TILLAGE EFFECTS ON PHOSPHORUS AVAILABILITY

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ABSTRACT

Vertical stratification of phosphorus (P) has been documented in both no-till and reduced tillage systems, yet very few studies have determined if this stratification has affected P uptake, and none of these studies have been conducted in Montana. Stratification of P was compared in 1.2 in layers in a small plot study composed of four tillage systems: long-term conventional (sweep) till (CT), 10-yr no-till (NT), 1-yr NT and 1-yr CT. Olsen P was measured in the upper 12 in., and a sequential extraction was performed on all layers in the upper 6 in. Fractions measured in this extraction included resin-P, $NaHCO_3$-P (bic-P), NaOH-P, and HCl-P. Olsen P concentrations in all tillage systems were approximately 6 fold higher in the surface 1.2 in. than below 4.8 in., demonstrating a substantial amount of vertical P stratification. Resin-P, bic-P and NaOH-P showed similar trends as Olsen P in the upper 6 in. There were very few significant differences in the concentrations of P fractions among tillage systems, possibly because there was only one tillage pass per year. Uptake of P by a winter wheat crop did not differ significantly between tillage systems. The best correlation between P uptake and available P concentrations (Olsen P and resin-P) occurred in the 2.4 to 3.6 in. depth, suggesting this may be the best depth to band fertilizer P. Based on this study, fertilizer P rates likely do not need to be adjusted for tillage system.

INTRODUCTION

The increasing adoption and use of no-till (NT) dryland cropping systems in the northern Great Plains has resulted in uniquely different patterns of soil phosphorus (P) distribution compared to conventionally tilled (CT) systems (Grant and Bailey 1994; Lupwayi et al. 2006; Selles et al. 1999). Consequently, P availability, and hence, P fertilizer needs, may be different in NT than in CT systems. Therefore, the objectives of this study were to 1) determine the difference in vertical P distribution patterns between NT and CT systems, as well as in the transition period from one tillage system to the other, and 2) correlate any P distribution differences with P uptake.

METHODS

This project was conducted on an existing small plot study designed to assess the effects of tillage, nitrogen (N), and previous crop on soil fertility and yield. The final study design map is attached. Four treatments included >30 yr CT (CTCT), NT since 1996 (NTNT), CT converted to NT in 2005 (CTNT) and NT converted to CT in 2005 (NTCT).

The layout was a randomized complete block design with 4 replicates, and each plot was 25 x 15 ft. Since 1996, tillage was completed with a 15 ft. IHC cultivator with 16 sweeps. A 47 degree shovel was used until 2003, and a 50 degree shovel was used starting in 2004. Tillage was performed once a year in the fall or spring depending on whether a winter or spring crop was planted. CT plots were leveled using a cultivator with a harrow attached. Prior to 1996, the study site was in a spring wheat/fallow rotation. In 1996, in conjunction with the NT and CT component, a cereal-oilseed rotation was implemented and the following crops were planted: spring wheat (1998, 2001), canola (1999), barley (2000, 2003), winter wheat (2002), and mustard (2004). Phosphorus fertilizer (either MAP or TSP) was applied with the seed in all years of the study. Seeding depth was 0.75 to 1.0 in. Additional site information is included as Table 1. Although four crop rotations were being evaluated in the existing system (fallow, spring wheat, pea, and pea forage, each followed by winter wheat), only the fallow treatment was soil sampled for P distribution in this study. Soil cores (1.0 in. diam.) were collected (August 22 to September 1, 2005) from the 0-12 in. depth at the center of each plot and each quadrant prior to winter wheat seeding. Cores were collected from each fallow plot that was to be applied with 80 lb N/ac within each tillage treatment. Each core was segmented into 1.2 in. increments and each of the respective five sub-samples was composited for each depth increment.

Table 1. Site information.

Average Precipitation	15.4 in.
Sept. 2005-Aug. 2006 Precipitation	15.0 in.
Organic matter	3.00%
Soil test K	>250 ppm
Soil texture	Clay loam

Olsen P concentrations and soil pH (2:1 water:soil slurry) were measured in each of the 1.2 in. increment soil samples. In addition, the upper five depths were averaged to produce a 0-6 in. concentration to determine if Olsen P in this standard sampling increment has changed with conversion to NT. Soil P availability from sequential P extractions was based on the methods of Yang et al. (2002). This sequence removes the labile P (resin-P, water, and bicarbonate (bic-P) extracts) and moderately labile P (NaOH-P and HCl-P extracts) as defined by Selles et al. (1999). One gram of soil was subjected to fractionation by the shaken-batch procedure with a 1:30 (soil:solution) mixture. Each tube was shaken for 16 h, centrifuged for 20 min at 10,000 rpm and an aliquot was removed for analysis. Resin capsules were made from Dowex® 1x8, strongly basic, chloride resin converted to carbonate form, using methods similar to Sibbesen (1978). The remaining extracts included a deionized water rinse, a solution of 0.5 *M* sodium bicarbonate (bic-P) at pH 8.5, a solution of 0.1 *M* sodium hydroxide (NaOH-P) and 1.0 *M* hydrochloric acid (HCl-P) in this sequence. Filtered extracts (0.22 µm) were analyzed for total P using a Hach DR 4000 UV/Vis spectrophotometer. For reporting purposes, the resin P and the subsequent water rinse were added to obtain “resin-P”. Average relative standard deviations for four duplicates of each extract were 9.6, 14.8, 7.7, and 13.6% for the resin-P, bic-P, NaOH-P, and HCl-P respectively.

In September 2005, all plots were seeded with winter wheat (cv. Yellowstone) using a ConservaPak no-till air drill equipped with hoe-type openers at 12 in. row spacing. Phosphorus fertilizer (0-45-0) was applied at 22.5 lb P_2O_5/ac with seed (0.75-1.0 in. deep) into the furrows. Nitrogen fertilizer (46-0-0) was broadcast at 0, 40, 80, and 120 lb N/ac. At harvest in 2006, one winter wheat plant bundle sample was collected from each plot where soil samples had been collected in 2005. The winter wheat bundle samples were cut from 3 rows over a 3.25 ft. long area. Wheat was threshed and dry biomass of grain and straw subsamples were weighed and analyzed for tissue P.

RESULTS AND DISCUSSION

The concentrations of Olsen P were highest in the upper 1.2 in. for all tillage systems (Fig. 1), likely because P was banded at the 1.0 in. depth. The Olsen P concentration in 10-yr NT was more stratified than in long-term CT, with concentration differences between the 0-1.2 in. and the 1.2-2.4 in. layers of 2 and 6.8 ppm for long-term CT and 10-yr NT, respectively. There were no significant differences in average Olsen P concentrations when the concentrations were averaged over 0 to 6 in. between tillage treatments at P=0.05, but the average Olsen P in 10-yr NT was significantly lower than under long-term CT at P=0.10 (data not shown). In addition, the Olsen P concentration in the 1.2-2.4 in. layer under 10-yr NT was significantly lower than for long-term CT (P<0.05), possibly due to pH differences or decreased O.M. decomposition rates under NT resulting in less release of P. There were no significant differences in Olsen P concentrations among tillage treatments in any other layer and there were no significant depth x tillage interactions, suggesting that vertical P stratification patterns were not altered by tillage. The general lack of differences in Olsen P concentrations and stratification is likely because sweep tillage moves soil horizontally more than vertically, and there was only one tillage pass per year.

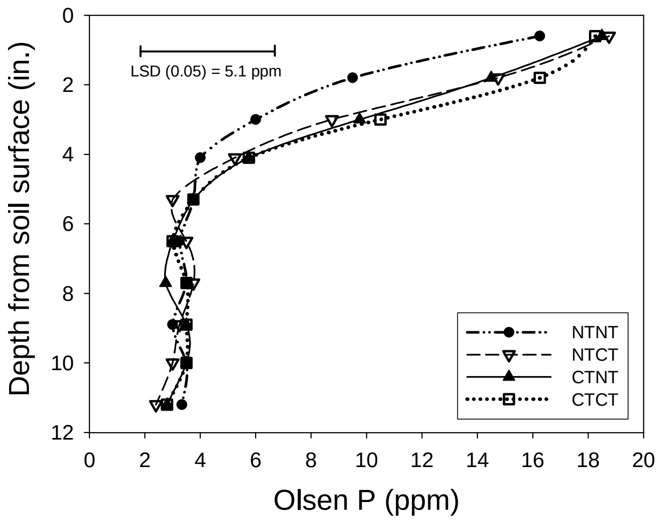

Figure 1. Distribution of Olsen P concentrations for each tillage treatment in the upper 12 inches (September, 2005 sampling).

Others studying vertical stratification of P have found results that have ranged from lower Olsen P concentrations under NT wheat than under CT (Grant and Bailey 1994), to no difference in labile inorganic P concentrations between NT and CT (Selles et al. 1999; Lupwayi et al. 2006), to higher bioavailable P (resin P) in the surface (0-1.6 in.) and lower in the subsurface (4.8-12 in.) in NT than in CT (Zibilske et al. 2002). These inconsistent findings suggest that specific site and management differences are causing differences in results, making it difficult to generalize about the effects of tillage system on vertical P stratification. For example, researchers have found that the effects of tillage on P stratification are dependent on soil texture (Grant and Bailey 1994), type of tillage (Zibilske et al. 2002), and crop (Bauer et al. 2002; Lupwayi et al. 2006). Alternatively, heterogeneity in soil P levels, due partly to banding of P, may make it difficult to find consistently significant differences, especially in short term NT.

Distribution of resin-P and HCl-P throughout the 0-6 in. soil profile showed no significant differences between tillage treatments, yet a substantial reduction in available P with depth (Fig. 2). The bic-P concentration in the 0-1.2 in. depth was significantly lower in the CTCT treatment than the NTCT treatment, yet there were no significant differences among these treatments at any other depth. The NTNT treatment had significantly lower NaOH-P concentrations than the other 3 tillage treatments at 2 depths (1.2-2.4 in. and 2.4-3.6 in.). These lower P levels may be attributed to higher pH at this soil depth (data not shown) or soil heterogeneity.

The only significant difference in extractable P concentrations between tillage treatments averaged over the top 6 in. occurred with the NaOH-P extraction (Fig. 3). Specifically, the 10-yr NT treatment had lower NaOH-P concentrations than the other three tillage treatments. Sodium bicarbonate-P (bic-P) was lower than Olsen P by about 50% for all tillage treatments. (Olsen P is also extracted with bicarbonate.) Since the bic-P extract follows the resin extract, more P was likely absorbed by the resin leaving less exchangeable P available. This capacity of the anion exchange resin to pull more P from solution and soil surfaces, yielding higher P concentrations than Olsen P, is similar to results found in Yang et al. (2002).

Aboveground P uptake by winter wheat was not significantly different between tillage treatments when the optimum N rate of 80 lb/ac was applied (Fig. 4). However, the P uptake in long-term CT was significantly greater than in 10-yr NT and 1-yr NT when no N was applied. This was likely due to differences in N limitation between tillage treatments (Chen et al., 2006), resulting in higher biomass and thus more root exploration in the long-term CT treatment. Uptake of P at the higher N rate should be a better estimate of P availability because yields were optimized at this N rate, increasing the likelihood that P was limiting growth. Lower Olsen P levels in 10-yr NT than in long-term CT combined with nearly identical P uptake between the two treatments suggest that inorganic labile P pools are not the only pool affecting P availability in this system. Selles et al. (1999) found that although inorganic labile pools of P were the same between NT and CT, organic pools of P were higher in NT, especially in continuous cropping systems.

Wheat uptake of P has previously been found to be similar between NT and CT systems, even when vertical P stratification was different (Lupwayi et al. 2006; Schwab et al. 2006). The results from our study, combined with these two recent studies, suggest that P fertilizer rates for winter wheat do not need to be adjusted based on tillage system. Because P fertilizer rates are often based on Olsen P concentrations, slightly more P would likely be recommended in the 10-yr NT system, which might be warranted because the 10-yr NT treatment had the lowest P uptake of the four treatments at 80 lb N/ac (though non-significant at P=0.05).

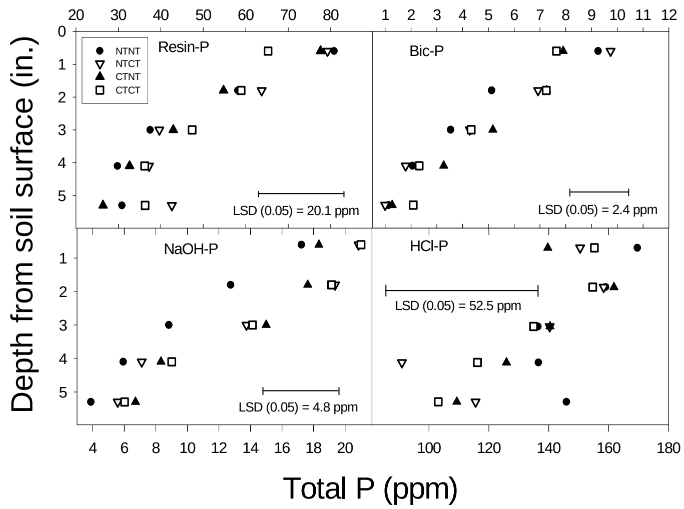

Figure 2. Mean P concentration per depth for each extract (Resin-P, bic-P, NaOH-P, and HCl-P).

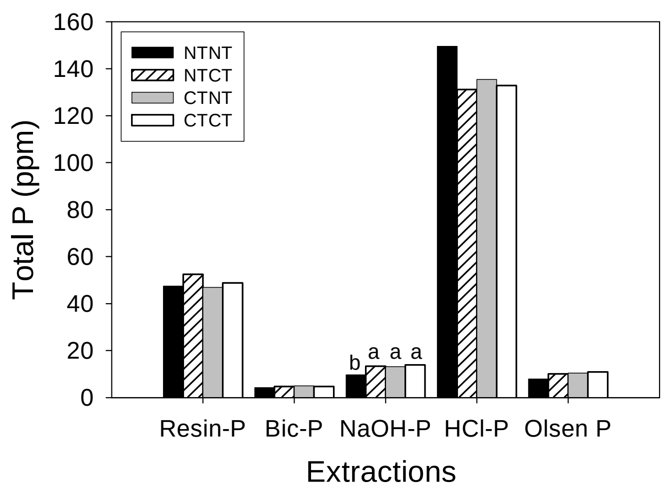

Figure 3. Mean P concentration over the 0-6 in. depth for each extraction. The same letter on a bar indicates the means are not different (P=0.05). Only Na-OH fractions had differences between treatments.

The best correlation (r^2=0.57; P<0.001) between Olsen P and aboveground P uptake occurred in the 2.4-3.6 in. layer (Table 2), suggesting that this may be the best layer to band P fertilizer. Significant correlations were also obtained between Olsen P and P uptake for each sampling depth up to 12 in. (averaged from individual layers), although the best correlations were obtained for the 0-3.6, 0-4.8, and 0-6.0 in. sampling depths. These results indicate that the Olsen P concentration in the standard 0-6 in. sampling depth is a good predictor of available P, even in NT and sweep till systems. The only non-significant correlation in the upper 6 in. occurred in the 4.8-6.0 in. depth, a depth where P fertilizer has likely not been applied, nor been moved to, based on uniform Olsen P concentrations below 4.8 in.

The best correlation between resin-P and uptake also occurred in the 2.4-3.6 in. layer (r^2 = 0.35; P<0.05) though resin P correlations were not as high as for Olsen P. The resin absorbed more labile and moderately labile P from solution and soil exchange sites as indicated by the higher P concentrations; therefore likely overestimating true P availability resulting in poorer correlations than Olsen P.

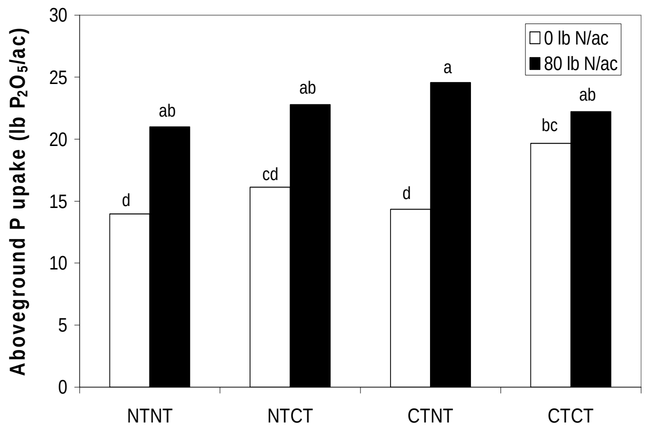

Figure 4. Aboveground winter wheat P uptake for each tillage treatment at two N rates. The same letter on a bar indicates the means are not different (P=0.05).

Both NT and sweep till systems accumulated P at the surface and depleted P in the subsurface. Due to frequent dry periods during the growing season in Montana, it is likely that there are extended periods where water, and thus P uptake, from the upper 2.4 in. of soil is minimal. Therefore, in long-term reduced tillage systems, it is recommended that when possible, that P be applied approximately 2.4-3.6 in. below the surface (based on correlations between labile P and P uptake). This agrees with the general recommendation of applying fertilizer approximately 2 in. below the seed. Applications of P at this depth should avoid stranding it near the surface, where it also has a better chance to be lost from wind or water erosion, especially in tilled systems. Some air drills are equipped with chisel type openers that allow the producer to band fertilizer 2 in. below the seed.

Table 2. Correlation coefficients between Olsen P and resin-P concentrations and aboveground P uptake in individual soil layers and averaged soil depths.

Depth (in.)	Olsen P r^2-value	Resin P r^2-value
Individual layers		
0 - 1.2	0.46**	0.12NS
1.2 - 2.4	0.46**	0.17NS
2.4 - 3.6	0.57***	0.35*
3.6 - 4.8	0.50**	0.13NS
4.8 - 6.0	0.17NS	0.005NS
Averaged depths		
0 - 2.4	0.53**	0.19NS
0 - 3.6	0.57***	0.28*
0 - 4.8	0.59***	0.30*
0 - 6.0	0.57***	0.27*
0 - 8.3	0.54**	
0 - 12.0	0.42**	
2.4 - 4.8	0.60***	0.32*

NS, not significant at P=0.05

*, **, *** significant at P<0.05, 0.01, 0.001 respectively

CONCLUSION

Stratification of Olsen P was relatively similar among 1-yr NT, 10-yr NT, 1-yr CT, and long-term CT, except that 10-yr NT had significantly less available P in the 1.2-2.4 in. layer than long-term CT. This difference appeared to be partially related to higher pH in the 10-yr NT system's root zone. The highest concentrations of available P in all four systems was in the top 1.2 in. Aboveground P uptake was not significantly different among tillage treatments, and was most highly correlated with Olsen and resin P concentrations in the 2.4-3.6 in. layer. The results of this study suggest that in long-term reduced tillage systems where P has only been placed with the seed, that deeper placement (1.4 to 2.6 in. below seed) should be considered to more efficiently use applied P fertilizer, at least in winter wheat systems. The combined results suggest that P fertilizer rates for winter wheat should continue to be based on Olsen P concentrations in the upper 6 in. in Montana soils and do not need to consider the type of tillage system.

ACKNOWLEDGEMENTS

This study was funded by the Montana Fertilizer Advisory Committee and the International Plant Nutrition Institute.

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