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TILLAGE EFFECTS ON NUTRIENT STRATIFICATION AND SOIL TEST RECOMMENDATIONS

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Soil testing is recognized as the best method of determining P, K, and lime need prior to planting. Conventional soil testing relies on a soil sampling approach that is intended to identify a single rate of nutrient application for a field that optimizes crop yield and economic return, with limited risk of nutrient loss. However, soil test values within a field are intrinsically variable because of natural factors (e.g., soil forming factors and erosion) and past management (e.g., nutrient application, crop management, field consolidation, and drainage). Soil sampling protocols are designed to account for spatial variability, both horizontally and vertically. While much emphasis has been given to addressing horizontal variability through grid soil sampling, cell size selection, and core number; often only casual attention is given to sample depth. Because P, K, and to some extent soil pH are immobile in soils nutrient and pH stratification will develop, especially when tillage intensity is low. Soil samples taken to inconsistent or improper depths may arguably cause more variability in fertilizer recommendations due to nutrient stratification than might be found due to variability across the extent of the field.

The causes of nutrient stratification are numerous. First, broadcast applications of immobile nutrients with no or incomplete mixing by tillage will increase nutrient concentration at the soil surface. Therefore, soil test P and K will be greater near the surface and typically pH will be lower from the hydrogen ions released by the nitrification of ammonium containing fertilizers or organic N sources. Another cause of nutrient stratification is the leaching of soluble nutrients from crop residues, especially at senescence or following a killing frost. Finally, tillage intensity has significantly decreased as more growers adopt conservation tillage systems. Even changing to sweeps instead of twisted shovels on a chisel plow increases the potential for stratification.

The soil sampling procedure for single-rate fertilizer and lime application has four considerations: (1) the size of the cell or field area represented by one sample; (2) the number of soil cores taken per sample; (3) the pattern with which the samples are taken; and, (4) the depth of the sample. With respect to tillage, UWEX soil sampling guidelines found in Bulletin A2100

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recommend sampling moldboard plowed fields to the depth of tillage, chisel plowed fields to three-fourths the depth of tillage, and no-till to a depth of 6 inches. It is assumed that strip-tilled fields should be sampled similarly to no-till. These guidelines offer some recognition of soil test stratification as it is suggested that long-term no-till fields should also be sampled at the 0- to 2-inch depth for soil pH.

Tillage practices for a given field are not always consistent because many farmers rotate tillage as they rotate crops (e.g., chisel tillage and no-till in a corn/soybean rotation). Forage stands that are maintained for multiple years actually become "defacto no-till" and may cause some confusion regarding sampling depth, especially if the dominant tillage is not known. Considering the amount of P and K that might be broadcast to alfalfa at optimum soil test levels it could be expected that nutrient stratification would develop in this scenario. Hay fields are commonly soil sampled prior to tillage, even though aggressive tillage management may occur in future years. Regardless of tillage management it should be obvious that soil sampling to a uniform depth is vital for obtaining accurate nutrient recommendations. The question of precision versus accuracy should favor precision such that sample depth and timing of sampling should be consistent over years. Thus, even if tillage is varied, a grower or consultant could monitor soil test, crop condition, and yield to determine if a proper indexing of nutrient availability based on soil test exists.

The objective of this paper is to examine the effect of tillage on nutrient stratification and the subsequent nutrient recommendation. Several fields that have been subjected to different tillage systems were incrementally sampled and recommendations were developed based on sampling to different depths.

Procedure

Soil samples were collected from field plots that had a history of various tillage practices at the Arlington and Lancaster Agricultural Research Stations. Samples were taken in increments of two in. to a depth of eight in. Samples were analyzed by the procedures of the UW Soil and Plant Analysis Laboratory for pH, organic matter, P, and K. From these soil test results, recommendations for phosphate, potash, and lime were developed for samples that hypothetically could have been collected at sampling depths of 0 to 4, 0 to 6, and 0 to 8 inches.

Samples were collected from the following studies using a standard soil probe.

1. Rotation x tillage x fertilizer placement study at Arlington — Corn/soybean and continuous corn rotation, with fall chisel with spring field cultivator, strip-till, and no-till. These treatments were established in 1997 and treatments of none, broadcast, or row-applied fertilizer as 200 lb 9-23-30/a were established in 2001. Soil samples were collected from all replications in the unfertilized and broadcast plots in June 2005. All plots to be planted to corn received 160 lb N/a broadcast as ammonium nitrate each year.

2. Tillage x K fertility study at Lancaster — This field had been in no-till corn and soybean production for at least the past 10 years. In the fall of 2003, tillage treatments including fall chisel with spring field cultivation and no-till were established for corn following soybean.

Soybean was no-till planted into corn stubble. Therefore the chisel treatment was chisel plowed in the fall of 2003 and 2005. An adjacent area that had been continuously no-tilled was moldboard plowed in the fall of 2006. Three replications of soil samples were collected from the third replication of the unfertilized K control in the chisel, no-till, and the adjacent moldboard plowed area. All plots received 35 lb P_2O_5/a row applied phosphate and 120 lb N/a broadcast as ammonium nitrate in the corn years of 2004 and 2006.

3. Tillage x herbicide study at Arlington — This study is managed by Professor Dave Stoltenberg of the UW Department of Agronomy and has had tillage treatments of moldboard, chisel, and no-till for the past 20 years. Samples were taken from the continuous corn portion of the study. The site received row applied NPK fertilizer annually at crop removal for P and K, as well as 160 lb N/a as urea each year. Lime has not been applied over this period.

4. Production alfalfa field at Arlington — This field was in no-till corn in 2003 and received beef manure in the spring of 2004, which was subsequently disked and then field cultivated. It was then direct seeded and culti-mulched in the spring of 2004. The field received 250, 300, and 300 lb 0-0-60/a in November 2004, August 2005, and November 2005, respectively. The field was not fertilized in 2006 and has been managed for alfalfa hay until the fall of 2006 when it was fall-killed to rotate to corn. Sampling was conducted following killing, but prior to any tillage.

Results and Discussion

Table 1 shows the effect rotation, tillage, and fertilization on the routine soil test for the Arlington location where the rotation and tillage treatments have been in place since 1997 and 2001 for the fertilizer treatments. Rotation significantly affected pH in the 0- to 2-inch and 2- to 4-inch increments such that the pH was higher in soybean following corn. The pH was lowest in the continuous corn and intermediate in the corn following soybean. Presumably the N fertilization where corn was grown contributed hydrogen somewhat more rapidly than might have been expected in the corn following soybean. The only other soil test parameter that was affected by rotation was K in the 0- to 2-inch increment. This effect was significant at the p=0.10 level in the 2- to 4-inch layer and was apparent at deeper depths. The greater level in the surface was likely due to a combination of the accumulation from K leached from the crop residue and the greater removal of K expected for corn/soybean compared to corn.

Tillage significantly affected the organic matter, P, and K in the 0- to 2-inch increment being highest in the strip-till. Soil pH tended to be lower in the reduced tillage treatments. Tillage affected soil pH at the 2- to 4-inch and 4- to 6-inch depths with the chisel having the lower value due to mixing of surface acidified soil at this depth. As would be expected broadcast fertilization increased soil test levels in the 0-2 and 2-4 in. increments with this effect continuing to the depth of sampling.

This stratification would lead to different fertilizer recommendation if sample depth was not consistent with tillage. While lime is not needed in this field for corn or soybean the lime recommendation for alfalfa (pH 6.8) would vary substantially if samples were taken to 4, 6, or 8 inches. Recall that both the soil pH and organic matter are components of the lime requirement equation. Estimates show that in this field the chisel would have a lime recommendation of 3.4, 2.2, 2.6 tons/a 60-69 lime for the 0- to 4-, 0- to 6-, and 0- to 8-inch sampling depths, respectively. The lime requirement for no-till would be 3.6, 2.4, and 1.2 tons/a for the same depth increments.

The effect on K recommendations was not affected as significantly by tillage; however sample depth did affect the K recommendation. The 0- to 4-, 0- to 6-, and 0- to 8-inch sampling depths resulted in K soil test levels of 123, 107, and 98 ppm K, respectively in chisel and 122, 106, and 96 ppm K in no-till for these depths. If corn with a 180 bu/acre yield goal was the crop 20 lb K_2O would be the recommendation for the 0- to 4-inch increment and 50 lb K_2O/a would be recommended for the 0- to 6- and 0- to 8-inch depth. If alfalfa with a 6 ton/acre yield goal was the crop the 0- to 4-inch increment would call for 150 lb K_2O/a and the other increments would receive 300 lb K_2O/acre.

The incremental soil test data for Lancaster is shown in Table 2. These data were analyzed in a tillage x depth ANOVA. Samples at this site were taken from single adjacent tillage plots and not from all reps and treatments as was done at the Arlington Rotation x Tillage study. Also the tillage history at this site is much shorter, that being two recent chisel events and one moldboard event in a field that has a long no-till history. Because the site was moldboard plowed once, it is apparent that the surface layer was inverted creating a soil test that contrasts that of the no-till. Long-term moldboard tillage would be expected to resolve this anomaly.

Table 2. Effect of tillage on the incremental soil test, Lancaster, Wis., 2006.

	Moldboard				Chisel				No-till			
Depth	pH	OM	P	K	pH	OM	P	K	pH	OM	P	K
inch		%	---- ppm ----			%	---- ppm ----			%	--- ppm ----	
0 – 2	6.8	1.9	25	120	6.9	2.8	31	130	6.7	3.3	35	130
2 – 4	6.8	2.1	23	120	7.0	2.6	23	117	7.0	2.5	22	95
4 – 6	6.6	2.2	26	123	7.1	2.6	16	106	7.1	1.9	16	96
6 - 8	6.6	2.3	29	130	7.1	1.7	18	109	7.1	1.6	17	108

Significance (Pr>F)

	pH	OM	P	K
Tillage	<0.01	0.02	0.07	0.03
Depth	0.21	<0.01	<0.01	0.04
T * D	0.02	<0.01	<0.01	0.18

Regardless, these data show that the single moldboard tillage (with a light disking), removed most of the stratification that was apparent in both the chisel and no-till. Lime would not be recommended in this field, but depending on the crop and sample depth different P and K recommendations would be obtained if managed under different tillage systems.

The most unique opportunity in this exercise was the sampling of Dr. Stoltenberg's long-term tillage study which was established at Arlington approximately 20 years ago. This study has focused on herbicide interactions in tillage, receiving uniform tillage and nutrient management over this time. The site contains both a continuous corn and corn/soybean rotation. Only one replication of the continuous corn portion was sampled for this preliminary evaluation.

The data for the incremental soil test are shown in Table 3, from which several interesting observations can be made. First, the incremental soil test results were clearly more uniform with depth in the moldboard compared to the chisel and no-till. As was observed in the other data sets, chisel plowing does not remove stratification — or more properly chisel plowing results in stratification. Soil pH was lower in all tillage treatments in the 0- to 2-inch increment, likely reflecting the 2006 application of urea. The pH tended to be lower at depth in both the moldboard and chisel compared to no-till with the soil pH at depth in the no-till surprisingly high. Organic matter content was enriched in the surface of the chisel and no-till, which lends some credence to the support of enhanced C sequestration in conservation tillage systems, even chisel plowing. This site had excessively high soil test P and for the most part the analyses, although showing stratification, would still result in a non-responsive soil test P level. Soil test K clearly shows stratification in the chisel and no-till. The value in the 0- to 2-inch level is unusually high in the chisel, which may be an artifact of the small sample size. Statistically long-term tillage differences have created very highly significant differences in all the soil test parameters.

Table 3. Effect of tillage on the incremental soil test, Arlington, Wis., 2006.

	Moldboard				Chisel				No-till			
Depth	pH	OM	P	K	pH	OM	P	K	pH	OM	P	K
inch		%	---- ppm ----			%	---- ppm ----			%	--- ppm ----	
0 – 2	5.7	3.6	57	91	5.6	4.2	77	148	5.6	4.6	57	108
2 – 4	5.9	3.8	57	82	5.6	4.1	68	114	6.5	3.7	39	86
4 – 6	6.0	3.8	58	86	5.8	4.0	56	89	6.6	3.3	33	74
6 - 8	6.0	3.9	59	92	6.2	3.4	33	70	6.6	3.2	24	70

Significance (Pr>F)

	pH	OM	P	K
Tillage	<0.01	<0.01	<0.01	<0.01
Depth	<0.01	<0.01	<0.01	<0.01
T * D	<0.01	<0.01	<0.01	<0.01

One obvious question is the effect that the soil test stratification has on soil test results, especially in a situation where samples were collected at inconsistent or improper depths. Assuming normal tillage depths, UWEX recommendations would suggest that the moldboard and possibly the chisel plot should be sampled to a depth of 8 inches and the no-till to a depth of 6 inches. What if conditions were very dry and the sample depth was just 4 inches or in contrast conditions were perfect and the sampler was "feeling their Wheaties" and sampled too deep?

Table 4 shows the lime and K fertilizer recommendations for the Stoltenberg plots had the sampler consistently taken cores to 4, 6, or 8 inches. Recommendations were calculated for both corn and alfalfa at reasonable yield goals. Clearly because moldboard plowing resulted in the most uniform soil test levels it also resulted in very uniform lime and potash recommendations relative to sample depth. The lime recommendation for chisel tillage was considerably higher than that for either moldboard or no-till. Even though the no-till had a high organic matter and an acidic surface layer it had the lowest lime recommendation because of the higher pH found in the deeper increments. Chisel also had the unusually high soil test K in the surface layers, a result that may be an effect of the small sample size. Clearly sample depth did affect lime and K recommendations for both crops in this example.

Table 4. Effect of tillage and sample depth on soil test and subsequent lime and K recommendation, Arlington, Wis., 2006. †

Tillage	Sampling depth	Soil test pH	Soil test OM	Soil test K	Corn		Alfalfa	
	inch		------ ppm ------		T lime/a	lb K_2O/a	T lime/a	lb K_2O/a
MB	0-4	5.8	3.7	87 L	1.2	80	5.9	330
	0-6	5.9	3.7	86 L	0.6	80	5.3	330
	0-8	5.9	3.8	88 L	0.4	80	5.5	330
CH	0-4	5.6	4.2	131 H	2.7	20	8.1	150
	0-6	5.7	4.1	117 H	2.0	20	7.2	150
	0-8	5.8	3.9	105 O	1.2	50	6.2	300
NT	0-4	6.1	4.2	97 O	0	50	4.7	300
	0-6	6.2	3.9	89 L	0	80	3.7	330
	0-8	6.3	3.7	85 L	0	80	3.0	330

† Recommendations calculated target pH of 6.0 for corn and 6.8 for alfalfa 180 bu/a corn and 6 ton/a alfalfa. LR (t 60-69 NI/a) = 0.16 x Δ pH x [OM x 10]

The final field that was sampled was a production alfalfa field at Arlington was seeded with modest tillage in 2004. In that time it has received 850 lb 0-0-60/a (510 lb K_2O/a). Prior to alfalfa establishment it was in no-till corn following 2 years of alfalfa. Thus it had been at least six years since it would have been chisel plowed.

If I were a crop advisor, I would prefer to sample this field prior to tillage for several reasons. First, it is simply much easier on the body and machine to traverse and sample an unplowed field. Furthermore, anyone who has sampled plowed fields knows the problems of sample tube plugging and inconsistent cores. If a soil test calls for lime or fertilizer it is more practical to apply it to the unplowed field where it can be distributed more uniformly and then incorporated. The soil test results for this alfalfa field are shown in Table 5. All soil test parameters show statistical differences with depth. Clearly the most obvious is the test for K where the soil test K level is three times higher in the surface 2 inches compared to the 6- to 8-

inch depth. There is also a 50% difference in soil test P. Depending on crop and sample depth the interpretation for P would all have been low for all depths for alfalfa and the deeper depths for corn. The shallow sampling depth would have resulted in an optimum P test for corn. The K interpretation would all be excessively high for corn, but would range between excessively high, very high, and high for alfalfa for the 0-4, 0-6, and 0-8 in. depths, respectively.

Table 5. Effect of sample depth on routine soil test in a long-term alfalfa stand, Arlington, Wis., 2006.

Depth	pH	OM	P	K
inch		%	------------------- ppm ------------------	
0-2	7.4	4.1	20	265
2-4	7.3	3.6	12	150
4-6	7.4	3.4	11	99
6-8	7.5	3.2	11	90
Pr>F	0.02	<0.01	<0.01	<0.01
LSD	0.1	0.1	3	35

Summary

Soil sampling is the best and only method of determining crop nutrient need prior to planting. The fertilizer recommendation is based on good calibration data and lab methods, but it can clearly be argued that nutrient recommendations can be incorrect if samples are not collected to a proper and consistent depth. As conservation tillage systems become the norm, nutrient stratification will increase and it is extremely important that samples be collected to the depth of the most aggressive tillage system in the rotation. Chisel tillage does not remove nutrient stratification and actually increases it over moldboard plowing. The soil test remains a valuable to for providing an index of nutrient availability. The interpretation of that index, followed by monitoring plant analysis and crop yield with appropriate adjustments, will be the best method of providing an adequate, but non-excessive nutrient supply.

Table 1. Main effect of rotation, tillage, and fertilization on the incremental soil test, Arlington, Wis., 2005.

	0 to 2 inches				2 to 4 inches				4 to 6 inches				6 to 8 inches			
Treatment	pH	OM	P	K	pH	OM	P	K	pH	OM	P	K	pH	OM	P	K
		%	---- ppm ----			%	---- ppm ----			%	--- ppm ---			%	---- ppm ---	
Rotation																
CC	5.4	4.0	58	165	6.4	3.5	44	109	6.8	3.3	34	81	6.9	3.0	25	73
CSb	6.5	3.6	56	145	6.7	3.4	38	94	6.9	3.2	33	74	6.9	3.0	25	68
SbC	5.7	4.0	50	139	6.4	3.7	45	91	6.8	3.5	42	72	6.9	3.4	36	65
LSD	0.3	NS†	NS	20	0.3	NS	NS	NS	NS	NS	NS	NS	NS	NS	9	NS
Tillage																
Chisel	6.0	3.6	49	141	6.4	3.5	44	104	6.8	3.4	35	77	6.9	3.1	27	68
No-Till	5.7	3.9	59	150	6.7	3.5	42	93	6.9	3.4	38	74	6.8	3.2	29	68
Strip-till	5.9	4.1	68	176	6.7	3.5	45	99	7.0	3.3	40	75	7.0	3.1	32	71
LSD	NS	0.2	12	19	0.2	NS	NS	NS	0.1	NS	NS	NS	NS	NS	NS	NS
Fert.																
None	5.9	3.8	43	127	6.5	3.5	38	89	6.9	3.3	35	73	6.9	3.1	27	67
Bdct.	5.8	3.8	67	171	6.5	3.5	47	106	6.8	3.4	38	78	6.9	3.1	30	70
LSD	NS	NS	5	11	NS	NS	3	7	NS	NS	NS	4	NS	NS	NS	NS
Significance (Pr>F)																
Rotation	<0.01	0.25	0.26	0.04	0.05	0.42	0.34	0.07	0.24	0.36	0.15	0.17	0.71	0.17	0.05	0.39
Tillage	0.38	<0.01	<0.01	<0.01	<0.01	0.90	0.74	0.08	0.03	0.76	0.81	0.21	0.14	0.73	0.70	0.06
R*T	0.76	0.24	0.52	0.76	0.21	0.06	0.21	0.39	0.24	0.04	0.22	0.03	0.41	<0.01	0.17	<0.01
Fert.	0.09	0.26	<0.01	<0.01	0.59	0.28	<0.01	<0.01	0.10	0.85	0.08	0.01	0.83	0.89	0.07	0.06
R*F	1.00	0.19	0.04	1.00	0.99	0.77	0.24	0.76	0.63	0.46	0.30	0.78	0.38	0.44	0.10	0.43
T*F	0.80	0.22	<0.01	0.01	0.81	0.29	0.42	0.27	0.75	0.17	0.40	0.63	0.71	0.77	0.21	0.69
R*T*F	0.29	0.77	0.99	0.42	0.06	0.28	0.54	0.60	0.41	0.90	0.14	0.71	0.42	0.99	0.11	0.39

† NS, not significant.