OPTIMUM PHOSPHORUS PLACEMENT FOR REDUCED TILLAGE SYSTEMS

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Abstract

Row-crop agriculture is under pressure to reduce sediment and nutrient losses to surface water resources by practicing less tillage and more precise application and placement of nutrients. Field studies started in 1997 were conducted through 2002 on very low to low P-testing (3 to 5 ppm Bray P_1) and medium to high-P testing (11 to 19 ppm Bray P_1) sites of a Nicollet-Webster clay loam complex at Waseca, MN. Four tillage systems (chisel + field cultivate, one-pass field cultivation or disking, strip-till, and no-till were compared in a corn-soybean rotation. Fertilizer P at rates of either 40 or 50 lb P_20_5/A was applied to corn as either a starter with the seed or as a deep-band (4 to 5 inches) below the row and was compared to 80 or 100 lb P_20_5/A applied broadcast and a no P control. The residual effect of the P treatments was measured in the soybean phase of the rotation.

On the low P-testing site, tillage affected the 6-yr average corn yields but not the 1998-2002 soybean yields. Starter fertilizer increased corn yield by 49 bu/A/yr across the 6-yr period, while soybean yields were increased by15 bu/A/yr across the 5-yr period due to the residual effects of the starter. A starter fertilizer x tillage interaction was never found for either crop. Corn and soybean yields were generally increased over the 50-lb starter P and deep-band P treatments by the 100-lb broadcast P treatment suggesting that band applications at a half-rate are usually not sufficient in low to very low P-testing soils.

On the high P-testing site, tillage affected the 6-yr and 5-yr corn and soybean averages. Highest yields were generally found with the chisel plow system followed by the one-pass and strip-till systems. Lowest yields were usually found with no tillage. Both corn and soybean yields were affected by the P treatments in 2002 (date not shown) because STP had declined to yield-limiting levels in the control plots in this third year of the corn-soybean cycle.

Soil test P in the 0- to 6-inch samples was greatly influenced by P management strategy whereas both tillage and P management strategy affected STP in the 0- to 2-inch layer. In general, STP in the 0- to 6-inch layer was greatest with the in-row starter and broadcast treatments. Broadcast P coupled with a shallow, one-pass tillage gave greatest STP in the 0- to 2-inch layer. Economic return to fertilizer P averaged almost \$100/A/yr on the low P-testing site with virtually no return to fertilizer P on the high P-testing site. On the low P-testing site, returns were greatest with the 100-lb broadcast treatment and lowest for the 50-lb "deep" band treatment.

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Introduction

Row-crop agriculture in the Mississippi River Basin is under intense pressure to reduce sediment and nutrient losses by practicing less tillage and more precise application and placement of nutrients (N and P). No-till, strip-till, and one-pass secondary tillage systems are being proposed as reduced tillage alternatives to conventional tillage. No-till corn production, however, has provided serious challenges to corn growers in the northern portions of the Corn Belt and has not been economically competitive with conventional tillage systems. This is especially true on the highly productive but poorly drained clay loam soils of northern Iowa and southern Minnesota where approximately 8 million acres are in corn production annually. Retarded early plant growth, delayed silking, greater moisture at harvest, and reduced corn yields are often associated with no-till systems that have high amounts of surface residue and cooler soil temperatures.

Strip tillage or zone tillage is suggested as an alternative to no-tillage in these northern climates where soils are cold at the time of planting and are slow to warm. This fall tillage method disturbs the soil to a 7- to 8-inch depth and creates a 4 to 6 inches wide by 1 to 2 inches high mound of soil that is free of residue. Corn can be planted early and directly into the strip area that is warmer and drier. One-pass, secondary tillage systems consist of no fall primary tillage and either field cultivation or a disking operation in the spring. This system is now quite popular for corn following soybeans in the Corn Belt.

Use of conservation tillage practices limits the opportunity for incorporation of phosphorus (P) containing fertilizers that are broadcast on the soil surface. Therefore, optimum placement of P fertilizers is essential in reduced tillage systems, especially in soils testing low in P. Thus, the purposes of this long-term study are to: (1) to determine the effect of P placement method in three reduced tillage systems and one conventional tillage system for corn-soybean rotations on: a) early plant growth, P removal, and yield of corn and soybeans, and b) phosphorus distribution in the soil profile, and (2) to provide management guidelines on phosphorus placement in very reduced tillage systems to corn producers, crop consultants, local advisors, and the fertilizer industry.

Experimental Procedures

The experiments were conducted on a tile drained Nicollet-Webster clay loam soil complex located at the Southern Research and Outreach Center, Waseca, Minnesota. The tile lines were spaced 75 feet apart and all rows were perpendicular to the tile lines. Two adjacent 3-acre sites were used. One site had been maintained at a high P test (19 ppm Bray P_1) with periodic P fertilizer applications while in a C-C-C-Sb rotation. Continuous corn receiving no fertilizer P for the last 15 years was planted on the other site to mine P and lower the soil test to very low levels (3-5 ppm Bray P_1). The P rates selected for this study were based on: (1) previous work that showed soil test P in a corn-soybean rotation to be maintained at a high level with about 40 lb of broadcast P_20_5/A/yr and (2) University of Minnesota recommendations that band rates of P can be optimized at half the broadcast rate. Therefore, the band and broadcast P rates applied prior to corn every other year were 40 and 80 lb P_20_5/A, respectively, for the high testing site and 50 and 100 lb P_20_5/A for the low testing site. DAP (18-46-0) was the P source for the deep-band and broadcast treatments, while 10-34-0 was the starter fertilizer. Beginning in the fall of 2000, 10-34-0 has been substituted for DAP in the deep-band treatments.

The experiment was started in the fall of 1996 with the application of the band and broadcast treatments for corn in 1997 on one set of plots. Another set of plots was started in the fall of 1997 for corn in 1998. This allows planting of both corn and soybeans each year in a continuous corn-soybean rotation. Each plot is 15 feet wide (6 – 30-inch rows) by 55' long. The 14 treatments for corn (Table 1) and soybean (Table 2) were replicated four times in a randomized, complete-block design. Corn was planted in 30-inch rows while soybean was planted in 8-inch rows with a no-till drill. Corn stalks were not stalk chopped prior to planting the no-till plots (treatments 1-2 and 7-10).

The strip-till and chisel tillage operations were performed following soybean harvest. The fall deep-band P treatment (no. 9) was applied about 5 inches deep with the strip tiller in a fixed position directly in the same strip-till zone each year prior to growing corn. The "random" placement of the deep band in the strip-till system (treatment 10) was located 8 inches to the side of the "random" zone where the fertilizer was placed in previous years. In the one-pass system where the plots are field cultivated in April prior to planting, the fall band treatment (no. 5) was placed about 5 inches deep in a band that runs at about a 2° angle to where the corn row will be planted. This assures that the fertilizer band will not be located continuously under the corn row, but will vary from directly under the row to as much as 15" from the row. The fall broadcast treatment (no. 14) was applied immediately before chiseling. The spring broadcast treatment (no. 6) was applied immediately before field cultivation.

Corn was planted in May at a population of 31,000 seeds/A with a John Deere Max-Emerge planter equipped with Yetter residue managers (row cleaners), which were used on the no-till and strip-till plots. Liquid starter fertilizer (10-34-0) was applied in the seed furrow at rates of 13 gal/A (50 lb P_20_5/A) in the low P-testing site and 10 gal/A (40 lb P_20_5/A) in the high P-testing site. After planting the corn, UAN was dribbled on the corn rows of the plots that did not receive any DAP or 10-34-0 at a rate of 7 gal/A to give the same rate of N applied near-the-row for all treatments. An additional 130 lb N/A as UAN was coulter-injected midway between the rows of all plots. Weed control was excellent with pre-emergence and post emergence herbicides. The corn was harvested with a plot combine.

Soybeans were planted in May following disking of the corn stalks on the one-pass treatments and field cultivation of the chisel plow treatments. A Tye drill was used to plant all plots. Roundup Ultra-Max was used to obtain excellent weed control on all plots. The soybeans were harvested with a plot combine.

Results and Discussion

<u>Yields on Low-Testing Soils</u>

Averaged across the 6-yr period (1997-2002), corn yield was affected significantly (P = 90% level) when tillage systems were compared across similar P management strategies (Table 1). Yields averaged 118, 127, 126, and 128 bu/A for the no-till, one-pass, strip-till, and chisel+f. cult. systems, respectively. A 49 bu/A yield response (101 vs 150 bu/A) was obtained with starter fertilizer when averaged across tillage systems. No interaction existed between tillage and starter fertilizer. Corn yields with the 100-lb P_20_5 broadcast rate were 12 to 13 bu/A greater than with the 50-lb starter rate. These data suggest that band applications of P at a half-rate on very low testing soils are not sufficient to optimize corn yields compared to broadcast applications of P at a full rate. Although an interaction existed between year and P management strategy (P = 95% level), year x tillage and year x tillage x P management interactions were not significant.

Averaged across the 5-yr period (1998-2002), soybean yield was not affected significantly (P = 90% level) when tillage systems were compared across similar P management strategies (Table 1). Yields averaged 41.3, 42.5, 43.3, and 40.9 bu/A for the no-till, one-pass spring disk, strip-till, and chisel systems, respectively. A 14.6 bu/A yield response (34.7 vs 49.3 bu/A) was obtained to the residual effect of starter fertilizer when averaged across tillage systems. No interaction was found between tillage system and starter fertilizer. When tillage systems using starter fertilizer were compared, yields were highest for the chisel system (50.4 bu/A) and slightly lower for the strip-till (49.7 bu/A), one-pass (49.1 bu/A), and no-till (48.0 bu/A) systems, but these yields were not statistically different (P=90% level). Soybean yields were 2.6 to 3.5 bu/A greater for the broadcast P treatments (100 lb P_20_5/A) compared to the starter and band P treatments (50 lb P_20_5/A). This difference was statistically significant at the P = 90% level. These data again suggest that band applications of P at a half-rate to low testing soils for corn are not sufficient to optimize soybean yields in the following year compared to broadcast application of P at a full rate.

Yields on High-Testing Soils

Averaged across the 6-yr period (1997-2002), corn yield was affected significantly [LSD (0.10) = 4 bu/A) when tillage systems were compared across similar P management strategies (Table 2). Yields were greatest with the chisel (168 bu/A), one-pass (165 bu/A) and strip-till (166 bu/A) systems and lowest for no tillage (158 bu/A). Starter fertilizer increased yields significantly (5 bu/A), but no interaction was found between tillage and starter fertilizer. Yields were different between the starter P and broadcast P treatments in the chisel system (170 vs 176 bu/A) and the one-pass, field cultivate system (168 vs 176 bu/A).

Averaged across the 5-yr period (1998-2002), soybean yield was affected significantly [LSD(0.10) = 1.7 bu/A] when tillage systems were compared across similar P management strategies (Table 2). Highest yields were obtained with the one-pass system (54.3 bu/A) and chisel system (53.4 bu/A) with somewhat lower yields for the strip-till (52.2 bu/A) and no-till (51.4 bu/A) systems. Soybean yield did not respond to the residual effect of starter fertilizer when averaged across tillage systems, and a tillage x starter fertilizer interaction did not occur. A yield difference was not found between the 80-lb broadcast rate of P_20_5 and the 40-lb rate applied either as a starter or as a deep-band below the corn row.

Soil Test P

Bray P_1 soil test values in the corn plots in June 2002 are shown in Table 1 for the low P-testing site and in Table 2 for the high P-testing site. The values are the composite of 12 cores (0 to 6 inches deep) taken in a fixed pattern of three sets of four cores. Each set was taken along a transect perpendicular to the row with one core directly in the row and the others at distance of 7.5, 15, and 22.5 inches from the row. Soil test P (STP) in the low testing site (VL-L) averaged 3 ppm for the unfertilized plots in all four tillage systems. Adding 50 lb P_2O_5/A in a starter band in the seed row in 1998, 2000, and 2002 resulted in STP values of 22, 17, 28, and 14 ppm for the no-till, one-pass, strip-till, and chisel systems, respectively. Applying the same 50-lb rate in deep-bands (about 5 inches below the row) for these same three crop-years resulted in much lower STP values ranging from 6 to 9 ppm, whereas broadcast applications of 100 lb P_2O_5/A for each of these three crop-years gave STP values ranging from 16 to 18 ppm. These soil test values reflect the difficulty of obtaining a "representative" STP value when P is consistently band-applied – even when a fixed soil-sampling pattern is used. When the P was placed as a starter in the row with the seed, it appears that this concentrated zone of P became part of the soil core in 3 of the 12 cores resulting in an elevated STP value similar to those obtained with broadcasting twice as much fertilizer P. However, when the P was placed in a "deep band" 5 inches below the row, the lower STP values suggest that the core taken in the row area missed the zone of P concentration either because the P was below the 6-inch sample depth or the P was distributed across a wider area (outside of the 1-

inch core diameter) in the 4- to 6-inch-wide strips. The latter reason is more likely, especially since the P was airflow-applied as DAP for the 1997 and 1999 crops. This application method would have distributed the DAP in a wider, horizontal pattern resulting in a less-concentrated zone of P–hence lower STP values compared to the more highly concentrated starter band placement of 10-34-0 with the seed.

At the high P-testing site, STP declined from the original 19 ppm (H) values to 8 to 12 ppm (M) in all tillage systems when no P was applied during this 6-year period (Table 2). The relative ranking of STP values for the starter, deep-band, and broadcast P treatments was somewhat similar to that found at the VL-L site. Soil test P values ranged from 21 to 37 ppm where the 40-lb P_2O_5 rate was placed in the row as a starter, from 13 to 16 ppm when placed 5 inches below the row in a "deep-band," and from 30 to 32 ppm when broadcast at the 80-lb P_2O_5 rate.

Soil test P (Bray P_1) values from 0- to 2-inch samples taken in October, 2002 after soybeans (3 cycles of a corn-soybean rotation) are shown in Table 3 for both the low and high testing sites. These data reflect the concentration of P in the surface 2 inches as influenced by three applications (1997, 1999, and 2001) of the P treatments shown in Tables 1 and 2 and six cropping years. At the low P-testing site, STP for the 0-lb P_20_5 control plots ranges from 4 to 6 ppm across tillage systems. Applying 50 lb P_20_5/A three times in the seed furrow as a starter resulted in STP ranging from 13 to 14 ppm for the reduced tillage systems and 10 ppm for the chisel system. Apparently the aggressive chisel tillage mixed the soil sufficiently, causing the lower STP values. When the same rate was applied 5" below the row in a "deep" band, STP was only 6 ppm. When 100 lb P_20_5/A was broadcast applied, STP ranged from 18 ppm in the chisel system with deeper mixing of the soil to 36 ppm in the one-pass system where only shallow tillage had been conducted. Similar results were obtained at the high P-testing site. When no P was applied during the 6-yr period, STP ranged from 12 to 15 ppm. Applying 40 lb P_20_5/A in 1997, 1999, and 2001 in the seed furrow as a starter resulted in STP values ranging from 21 (chisel tillage) to 29 ppm (no tillage). When applying the same 40-lb P_20_5 rate in a 5-inch "deep" band below the row, STP ranged from 16 to 17 ppm. Three broadcast applications of 80 lb P_20_5/A gave STP values of 50 ppm in a one-pass shallow tillage system and 35 ppm in a deeper chisel plow tillage system.

Soil test P has been shown to be highly and positively related to the potential for P eutrophication of surface water bodies. Thus, the importance of tillage system and P management strategy (placement and rate) from an environmental water quality perspective is readily seen in this study. Shallow, conservation tillage systems coupled with broadcast P application can result in greatly elevated STP levels, creating a high potential for significant P losses to surface water. On the other hand, in-furrow starter or "deep" band placement of P minimizes the potential for substantial P loss; although yields may suffer slightly under low STP conditions.

In summary, these data very clearly and consistently show the importance of P placement methods relative to STP values in all tillage systems even when using a very fixed sampling pattern. STP in the 0- to 6-inch layer was greatly increased when a concentrated band of starter P was sampled as part of only 3 cores in a composite sample of 12 cores. Applying the same P_2O_5 rate in a slightly wider (4 to 6 inches) and deeper band (5 inches below the row) resulted in considerably lower STP values. Broadcast applications of a 2X P_2O_5 rate gave 0- to 6-inch layer STP values midway between an X rate of P_2O_5 applied as a starter with the seed and the same X rate applied in a wider deep-band below the seed. The influence of tillage on the STP concentrations in the surface 2 inches was particularly evident. Shallow tillage systems (field cultivate and disk) resulted in very high P concentrations, especially when coupled with broadcast application. When P was either in-row or broadcast applied, deeper more aggressive chisel tillage tended to mix the P deeper in the soil and thus lower STP in the top 2 inches.

Economic Return to Fertilizer P

The annual economic returns combined across the 11 cropping years (six corn and five soybean) are shown in Table 4. Assuming a 50:50 corn-soybean rotation, economic return ranged from $74 to $116/A/yr for the low P-testing site and from $-6 to $8/A/yr for the high P-testing site. On the low P-testing site, greatest returns were achieved with the 100-lb broadcast treatment ($110/A/yr), intermediate with the in-furrow 50-lb starter treatment ($86/A/yr), and least with the 50-lb "deep" band treatment ($75/A/yr).

In summary, economic analyses of the P management strategies strongly supports the 100-lb broadcast P_2O_5 treatment on the low P-testing site and no P applied to the high-testing site. However, the broadcast treatment generates the highest STP values in the surface 2-inch layer, and thus, greatest potential for environmental loss of P to surface water. Based on these data, it seems prudent to keep soil test levels in the high category (16 to 20 ppm Bray P_1) and then apply starter fertilizer as needed to maintain STP in the high category. If, however, STP levels become low to very low, it would be wise to broadcast apply at least 100 lb P_2O_5/A once and perhaps twice and chisel it each time to incorporate the P deeper in the profile. After raising STP into the medium category (11 to 15), starter fertilizers coupled with reduced tillage could then be used to optimize profit and minimize P loss potential.

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Table 1. Corn and soybean yield and soil test P (STP) in a C-Sb rotation on a LOW P-testing soil as affected by tillage and P management strategies for corn.

Trt. No.	Tillage	P mgmt.[1/] strategy	P_2O_5 rate	Corn yield 6-yr.avg.	Soybean yield 5-yr. avg.	STP[2/]
			lb/A	- - - - - - - - - bu/A	- - - - - - -	ppm
1	No till	-	0	97	34.5	3
2	"	Starter	50	140	48.0	22
3	Field cult.	-	0	102	35.9	3
4	"	Starter	50	153	49.1	17
5	"	Fall Band	50	146	49.1	7
6	"	Spr. Bdct.	100	166	52.6	16
7	Strip till	-	0	101	37.0	3
8	"	Starter	50	152	49.7	28
9	"	Fall Band (f)	50	148	47.9	9
10	"	Fall Band (r)	50	141	43.9	6
12	Chisel, f.c.	-	0	103	31.5	3
13	"	Starter	50	154	50.4	14
14	"	Fall Bdct.	100	166	53.0	18
		LSD (0.10) =		6	2.8	-

[1/] Fall band (f) = fixed in same position each year. Fall band (r) = random and band moved 8 inches laterally each year prior to planting corn.

[2/] Bray P_1 soil test P in 2002, 0- to 6-inch layer.

Table 2. Corn and soybean yield and soil test P (STP) in a C-Sb rotation on a HIGH P-testing soil as affected by tillage and P management strategies for corn.

Trt. No.	Tillage	P mgmt.[1/] strategy	P_2O_5 rate	Corn yield 6-yr. avg.	Soybean yield 5-yr. avg.	STP[2/]
			lb/A	- - - - - - - bu/A	- - - - - -	ppm
1	No till	-	0	156	50.5	12
2	"	Starter	40	160	52.4	37
3	Field cult.	-	0	161	54.0	10
4	"	Starter	40	168	54.6	21
5	"	Fall Band	40	165	54.1	16
6	"	Spr. Bdct.	80	176	54.9	30
7	Strip till	-	0	164	52.6	11
8	"	Starter	40	168	51.8	27
9	"	Fall Band (f)	40	165	53.8	19
10	"	Fall Band (r)	40	166	52.5	13
12	Chisel, f.c.	-	0	165	52.1	8
13	"	Starter	40	170	54.6	22
14	"	Fall Bdct.	80	176	55.2	32
		LSD (0.10) =		5	2.0	-

[1/] Fall band (f) = fixed in same position each year. Fall band (r) = random and band moved 8 inches laterally each year prior to planting corn.

[2/] Bray P_1 soil test P in 2002, 0- to 6-inch layer

Table 3. Soil test P (Bray P_1) in the top 2 inches in Nov. 2002 as affected by tillage system and P management strategies for a corn-soybean rotation grown for 6 years on initially LOW and HIGH P-testing soils.

Trt.	Tillage for		P mgmt.[1/]	P_2O_5 [2/]	Initial P test	
No.	Corn	Soybean	strategy	rate	LOW	HIGH
				lb/A	- - - - ppm - - - -	
1	No till	No till	-	0	5	15
2	"	"	Starter	50 (40)	14	29
3	Field cult.	Spr. disk	-	0	6	12
4	"	"	Starter	50 (40)	13	26
5	"	"	Fall band	50 (40)	6	18
6	"	"	Spr. bdct.	100 (80)	36	50
7	Strip till	No till	-	0	4	12
8	"	"	Starter	50 (40)	13	24
9	"	"	Fall band	50 (40)	6	17
12	Chisel, f.c.	Chisel, f.c.	-	0	4	15
13	"	"	Starter	50 (40)	10	21
14	"	"	Fall bdct.	100 (80)	18	35

[1/] Starter and band treatments received 10-34-0; Bdct. treatments received 18-46-0.

[2/] 50 and 100 lb P_2O_5/A applied to LOW site; 40 and 80 lb P_2O_5/A applied to HIGH site.

Table 4. Economic return to fertilizer P by corn (6-site years) and soybean (5 site-years) as affected by P management strategies within tillage management systems on initially LOW and HIGH P-testing soils.

Trt.	Tillage for [1/]		P mgmt.[2/]	Economic return to P					
				LOW P-testing Site			HIGH P-testing site		
No.	Corn	Soybean	strategy	Corn	Soyb.	C-Sb[3/]	Corn	Soyb.	C-Sb[3/]
				- - - - - - - - - - - - - - - $/A/yr - - - - - - - - - - - - - - - - - -					
1	NT	NT	-	0	0	0	0	0	0
2	"	"	SF	82	71	76	-4	10	3
3	FC	SD	-	0	0	0	0	0	0
4	"	"	SF	100	69	85	-1	3	1
5	"	"	Band	84	69	76	-8	1	-4
6	"	"	Bdct.	121	88	105	8	5	6
7	ST	NT	-	0	0	0	0	0	0
8	"	"	SF	100	67	84	-8	-4	-6
9	"	"	Band	91	57	74	-15	6	-4
12	CP+	CP+	-	0	0	0	0	0	0
13	"	"	SF	100	99	100	-6	13	4
14	"	"	Bdct.	119	113	116	-1	16	8

[1/] NT = no tillage, FC = field cultivate, SD = spring disk, ST = strip tillage, and CP+ = chisel plow and field cultivate.

[2/] SF = starter fertilizer (10-34-0), Band = 5 inches deep (10-34-0), and Bdct = broadcast DAP.

[3/] Assuming a 50:50 corn:soybean rotation.