughout the soil profile in the long run (Jobbágy & Jackson, 2001; Karlen et al., 2006;

Blanco-Canqui & Lal, 2008; Franzleubbers, 2010). However, it remains unclear whether long-term crop diversification can mitigate P and K stratification and whether the underlying mechanism of P and K stratification differ by nutrient (*P vs K*), and the intensities of crop diversity (*Continuous Corn, Corn soybean, Forage, Forage, Corn*) and tillage (*Moldboard, Chisel, and No-till*), and inherent soil properties *(% clay*). Here we evaluated the effects of these factors on P and K stratification ratios after 62 years of No-till in two sites with distinctive edaphic properties.

MATERIALS AND METHODS

Site & Experimental design

Research was conducted on the Triplett-Van Doren Tillage and Crop Rotation Experiment initiated in 1962 near Wooster, Ohio, USA (40°45′ N, 81°54′ W) and in 1963 near Hoytville, Ohio, USA (40°45′ N, 81°54′ W). The Wooster site is a well-drained silt loam (fine-loamy, mixed, active, mesic Oxyaquic Fragiudalfs), with a 2 to 6 % slope. The Hoytville site is a poorly drained clay loam (fine, illitic, mesic Mollic Epiaqualfs) with a 0 to 1 % slope.

The study design was a randomized complete block design with three replications of three tillage intensity levels and three crop rotations. Tillage categories were (1) No-till (2) chisel plow since 1984 (a paraplow was used from 1962 to 1983) and (3) moldboard at approximately 8 inches inversion. Crop rotations were (1) continuous-corn (*Zea mays* L.); (2) 2-year corn and soybean (*Glycine max* L.) rotation; and (3) 3-year corn and oat (*Avena sativa* L.) and/or alfalfa (*Medicago sativa)* or clover (*Trifolium repens* L.) rotation. (Corn-Forage-Forage)

Soil Sampling

Soil samples were taken in the Spring of 2024. Each core was then divided at 4 inch depth intervals. Soils were homogenized by depth and sieved to pass through a 2 mm sieve. A subsample was sent to a commercial lab to determine available P and K concentrations using a Mehlich-3 extractant solution (Mehlich, 1984) and analyzed with an inductively coupled plasma atomic emission spectrophotometer (Spectrum Analytics, Washington Courthouse, OH). Stratification ratios were calculated from Mehlich-3 P and K concentrations at 0 to 4 inches divided by those at 4 to 8 inches.

Statistical Analysis

A mixed effect ANOVA was conducted by site in R version 4.5.2 using the lme4 package (Bates et al., 2015). The model included the stratification ratios as response variable, tillage intensity (Moldboard, Chisel and No-till), crop rotation (Continuous corn, Corn-soybean, Corn-Forage-Forage-) and the combination of both crop rotation and tillage as fixed factors. Replications were added as random factors. Mean separation was evaluated through the Tukey test and statistical significance was defined at probability levels < 0.05.

RESULTS

P-stratification as influenced by tillage and crop diversity

P-stratification ratios were generally higher than 1 indicating that P tended to accumulate more in the upper 10 cm of the soil profile compared to the 4-8 inches (Table 1). The P-stratification ratios ranged from 0.98-6.47. These ratios were much greater in soils under conservation tillage and decreased with tillage intensity. In Hoytville**,** the tillage × crop rotation interaction was significant, indicating that the reduction in P stratification with increasing tillage intensity was more pronounced under diversified crop rotation (Corn-soybean) and (CFF) than under continuous corn (Table 2). The highest P-stratification ratio was found in the No-till systems under continuous corn (6.47). When soybean is added to the rotation (continuous-corn vs corn soybean), P-stratification ratio was reduced by approximately 50%. The longer rotation (CFF) did not further reduce the No-till induced P-stratification ratio compared to the Corn-Soybean rotation.In Wooster, tillage intensity and crop rotation affected stratification ratio, however, the interaction between tillage and crop rotation was non-significant.

K-stratification as influenced by tillage and crop diversity

In Hoytville, K-stratification ratio was mainly influenced by tillage intensity. K-stratification ratios ranged from 1.02 to 1.28 regardless of crop rotation. In Wooster, K-stratification followed the same trend but was affected by both crop rotation and tillage intensity independently.

CONCLUSIONS

Our results showed that both P and K tend to accumulate in the 0 to 4 inches soil layer and that the accumulation of these nutrients increases with reduced tillage intensity, even after 60+ years of no-tillage. The effect of crop diversity on No-till induced stratification is site-specific and differs between rotations. In the clay-loam soil in Hoytville, we found that the effect of tillage intensity was influenced by diversified rotation compared to continuous corn crop. However, there was no significant interaction between tillage intensity and crop rotation for potassium at the same site. In Wooster, the effect of P and K stratification ratios was equally influenced by rotation and tillage intensity. Although long-term No-till increased P and K stratification, the numerous benefits that No-till adoption has provided to overall agroecosystem sustainability should not be overlooked. Here, we are proposing crop diversification as an alternative to redistribute nutrients through the profile without soil disturbance and while maintaining nutrient availability and reducing environmental losses.

ACKNOWLEDGMENTS

Research support was provided by Ohio Soybean Council.

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Table 1. Stratification ratios of P and K after 63 years of different tillage intensities and crop rotations in Ohio. Different letters within tillage show statistical differences on crop rotation within that tillage category.

		P-stratification ratio			K-stratification ratio		
Site	**Tillage**	**Cont.Corn**	**Corn-Soybean**	**CFF**	**Cont. Corn**	**Corn-Soybean**	**CFF**
Hoytville	**Chisel(MT)**	2.31a	1.41a	1.77a	1.07a	1.02a	1.24a
	Moldboard	0.98a	1.07a	1.09a	1.03a	1.01a	1.03a
	No-till	6.47b	3.21a	3.43a	1.14a	1.22a	1.28a
Wooster	**Chisel (MT)**	1.27a	0.90a	1.36a	1.64ab	1.35a	2.01b
	Moldboard	1.07a	0.96a	1.11a	1.24ab	0.96a	1.41b
	No-till	1.98a	1.51a	1.90a	1.64a	1.75a	1.95a

Table 2. Analysis of variance for Mehlich-3 P and Mehlich-3 K at Wooster and Hoytville following 63 years of no-tillage

		Hoytville			
		P_Stratification Ratio		K_Stratification Ratio	
Source	df	*F value*	*P-value*	*F value*	*P-value*
Tillage (T)	2	58.33	0.0001	6.16	0.0091
Rotation (R)	2	10.35	0.001	2.52	0.1085
T × R	4	6.16	0.0026	0.96	0.4537
		Wooster			
Source	df				
Tillage (T)	2	23.66	0.0001	20.99	<0.0001
Rotation (R)	2	5.24	0.0161	10.72	0.0008
T × R	4	0.56	0.6951	1.47	0.2539

Table 3. Average Mehlich-3 P and Mehlich-3 K concentrations and standard deviations in () by crop rotation in surface 0-10 cm and 10-20 cm depth layers at the Hoytville and Wooster sites.

Sites	Tillage Intensity	Crop Rotation					
		Continuous Corn		Corn-Soybean		Corn-Forage-Forage	
		Mehlich-3 P					
		0-10 cm	**10-20 cm**	**0-10 cm**	**10-20 cm**	**0-10 cm**	**10-20 cm**
	Moldboard	15.7 (2)	16 (1.5)	18.7 (2.2)	17.7 (2.7)	21.3 (2)	19.7 (1.8)
	Chisel	19.7 (4.8)	9 (3)	26 (1.7)	18.7 (1.2)	29 (3.5)	16.3 (0.7)
	No-till	55.3 (6.2)	8.7 (1.2)	41.3 (8.8)	13.3 (0.9)	34.3 (4.3)	10 (0)
Hoytville		*Mehlich-3 K*					
	Moldboard	233 (14)	226 (15)	246 (13)	243 (13)	250 (30)	245 (38)
	Chisel	244 (18)	227 (9)	245 (5)	241 (13)	285 (5)	230 (16)
	No-till	254 (23)	226 (40)	263 (27)	218 (28)	283 (42)	224 (42)
		Mehlich-3 P					
	Moldboard	37.7 (3.3)	35 (3.1)	43.3 (0.9)	37 (6.6)	41.3 (13.4)	20 (4)
	Chisel	40 (7.5)	41.7 (8)	49.3 (7.5)	55 (3.8)	32.7 (2.3)	21.7 (0.3)
	No-till	39.3 (7.3)	35.7 (7.4)	58.7 (7.8)	43.7 (6.1)	45.7 (6.2)	24 (3)
Wooster		*Mehlich-3 K*					
	Moldboard	147 (32)	120 (25)	130 (15)	135 (17)	189 (46)	137 (38)
	Chisel	156 (36)	94 (15)	142 (23)	106 (8)	276 (23)	138 (15)
	No-till	126 (23)	76 (10)	137 (32)	79 (24)	149 (15)	77 (4)

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