Calibration of the P Index – Northern New York

Assessment of P fertility Status, P Release, Storage Capacity and Distribution

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Introduction

Phosphorus (P) from agricultural soils, fertilizer and manures can contribute to the eutrophication of lakes if it moves from fields into surface waters. New York State has taken numerous steps to help minimize agricultural nutrient losses to the environment, including the development and implementation of the New York Phosphorus Runoff Index (NY-PI). While many of the processes that drive P losses are physical, inherent chemical properties of the different soil series can be a significant source of variability in determining the risk associated with P loss. The current NY-PI uses the agronomic soil test P (Cornell Morgan P) as predictor for the contribution of the soil to P runoff and indicator of past management practices (application versus crop removal). What is the current status of P fertility for New York soils and how good of a predictor is soil test P for P release from our agricultural soils?

Trends in soil fertility status of Northern New York agricultural soils

Recent studies regarding New York State trends in phosphorus soil fertility (Ketterings et al., 2005) showed that the highest soil test levels occur in vegetable production regions on Long-Island and the highly productive dairy, vegetable and fruit areas in Western New York and that there has been a steady increase in the percentage of fields testing high or very high in P where agronomic P recommendations would be limited to no more than small starter applications (Figure 1). With funding from the Northern New York Agricultural Development Program, phosphorus soil fertility trends were also evaluated for the six Northern New York counties. Table 1 shows these results. The greatest increases over time in the six counties took place in the dairy-dominated northern and northeastern regions, and this increase seems related to the increase in intensity of milk production (milk per acre cropland) (Figure 2).

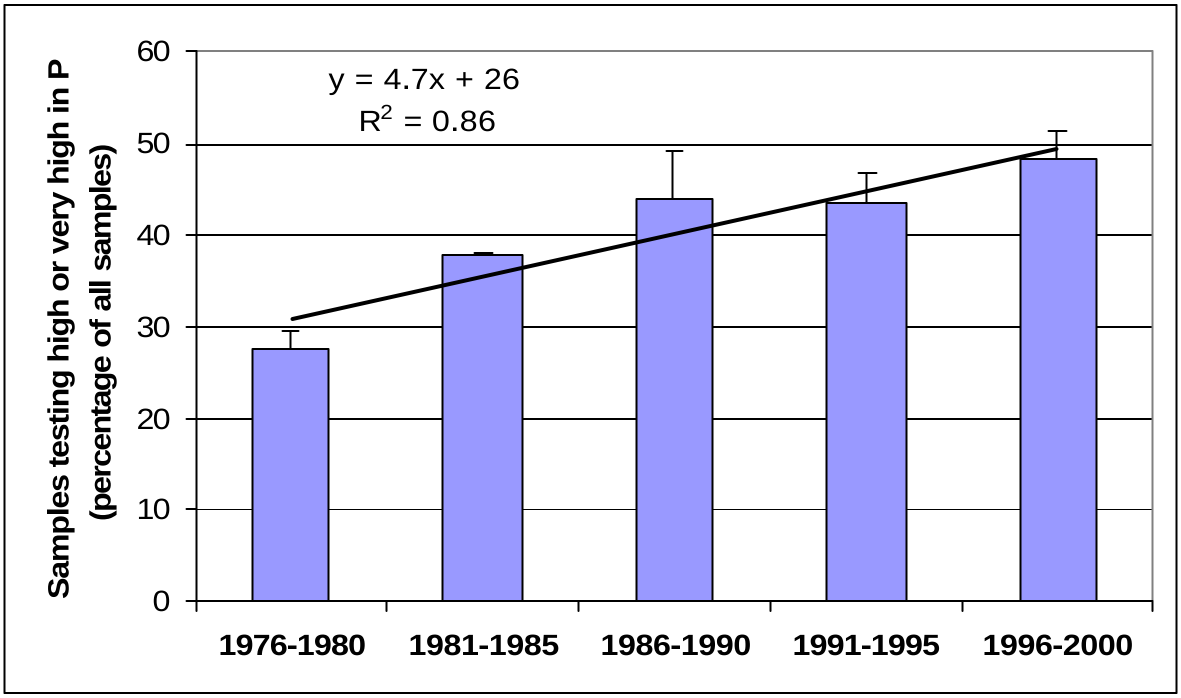

Figure 1: Increase in percentage of soils testing high or very high in P in New York (state average) over the past 25 years.

Table 1: Distribution of soil test classifications for Northern New York agronomic soil samples submitted to the Cornell Nutrient Analysis Laboratory in 1995-2001.

County	No. of Samples	Soil test P classification for field crops Frequency, %				
		Very Low + Low	Medium	High	Very High	High+ Very High
Jefferson	2,526	32.1	29.2	33.5	5.2	38.7
Lewis	2,070	33.4	29.0	33.3	4.3	37.6
St. Lawrence	4,323	39.5	25.6	30.7	4.2	34.9
Clinton	6,034	20.5	23.3	41.7	14.5	56.2
Essex	1,180	41.4	36.2	17.4	5.0	22.4
Franklin	1,956	30.2	31.4	35.4	3.0	38.4
Total	119,326	27.7	24.9	37.3	10.1	47.4

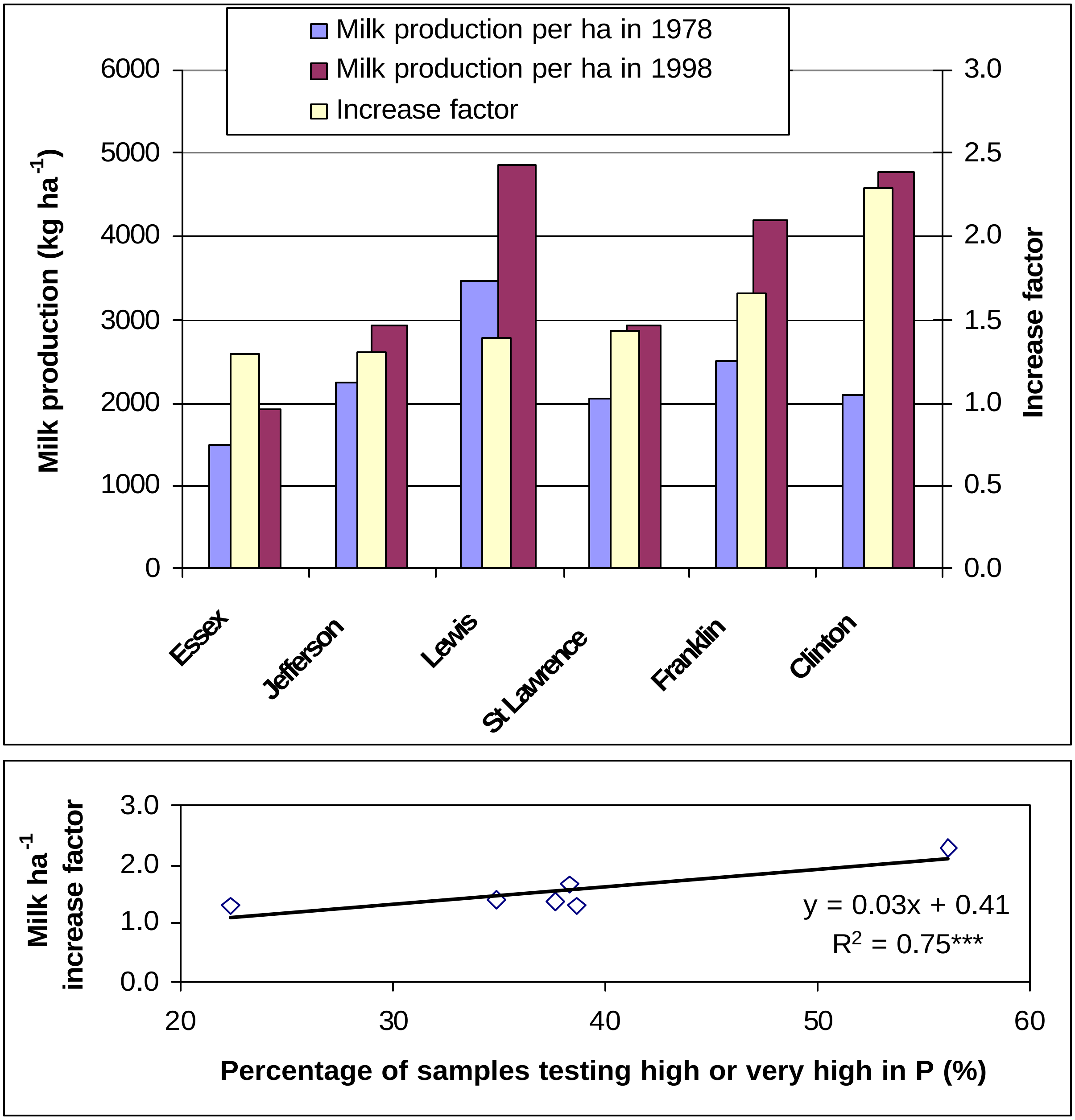

Figure 2: Percentage of the samples testing beyond the agronomic threshold and increase in milk production per area cropland for 6 dairy dominated northern and northeastern counties. Increase factors (ratio of milk production per acre cropland in 1998 and 1978) were derived from New York Agricultural Statistics Service (2003).

Over time, P accumulation in soils leads to increased P saturation levels of soils. The reason this is of concern is that this could lead to increased P runoff and leaching losses from agricultural fields to surface and ground water. Thus, as these soils reach progressively higher P levels, they may require more attentive management to ensure that environmental thresholds are not exceeded.

Do soils differ and is soil test P the correct indicator for runoff/leaching risk?

As mentioned before, the current NY-PI uses the agronomic soil test P (Cornell Morgan P) as a predictor for the contribution of soil P to runoff risk and indicator of past management practices (application versus crop removal). Our results on P trends show that soil test P is a good indicator of past management practices and that we need to monitor soil test levels over time and adjust our P application rates (whether from manure or from fertilizer) to avoid soils from becoming saturated. However, can we regard all soils to be equal? Can soil test P serve as an indicator of P release independent of other soil chemical characteristics?

Recent literature shows that soil chemical characteristics such as the amount of extractable Fe, Al and Ca, total sorption capacity of the soils and P saturation level may improve our predictions of P release from soils beyond what is possible with agronomic soil test P assessment only. Northern New York counties, as well as other parts of the state, are characterized by a wide diversity of soil series; and thus for more accurate P loss assessment it could be that we may need to incorporate soil specific characteristics in the NY-PI. Consequently, we set out to determine the extent of the differences in current P fertility status, P release, storage capacity and distribution over depth among 10 soil types in the 3 country region of Northern NY.

In 2004, we worked in conjunction with the with Cornell Nutrient Analysis Laboratory and the Western NNY counties to collect over 1000 soil samples that measure high or very high in P. We worked with collaborating field crop educators from Jefferson Co., Lewis Co. and St Lawrence Co. to select several representative soil series that are prevalent in their county's agricultural production areas. The soil series that we selected and the acres within each of the 3 counties are presented in Table 2. St Lawrence County is classified as a frigid temperature regime. The frigid equivalent of the mesic soil series Rhinebeck and Galway are Muskellunge (with 107,811 acres) and Nehasne (with 5,116 acres), respectively. A more detailed description of each of the soil series can be found in Appendix A.

Table 2: Acreage of major soil series in Jefferson, Lewis and St Lawrence counties.

Soil Series	Jefferson	Lewis	St Lawrence	Total
Muskellunge	4720	0	107811	112531
Nellis	12575	14082	0	26657
Collamer	29280	0	0	28280
Farmington	27920	7098	0	35018
Kingsbury	35960	0	0	35960
Croghan	0	6703	33815	40518
Rhinebeck	44635	1503	0	46138
Herkimer	0	5107	0	5107
Galway	42280	9811	0	52091
Hogansburg	0	0	78018	78018

We took a subset of 132 soils and analyzed those for Mehlich-3 extractable P, Al, Fe, and Ca (in addition to Cornell Morgan extractable nutrients). Although calibration studies are needed for accurate determination of the soils' sorption capacity, initial assessment of Mehlich-3 extractable Fe, Al, and Ca allows us to determine if soil series specific studies may be needed; i.e. whether or not it is likely that soil series differ in their ability to hold on to P. The main question is: do these soil series differ in soil chemical parameters that are thought to impact P dynamics.

The Morgan soil test summary statistics of the soil samples selected for this study are characterized by soil series in the tables B1 through B7 of the appendix. Appendix C1-C8 show the summary statistics based on the Mehlich-3 analyses for the soils. If we look at Table 3, we see a substantial range in Mehlich-3 extractable Al (from 1442 ppm for a Kingsbury soil to 542 ppm for a Hogansburg soil). There was a substantial amount of variability among the samples within each soil series but the mean Al concentration of the four Croghan soils was significantly higher than those of the others soil series. Collamer soils also contained on average more extractable Al than the Farmington, Kingsbury, Galway, Rhinebeck, Hogansburg and Herkimer soils. With regards to Mehlich-3 extractable Fe, soils ranged from 92-301 ppm. The Farmington soils shad the lowest average Fe concentrations. The highest Fe levels were seen for Rhinebeck, Herkimer and Muskellunge soils (Table 4).

Table 3: Mehlich-3 extractable Al (ppm)[1].

Soil Series	SMG[2]	N	Mean		Median	St Dev	Min	Max
Croghan	5	4	1248	a	1366	274.1	839	1422
Collamer	3	14	1069	b	1035	111.1	905	1277
Nellis	4	14	1003	bc	966	200.1	619	1308
Muskellunge	3	15	948	bcd	917	200.4	659	1353
Farmington	3	15	905	cd	927	170.7	604	1308
Kingsbury	1	15	901	cd	899	186.5	628	1442
Galway	4	14	886	cd	821	212.4	661	1375
Rhinebeck	2	12	880	cd	881	128.9	697	1219
Hogansburg	4	14	865	cd	879	135.5	542	1082
Herkimer	3	10	836	d	777	139.5	660	1051

Table 4: Mehlich-3 extractable Fe (ppm)[1].

Soil Series	SMG[2]	N	Mean		Median	St Dev	Min	Max
Rhinebeck	2	12	200	a	194	54.4	136	301
Herkimer	3	10	182	ab	185	24.8	143	213
Muskellunge	3	15	181	ab	175	31.3	138	246
Collamer	3	14	173	bc	174	19.7	142	207
Nellis	4	14	173	bc	162	37.1	118	244
Hogansburg	4	14	170	bc	167	21.0	131	214
Kingsbury	1	15	169	bc	168	26.7	129	215
Croghan	5	4	161	bc	164	27.6	128	189
Galway	4	14	148	cd	138	38.4	107	240
Farmington	3	15	122	d	121	24.5	92	171

[1] Means followed by the same letter are not significantly different at $\alpha = 0.05$.

[2] Soil Management Group

Several studies in the scientific literature reported that available Al and Fe are related to the P sorption capacity of the soils. However, these studies are also inconclusive as to what the exact relationships are and what mechanism control P sorption and desorption. Thus, we currently are working at better quantifying the role of Al and Fe for major New York agricultural soils in predicting P release from these soils. A decrease in extractable Fe and Al is generally seen with an increase in pH but for the soils investigated in this study, the inherent soil properties apparently have greater effects than pH. As shown in Figure 3, there is no correlation of extractable Fe with pH, and only a weak correlation for Al. Perhaps including more acidic soils would be beneficial to better quantifying this relationship, but other factors such as soil mineralogy and even the extraction method are also most likely involved.

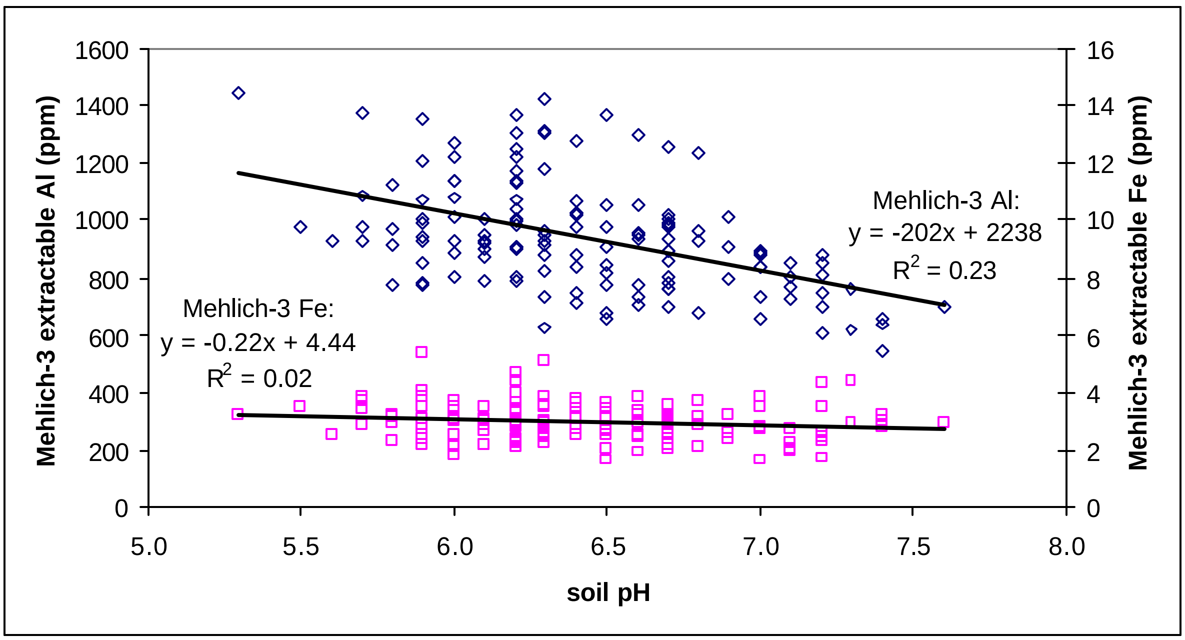

Figure 3: Soil pH and Mehlich-3 extractable Al and Fe for NNY soils.

Several studies have indicated that the extractable P levels of soils high in Fe are more likely to be impacted by the water saturation status of the soil rather than soils with correspondingly high Al levels. This is because phosphorus is released into solution when iron is reduced from Fe^{3+} to Fe^{2+} in saturated soils. Thus, the soils where P release is most likely influenced by soil moisture conditions are those with the highest Fe to Al ratio (Table 5).

Although extractable Fe can be indicative of sorption capacity as well, it is generally the much higher levels of extractable Al that are thought to dominate the P sorption capacity estimates (Table 6). Studies reported in the literature seem to suggest that P saturation may be a better predictor of P loss than agronomic soil test P levels. The results of our studies of the 10 NNY soil series shows that we may need to treat our soils differently (versus relying on soil test P only).

Table 5: Molar ratio of Mehlich-3 extractable Fe and Al (Fe/Al)[3].

Soil Series	SMG[4]	N	Mean		Median	St Dev	Min	Max
Rhinebeck	2	12	0.111	a	0.105	0.029	0.074	0.155
Herkimer	3	10	0.109	ab	0.108	0.028	0.070	0.149
Hogansburg	4	14	0.097	abc	0.089	0.022	0.072	0.162
Muskellunge	3	15	0.096	abc	0.091	0.024	0.066	0.151
Kingsbury	1	15	0.093	abc	0.096	0.020	0.061	0.129
Nellis	4	14	0.089	bc	0.081	0.037	0.044	0.190
Galway	4	14	0.085	cd	0.073	0.031	0.050	0.166
Collamer	3	14	0.079	cd	0.080	0.013	0.056	0.101
Farmington	3	15	0.067	d	0.061	0.017	0.050	0.110
Croghan	5	4	0.066	d	0.060	0.026	0.043	0.103

Table 6: Molar sum of Mehlich-3 extractable Fe and Al[3].

Soil Series	SMG[4]	N	Mean		Median	St Dev	Min	Max
Croghan	5	4	49.15	a	53.66	9.94	34.28	54.99
Collamer	3	14	42.72	b	41.59	4.09	36.94	50.44
Nellis	4	14	40.28	b	39.66	6.98	27.31	50.59
Muskellunge	3	15	38.37	bcd	37.08	7.54	27.20	53.67
Kingsbury	1	15	36.40	cd	36.76	6.99	25.75	56.69
Rhinebeck	2	12	36.20	cd	36.19	5.08	29.43	48.51
Farmington	3	15	35.73	cd	36.11	6.48	24.86	51.20
Galway	4	14	35.49	cd	32.63	7.87	27.30	53.86
Hogansburg	4	14	35.11	cd	35.18	5.14	23.35	43.93
Herkimer	3	10	34.23	d	31.71	4.96	28.11	41.67

One issue that has not been studied much with regards to predictors of P sorption and holding capacities of different soils is the contribution of extractable Ca. However, it is known that P can precipitate as Ca-P forms in calcareous soils or in soils with a high pH and large amounts of extractable Ca. Preliminary data from laboratory studies using soils from a farm in Southern NY show that Ca should be included in sorption capacity assessment of soils. Therefore, we looked at exchangeable Ca and the molar sum of Al, Fe, and Ca as well.

In Figure 4 we see that in general the amount of extractable Ca increases with the pH of the soils but that also here there is a fair amount of variability (soil pH explains only 33% of the variability in extractable Ca). Table 7 indicates that our soil series differ in the amount of Ca and this is furthermore an indication that P release from these soils may differ.

[3] Means followed by the same letter are not significantly different at $\alpha = 0.05$.

[4] Soil Management Group

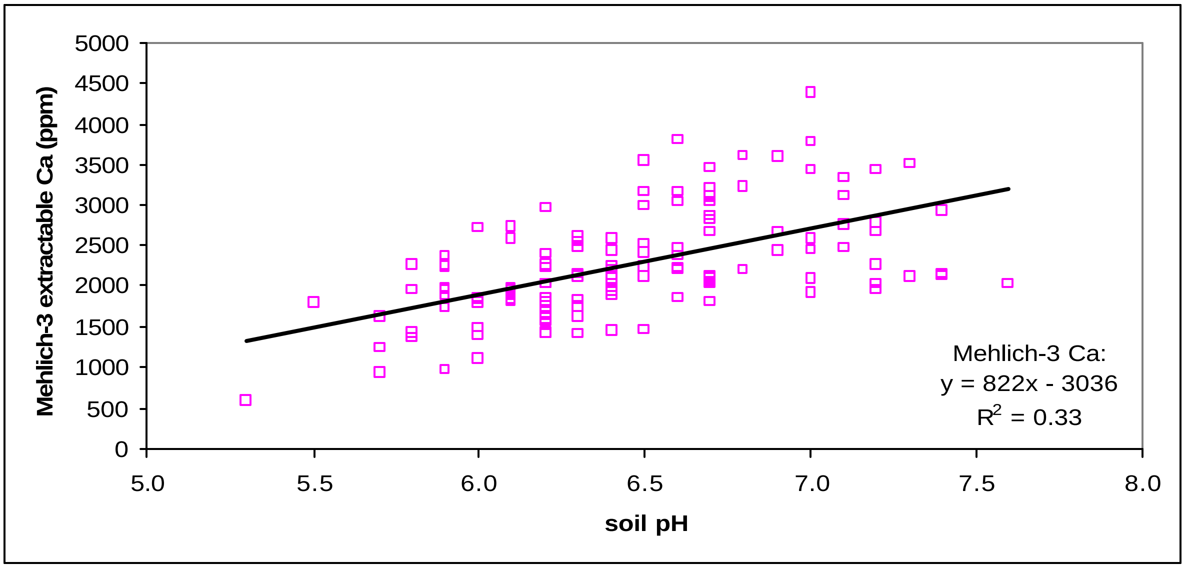

Figure 4: Soil pH and Mehlich-3 extractable Ca for NNY soils.

Table 7: Mehlich-3 extractable Ca (ppm)[5].

Soil Series	SMG[6]	N	Mean		Median	St Dev	Min	Max
Farmington	3	15	2804	a	2725	538.3	1601	3543
Galway	4	14	2584	ab	2818	753.3	937	3603
Herkimer	3	10	2472	abc	2428	506.2	1845	3199
Kingsbury	1	15	2325	abc	2369	927.5	605	4379
Nellis	4	14	2253	bc	2106	659.7	1421	3586
Muskellunge	3	15	2240	bc	2122	660.7	973	3804
Hogansburg	4	14	2061	cd	2105	280.8	1229	2535
Rhinebeck	2	12	2034	cd	1889	423.2	1622	3089
Collamer	3	14	1726	cd	1788	336.4	1104	2435
Croghan	5	4	1589	d	1525	210.3	1415	1890

Table 8: Molar sum of Mehlich-3 extractable Fe, Al, and Ca[5].

Soil Series	SMG[6]	N	Mean		Median	St Dev	Min	Max
Farmington	3	15	105.7	a	104.6	13.7	81.9	126.7
Galway	4	14	100.0	ab	100.1	13.6	77.2	118.7
Nellis	4	14	96.5	abc	92.8	13.4	81.4	125.5
Herkimer	3	10	95.9	abc	89.8	11.8	85.5	116.2
Kingsbury	1	15	94.4	bc	87.4	21.0	71.8	146.0
Muskellunge	3	15	94.3	bc	92.5	12.1	78.0	126.8
Croghan	5	4	88.8	c	90.3	5.1	81.4	93.1
Rhinebeck	2	12	86.9	c	85.9	9.3	77.4	106.5
Hogansburg	4	14	86.5	c	85.1	7.2	74.6	100.6
Collamer	3	14	85.8	c	86.8	6.1	75.3	100.9

[5] Means followed by the same letter are not significantly different at $\alpha = 0.05$.
[6] Soil Management Group

Our 2004 soil sampling and analyses results to date show that the soils in NNY vary significantly in extractable Al, Fe, and Ca. This warrants studies that are soil series specific and raises question like: can we quantify how our soils differ in their reaction to additional P (either as manure or as fertilizer)? Or in other words: how much would a Morgan soil test P increase with P addition and how easily is that additional P released in solution? And the most important question, are there chemical soil characteristics that can be used as indicators for soil specific accumulation and P release dynamics? Additional research is needed to now relate these data to P saturation levels and the potential for P loss for the Northern New York Counties. Our initial assessment points us towards the hypothesis that soils do differ and it is our intention to investigate this further for the major soil series in 2005 with NNYADP funds.

Rainfall Simulation Studies

In conjunction with the soil test evaluations described above, we used NNYADP funds to look at actual runoff from farm fields. The NY-PI is a management tool designed to rank fields based on their potential to create runoff P losses. Although laboratory studies are essential, validation and improvement of this tool requires also the direct field measurements of P losses. The objective of this part of our phosphorus studies was to determine actual P concentrations in runoff water from Northern New York farm fields under different management systems. A simulation approach was used to ensure that all sites would receive identical precipitation rates and to make certain that sampling could continue throughout the growing season with less dependence on the weather.

The protocol for the rain simulation was developed by the National Phosphorus Project to characterize the relationship between soil test phosphorus and surface runoff P. This protocol was chosen because it is designed to facilitate data collection on all major land resource areas in the US that receive manure, and allows New York data to be pooled with other research data for additional comparisons. A picture of the setup is shown below (Figure 5).

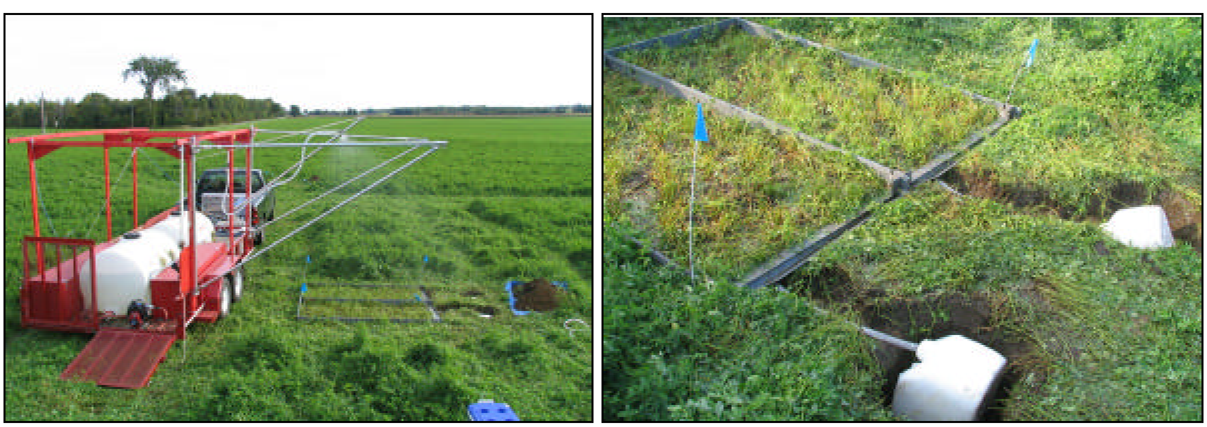

Figure 5: rainfall simulation setup at Greenwood Farms.

During the initial phase of this study three farms were selected based on their soil test P levels, soil type, proximity to surface waters and farmer interest in on-farm research. The selection of farms and fields was done with considerable input from field crops extension educators in Jefferson, Lewis and St. Lawrence counties. The sampling sites that we selected for our initial assessment are described in Table 9. At each site, we established 2-4 plots. Each plot consisted of a 2 x 2 meter frame (79 by 79 inches) pounded into the ground and bisected by a divider that split the main plot into two equal sized subplots. The downslope end of each subplot contained a runoff collection trough there water was collected for measurement.

Simulated rainfall was applied to the plots for three consecutive days at a rate of 4.15 cm hr^{-1} or 1.63 inches per hour. Water samples were collected from plots on days 2 and 3 during simulated rain events with the sample collection lasting 30 minutes from the time of initial runoff. This water was then analyzed for ortho-phosphorus, the directly available form of P.

Table 9: Characteristics of the field sites selected for initial rainfall simulation studies.

Farm	Plot	Cover	Soil Type	Slope (%)	STP
Greenwood	Plot 1	Alfalfa	Madrid	5	Very High
	Plot 2	Alfalfa	Madrid	5	Very High
	Plot 3	Alfalfa	Madrid	4	Very High
	Plot 4	Alfalfa	Madrid	6	Very High
Porterdale	Plot 1	Fallow Sod	Galway	10	Very High
	Plot 2	Alfalfa	Galway	4	Very High
	Plot 3	Alfalfa	Galway	6	Very High
	Plot 4	Killed Sod	Galway	8	Very High
Williams	Plot 1	Alfalfa	Kendaia	5	Very High
	Plot 2	Alfalfa	Kendaia	7	Very High

The on-farm rainfall simulations were conducted over the course of three weeks, beginning at the Williams Farm in Lewis County on September 1 2004. Set-up and data collection at each farm takes approximately 4 days, including 1 day to install the plot frames, one day to saturate the soils and two days to collect runoff. This initial assessment gave us very valuable information for both understanding P transport and for further refining measurement technique. The results of the simulations are listed in Table 10. Both runoff volume and P concentrations in the runoff were measured.

One observation was that the extreme labor and capital requirements in collecting this type of data necessitate carefully focused research plans, a generally limited number of observational sites and a degree of innovation. To facilitate working in NNY where research sites may span across large distances, the project manufactured an improved rain simulator design that is permanently mounted on a trailer. This innovation (see Figure 5 above) allowed us to collect significantly more data than would otherwise be possible using the standard National Phosphorus Project equipment.

Table 10: Preliminary runoff volume and P concentrations from 3 NNY farms.

Plot	Day	Sub Plot	Time to runoff (min)	Runoff Volume (L)	Mean Runoff Volume (L)	Source Water P (mg/L)	Runoff P (mg/L)	Mean Runoff P (mg/L)	Stdev. Runoff P (mg/L)
---Greenwood Farm---									
1	1	A	4	42.2	32.5	0.03	0.42	0.39	0.04
1	1	B	5	22.8		0.03	0.36		
2	1	A	6	43	34.1	0.03	0.46	0.46	0.00
2	1	B	6	25.2		0.03	0.46		
3	1	A	10	16.7	9.3	0.03	0.26	0.23	0.03
3	1	B	10	1.8		0.03	0.21		
4	1	A	7	22.7	20.1	0.03	1.98	1.46	0.73
4	1	B	7	17.5		0.03	0.94		
1	2	A	5	34.8	33	0.02	0.29	0.26	0.05
1	2	B	5	31.1		0.02	0.23		
2	2	A	4	46.4	44.8	0.02	0.28	0.28	0.01
2	2	B	4	43.1		0.02	0.27		
3	2	A	4	21.3	21.7	0.02	0.24	0.22	0.02
3	2	B	4	22		0.02	0.20		
4	2	A	5	46.4	38.3	0.02	0.47	0.42	0.08
4	2	B	5	30.2		0.02	0.36		
---Porterdale Farm**---									
1	1	A	*	*	*	1.95	*	*	*
1	1	B	*	*		1.95	*		
2	1	A	5	31.1	25.5	1.95	1.74	1.76	0.03
2	1	B	5	19.8		1.95	1.78		
3	1	A	5	14.1	14.9	1.95	1.74	1.70	0.05
3	1	B	5	15.7		1.95	1.66		
4	1	A	12	1.2	9.1	1.95	1.75	1.74	0.01
4	1	B	12	17.1		1.95	1.74		
1	2	A	*	*	*	1.95	*	*	*
1	2	B	*	*		1.95	*		
2	2	A	6	26.7	31.8	1.95	1.89	1.87	0.02
2	2	B	5	37		1.95	1.86		
3	2	A	4	20.8	20.2	1.95	1.81	1.81	0.00
3	2	B	4	19.6		1.95	1.81		
4	2	A	5	6.6	10	1.95	1.83	1.80	0.05
4	2	B	5	13.3		1.95	1.76		
---Williams Farm---									
1	1	A	2	27	19.6	0.35	0.20	0.21	0.01
1	1	B	2	12.1		0.35	0.22		
2	1	A	4	35.2	33	0.35	0.29	0.30	0.01
2	1	B	4	30.7		0.35	0.30		
1	2	A	4	52.7	49.5	0.33	0.09	0.09	0.00
1	2	B	5	46.2		0.33	0.09		
2	2	A	5	43.2	40.2	0.33	0.20	0.20	0.00
2	2	B	5	37.2		0.33	0.21		

* This site did not experience any runoff after one hour of rainfall on either day one or day two.
** At this site the source water was higher in P than the runoff water indicating P sorption.

Additionally, source water supply is an ongoing challenge for carrying out these rainfall simulation studies. The water requirements are generally in excess of 900 gallons, which can be a strain on farm wells. Water for simulations must be low in P and otherwise clean. In one instance, at the Porterdale Farm, the source water was obtained from a nearby business out of concern that the local surface waters may have high P concentrations because if the proximity to nearby manured fields. After analysis it was learned that the source water had very high P levels and was not suitable for conducting this type of experiment. This explains the apparent absorption of P during the rainfall event.

We propose to continue our rainfall simulation work using a carefully designed sampling schedule in 2005. The data are needed to place our laboratory studies and soil test P assessments in a wider framework of P dynamics and calibration of the NY-PI.

Outreach

To enable local communities to participate in the study and to increase awareness of phosphorus issues and ongoing research, field days were held in conjunction with the rainfall simulations. The Lewis County field day involved approximately 15 participants and was coordinated by Jen Beckman. Peter Barney arranged a field day in St Lawrence County with eight attendees on September 17 at the Greenwood Farm. The Jefferson County site was sampled beginning on September 21 with a field day arranged by Mike Hunter held two weeks later on October 5 to coincide with the FFA Land Judging competition. Over 250 students participated in a demonstration of the rain simulator and discussed phosphorus management. A field meeting later that same day drew a group of 10 people to learn more about efforts to refine the P index.


Figure 6: Field days at the Williams farm in Lewis County (left) and at the Porterdale Farm in Jefferson County (right).

A newspaper article appeared in the Watertown Daily Times on the event that included the 250 students, further exposing the region to our work. Fact sheets were generated under leadership of Kara Dunn, NNADP, and in collaboration with us. Current fact sheets include:

- Why is phosphorus an issue for New York farms?
- Trends in soil phosphorus status.
- Developing a phosphorus index for NNY soils.
- Limiting phosphorus use for corn growing in Northern New York.

We created a website that lists our ongoing Northern New York projects and allows those interested to download extension documents such as the soil test summaries and the fact sheets: http://nmsp.css.cornell.edu/projects/nny.asp. We hope to expand the website with additional fact sheets and project updates and to will continue our on-farm work including local extension offices and the farming communities in 2005.

Major Conclusions to Date

- Northern New York soils are steadily increasing in soil test P levels
- The increase is correlated to the intensity of farming (most rapid increase in Clinton County where milk production per acre cropland has increased most over the past 20 years.
- Major soil series in Northern New York differ in the chemical composition (extractable Fe, Al, Ca).
- These differences are likely to cause soils to react differently to P application.
- On-farm rainfall simulations studies give us very valuable information for both understanding P transport and for further refining measurement techniques.
- Strong response to our outreach efforts demonstrate increasing grower interest in environmental and agronomic P management.

Proposed Work in 2005

- Whole farm nutrient balance assessment (6-10 farms, more depending on local participation in the assessment).
- Laboratory studies to quantify increase in soil test P and P saturation with addition of fertilizer and manure P; investigation of the role of extractable Fe, Al and Ca as predictors. This involves sampling of major soil series in the counties and incubation studies in the laboratory.
- Laboratory studies that let us relate soil test P, Fe, Al, and Ca to total sorption capacity and P saturation and P release (development of a tool that could possibly replace soil test P in the P index).
- Continuation of on-farm runoff assessments to link findings in the laboratory with in-field assessments of runoff.

Appendix A: Soil Descriptions (from the NRCS Soil Database)

COLLAMER SERIES. The Collamer series consists of very deep, moderately well drained soils formed in silty glacio-lacustrine sediments. They are on lake plains and till plains that have a thick mantle of lake sediments. Slope ranges from 0 to 25%. Mean annual precipitation is 37 inches, and mean annual air temperature is 49^{o}F. The taxonomic class is: Fine-silty, mixed, active, mesic Glossaquic Hapludalfs. Currently there are no other soils in this family. The Amboy, Cazenovia, Conesus, Hilton, Honeoye, Hudson, Jonesboro, Lansing, Lima, Ontario, Schoharie, Scio, Unadilla, and Williamson series are similar soils in related families. Amboy, Scio, Unadilla, and Williamson soils have coarse-silty particle-size control sections and lack argillic horizons. Cazenovia, Conesus, Hilton, Honeoye, Lansing, Lima, and Ontario soils have fine-loamy particle size control sections. Hudson and Schoharie soils have fine particle-size control sections. Jonesboro soils are more than 60 inches to the base of the argillic and have a superactive CEC activity class.

CROGHAN SERIES. The Croghan series consists of very deep, moderately well drained soils formed in deltaic or glacio-fluvial deposits. They are on terraces and sand plains. Permeability is moderately rapid or rapid in the surface and subsurface horizons and rapid or very rapid below. Slope ranges from 0 to 15%. Mean annual temperature is about 42^{o}F, and mean annual precipitation is about 38 inches. The taxonomic class is: Sandy, isotic, frigid Aquic Haplorthods. The Skowhegan series is the only other series in the same family. Skowhegan soils have a thinner solum than Croghan soils and contain appreciable amounts of dark colored minerals.

FARMINGTON SERIES. The Farmington series consists of shallow, well drained and somewhat excessively drained soils formed in till. They are nearly level to very steep soils on glaciated uplands. Bedrock is at a depth of 10 to 20 inches. Slope ranges from 0 to 70%. The mean annual temperature is 49^{o}F. and the mean annual precipitation is 37 inches. The taxonomic class is: Loamy, mixed, active, mesic Lithic Eutrudepts. The Newbern series is the only competing series. The Newbern soils have angular shale fragments of residual origin, lack a 2R horizon, have less than 2% organic matter in the surface layer, and have a warmer mean annual soil temperature. The Amenia, Arnot, Benson, Catlett, Dover, Grenville, Hogansburg, Holyoke, Klinesville, Nassau, Nellis, Pequea, Wassaic, and Weikert series are similar soils in related families. Amenia, Dover, Grenville, Hogansburg, Nellis, Pequea, and Wassaic soils have bedrock at depths greater than 20 inches. Arnot, Catlett, Klinesville, Nassau, and Weikert soils have more than 35 percent rock fragments and less than 60% base saturation. Benson soils have more than 35% rock fragments. Holyoke soils have less than 60% base saturation.

GALWAY SERIES. The Galway series consists of moderately deep, well drained and moderately well drained soils formed in till. They are nearly level to very steep soils that are 20 to 40 inches deep over calcareous sedimentary bedrock. Permeability is moderate. Slope ranges from 0 to 60%. The mean annual temperature is 49^{o}F and mean annual precipitation is 39 inches. The taxonomic class is: Coarse-loamy, mixed, superactive, mesic Typic Eutrudepts. A typical pedon is a Galway loam in an abandoned pasture on a 5 percent southeast-facing slope. The Nellis, Salter, and Sunburg series are in the same family. Nellis, Salter, and Sunburg soils are deeper than 40 inches to bedrock. The Amenia, Benson, Farmington, Hogansburg, and Wassaic series are similar soils in related families. Amenia and Hogansburg soils have mottles with chroma of 2 within a depth of 25 inches and are deeper than 40 inches to bedrock. Benson and Farmington soils have bedrock at a depth of 10 to 20 inches. Wassaic soils have an argillic horizon.

HERKIMER SERIES. The Herkimer series consists of very deep, well drained or moderately well drained soils formed in old alluvium. The alluvium is dominated by dark colored calcareous shale and smaller amounts of sandstone and limestone. They are on alluvial fans. Slope ranges from 0 to 10% normally, but can go as high as 25%. Mean annual temperature is 49^{o}F. and mean annual precipitation is 39 inches. The taxonomic class is: Coarse-loamy, mixed, active, mesic Dystric Eutrudepts. The Lowville, Pittsfield, Reger (T), Spoolville, Urne, and Wakeman series are in the same family. Lowville, Pittsfield, and Urne soils have less than 10 percent shale fragments. Reger (T) and Wakeman have bedrock within 40 inches. Spoolville soils have bedrock within 60 inches. The Amenia, Camillus, Dover, Grenville, Hogansburg, Manlius, Mohawk, Nellis and Palatine series are similar soils in related families. All of these soils except Manlius have carbonates within 40 inches of the surface. Manlius soils have bedrock at depth of 20 to 40 inches.

HOGANSBURG SERIES. The Hogansburg series consists of very deep, moderately well drained soils formed in glacial till having a high content of limestone. These are nearly level to moderately steep soils on till plains. Slopes range from 0 to 25%. Mean annual temperature is 44^{o}F and mean annual precipitation is 38 inches. The taxonomic class is: Coarse-loamy, mixed, semiactive, frigid Aquic Eutrudepts. There are no other series in the same family. The Amenia, Bombay, Eelweir, Georgia, Grenville, and Kalurah soils are similar soils in related families. Amenia, Bombay, and Georgia soils have a mesic temperature regime; in addition, Amenia soils have a lower content of magnesium and a high content of calcite, Bombay soils have an argillic horizon, and Georgia soils lack free carbonates within a depth of 40 inches. Eelweir and Kalurah soils lack carbonates within a depth of 40 inches. In addition, Eelweir soils have less than 5 percent rock fragments in the subsoil and substratum. Grenville soils lack 2 chroma mottles within a depth of 24 inches.

KINGSBURY SERIES. The Kingsbury series consists of very deep, somewhat poorly drained soils formed in lacustrine or marine sediments. They are nearly level and gently sloping soils on lake plains. Slope ranges from 0 to 8%. The mean annual temperature is 47^{o}F and the mean annual precipitation is 37 inches. The taxonomic class is: Very-fine, illitic, mesic Aeric Epiaqualfs. The Roselms series is the only other member of the same family. Roselms soils lack the fracturing of the C horizon which resembles angular blocky structure and has mean temperature higher than 49^{o}F. The Chaumont, Covington, Panton, Rhinebeck, Vergennes and Wilpoint series are members of other families. Chaumont and Wilpoint soils have bedrock at depths of less than 40 inches. Covington and Panton soils have gray colors dominant in all subsurface horizons. Rhinebeck soils have a fine particle-size control section. Vergennes soils lack colors in the Bt horizon indicative of an aquic moisture regime.

NELLIS SERIES. The Nellis series consists of very deep, well drained soils formed in calcareous till. They are nearly level to very steep soils on upland ridges, knolls and hillsides. Permeability is moderate in the surface and subsoil, and moderately slow or moderate in the substratum. Slope ranges from 0 to 60%. Mean annual temperature is 47^{o}F and mean annual precipitation is 39 inches. The taxonomic class is: Coarse-loamy, mixed, superactive, mesic Typic Eutrudepts. Galway, Salter, and Sunburg are other series in this family. Galway soils have bedrock at depths of 20 to 40 inches. Salter has stratification of textures and rock fragments in the upper 40 inches. Sunburg has carbonates within 15 inches of the surface. The Amenia, Farmington, Grenville, Hogansburg, Pittsfield, and Stockbridge series are similar soils in related families. Amenia and Hogansburg soils have mottles with chroma of 2 or less within a depth of 24 inches. Farmington soils have a lithic contact within a depth of 20 inches. Grenville soils have a frigid temperature regime. Pittsfield and Stockbridge soils lack carbonates within a depth of 40 inches.

MUSKELLUNGE SERIES. The Muskellunge series consists of very deep, somewhat poorly drained soils formed in water deposited materials. They are on glacial lake plains and uplands mantled with lake sediments. Permeability is slow. Slope ranges from 0 to 15%. The mean annual air temperature is 42°F and mean annual precipitation is 36 inches. The taxonomic class is: Fine, mixed, active, frigid Aeric Epiaqualfs. There are no other series in this family. The Matoon and Rhinebeck series are similar soils in related families. Matoon soils are less than 40 inches to a lithic contact. Rhinebeck soils have illitic mineralogy and a mesic temperature regimes.

RHINEBECK SERIES. The Rhinebeck series consists of very deep, somewhat poorly drained soils formed in clayey lacustrine sediments. They are on glacial lake plains and uplands mantled with lake sediments. Slope ranges from 0 to 15%. Mean annual temperature is 48°F, and mean annual precipitation is 39 inches. The taxonomic class is: Fine, illitic, mesic Aeric Endoaqualfs. The Brockport, Caneadea, Churchville, Lockport, Odessa, and Remsen series are in the same family. Brockport and Lockport soils have bedrock within depths of 40 inches. Caneadea soils have a solum thicker than 40 inches. Churchville soils have a lithologic discontinuity and 10 to 35% rock fragments in the series control section. Odessa soils have hue of 5YR or redder in the Bt horizon. Remsen soils formed in till and have a higher sand and rock fragment content in individual layers.

Appendix B: Morgan Summary Statistics for Selected Northern NY Soils

Appendix B1: Morgan extractable P (lbs P/acre)[7].

Soil Series	SMG[8]	N	Mean		Median	St Dev	Min	Max
Galway	4	14	26	a	9	30.1	1	77
Herkimer	3	10	22	ab	13	21.0	4	66
Hogansburg	4	14	14	abc	11	10.9	3	37
Rhinebeck	2	12	13	abc	4	19.2	1	66
Kingsbury	1	15	13	bc	6	16.5	1	54
Farmington	3	15	12	bc	9	13.5	1	56
Nellis	4	14	8	c	5	8.3	2	32
Croghan	5	4	7	c	4	8.2	1	19
Muskellunge	3	15	6	c	4	5.2	1	18
Collamer	3	14	6	c	6	3.1	1	13

Appendix B2: Morgan extractable Fe (lbs Fe/acre)[7].

Soil Series	SMG[8]	N	Mean		Median	St Dev	Min	Max
Kingsbury	1	15	28.2	a	16.0	35.9	6	151
Rhinebeck	2	12	23.5	ab	14.0	22.5	4	85
Muskellunge	3	15	13.6	bc	10.5	11.8	2	39
Collamer	3	14	12.9	bc	11.5	5.6	6	24
Nellis	4	14	10.6	bc	8.0	6.5	3	21
Herkimer	3	10	8.6	c	8.0	4.0	3	14
Croghan	5	4	7.5	c	7.5	2.4	5	10
Galway	4	14	6.1	c	3.5	8.1	1	33
Farmington	3	15	5.9	c	5.0	4.5	1	15
Hogansburg	4	14	5.5	c	4.0	3.8	3	15

Appendix B3: Morgan extractable Al (lbs Al/acre)[7].

Soil Series	SMG[8]	N	Mean		Median	St Dev	Min	Max
Collamer	3	14	117	a	107	44.3	64	206
Nellis	4	14	110	a	84	83.4	20	291
Kingsbury	1	15	109	a	89	104.8	12	452
Croghan	5	4	95	ab	96	54.2	40	148
Rhinebeck	2	12	88	ab	79	47.7	25	205
Muskellunge	3	15	79	ab	45	69.3	16	258
Herkimer	3	10	74	ab	64	39.9	31	156
Galway	4	14	73	ab	37	95.6	14	370
Farmington	3	15	71	ab	60	45.6	14	145
Hogansburg	4	14	41	b	23	34.4	12	131

[7] Means followed by the same letter are not significantly different at $\alpha = 0.05$.

[8] Soil Management Group

Appendix B4: Morgan extractable Ca (lbs Ca/acre)[9].

Soil Series	SMG[10]	N	Mean		Median	St Dev	Min	Max
Farmington	3	15	5483	a	5490	1470	2690	8170
Galway	4	14	5249	ab	5195	1909	1580	7950
Kingsbury	1	15	5049	abc	4830	2146	870	9620
Herkimer	3	10	4994	abcd	4685	1940	3280	9690
Nellis	4	14	4378	abcd	4335	1653	2350	8300
Rhinebeck	2	12	4093	bce	3910	841	3100	6290
Hogansburg	4	14	3934	cde	4025	870	1910	5360
Muskellunge	3	15	3464	def	3300	1560	59	6080
Collamer	3	14	2999	ef	3140	707	1780	4440
Croghan	5	4	2278	f	2120	542	1810	3060

Appendix B5: Molar sum of Morgan extractable Fe and Al[9].

Soil Series	SMG[10]	N	Mean		Median	St Dev	Min	Max
Collamer	3	14	2.287	a	2.122	0.849	1.249	3.943
Kingsbury	1	15	2.280	a	1.846	1.975	0.897	8.806
Nellis	4	14	2.136	a	1.642	1.586	0.442	5.572
Rhinebeck	2	12	1.837	ab	1.615	1.002	0.517	4.112
Croghan	5	4	1.823	ab	1.832	1.024	0.795	2.832
Muskellunge	3	15	1.571	ab	0.968	1.371	0.314	5.005
Herkimer	3	10	1.454	ab	1.235	0.768	0.601	3.007
Galway	4	14	1.399	ab	0.712	1.843	0.295	7.152
Farmington	3	15	1.368	ab	1.157	0.878	0.277	2.786
Hogansburg	4	14	0.806	b	0.453	0.670	0.258	2.562

Appendix B6: Molar sum of Morgan extractable Fe, Al, and Ca[9].

Soil Series	SMG[10]	N	Mean		Median	St Dev	Min	Max
Farmington	3	15	69.8	a	68.8	18.0	35.8	102.9
Galway	4	14	66.9	ab	65.4	22.4	26.9	99.8
Kingsbury	1	15	65.3	abc	62.1	25.4	19.7	120.9
Herkimer	3	10	63.8	abc	59.2	23.9	42.6	122.1
Nellis	4	14	56.8	abcd	55.3	19.8	34.1	104.0
Rhinebeck	2	12	52.9	bcd	50.9	10.0	40.6	79.0
Hogansburg	4	14	49.9	cde	51.3	10.4	26.4	67.1
Muskellunge	3	15	44.8	cde	42.6	19.1	1.1	76.2
Collamer	3	14	37.0	ef	39.2	12.7	2.7	56.9
Croghan	5	4	30.2	f	29.1	6.4	23.7	39.0

[9] Means followed by the same letter are not significantly different at $\alpha = 0.05$.
[10] Soil Management Group.

Appendix B7: Molar ratio of Morgan extractable Fe and Al (Fe/Al)[11].

Soil Series	SMG[12]	N	Mean		Median	St Dev	Min	Max
Kingsbury	1	15	0.245	a	0.050	0.773	0.025	3.040
Rhinebeck	2	12	0.062	a	0.043	0.045	0.026	0.187
Muskellunge	3	15	0.039	a	0.041	0.020	0.000	0.081
Hogansburg	4	14	0.037	a	0.034	0.014	0.021	0.081
Herkimer	3	10	0.031	a	0.028	0.014	0.014	0.064
Nellis	4	14	0.030	a	0.023	0.022	0.010	0.097
Collamer	3	14	0.027	a	0.028	0.008	0.012	0.039
Galway	4	14	0.025	a	0.020	0.016	0.011	0.069
Croghan	5	4	0.022	a	0.019	0.009	0.016	0.036
Farmington	3	15	0.020	a	0.018	0.009	0.012	0.041

[11] Means followed by the same letter are not significantly different at $\alpha = 0.05$.
[12] Soil Management Group.

Appendix C: Mehlich-3 Summary Statistics for Selected Northern NY Soils

Appendix C1: Mehlich-3 extractable P (ppm)[13].

Soil Series	SMG[14]	N	Mean		Median	St Dev	Min	Max
Herkimer	3	10	120	a	118	63.4	44	220
Galway	4	14	113	ab	78	85.1	19	269
Croghan	5	4	99	abc	74	89.0	20	226
Farmington	3	15	74	bcd	60	42.5	22	188
Nellis	4	14	73	cd	57	34.9	41	151
Hogansburg	4	14	69	cd	71	23.5	34	117
Collamer	3	14	61	cd	60	23.6	33	106
Rhinebeck	2	12	58	d	45	30.8	28	120
Muskellunge	3	15	53	d	41	25.5	25	100
Kingsbury	1	15	50	d	33	39.1	21	133

Appendix C2: Mehlich-3 extractable Fe (ppm)[13].

Soil Series	SMG[14]	N	Mean		Median	St Dev	Min	Max
Rhinebeck	2	12	200	a	194	54.4	136	301
Herkimer	3	10	182	ab	185	24.8	143	213
Muskellunge	3	15	181	ab	175	31.3	138	246
Collamer	3	14	173	bc	174	19.7	142	207
Nellis	4	14	173	bc	162	37.1	118	244
Hogansburg	4	14	170	bc	167	21.0	131	214
Kingsbury	1	15	169	bc	168	26.7	129	215
Croghan	5	4	161	bc	164	27.6	128	189
Galway	4	14	148	cd	138	38.4	107	240
Farmington	3	15	122	d	121	24.5	92	171

Appendix C3: Mehlich-3 extractable Al (ppm)[13].

Soil Series	SMG[14]	N	Mean		Median	St Dev	Min	Max
Croghan	5	4	1248	a	1366	274.1	839	1422
Collamer	3	14	1069	b	1035	111.1	905	1277
Nellis	4	14	1003	bc	966	200.1	619	1308
Muskellunge	3	15	948	bcd	917	200.4	659	1353
Farmington	3	15	905	cd	927	170.7	604	1308
Kingsbury	1	15	901	cd	899	186.5	628	1442
Galway	4	14	886	cd	821	212.4	661	1375
Rhinebeck	2	12	880	cd	881	128.9	697	1219
Hogansburg	4	14	865	cd	879	135.5	542	1082
Herkimer	3	10	836	d	777	139.5	660	1051

[13] Means followed by the same letter are not significantly different at $\alpha = 0.05$.

[14] Soil Management Group

Appendix C4: Mehlich-3 extractable Ca (ppm)[15].

Soil Series	SMG[16]	N	Mean		Median	St Dev	Min	Max
Farmington	3	15	2804	a	2725	538.3	1601	3543
Galway	4	14	2584	ab	2818	753.3	937	3603
Herkimer	3	10	2472	abc	2428	506.2	1845	3199
Kingsbury	1	15	2325	bc	2369	927.5	605	4379
Nellis	4	14	2253	bc	2106	659.7	1421	3586
Muskellunge	3	15	2240	b	2122	660.7	973	3804
Hogansburg	4	14	2061	cd	2105	280.8	1229	2535
Rhinebeck	2	12	2034	cd	1889	423.2	1622	3089
Collamer	3	14	1726	d	1788	336.4	1104	2435
Croghan	5	4	1589	d	1525	210.3	1415	1890

Appendix C5: Molar sum of Mehlich-3 extractable Fe and Al[15].

Soil Series	SMG[16]	N	Mean		Median	St Dev	Min	Max
Croghan	5	4	49.15	a	53.66	9.94	34.28	54.99
Collamer	3	14	42.72	b	41.59	4.09	36.94	50.44
Nellis	4	14	40.28	bc	39.66	6.98	27.31	50.59
Muskellunge	3	15	38.37	bcd	37.08	7.54	27.20	53.67
Kingsbury	1	15	36.40	cd	36.76	6.99	25.75	56.69
Rhinebeck	2	12	36.20	cd	36.19	5.08	29.43	48.51
Farmington	3	15	35.73	cd	36.11	6.48	24.86	51.20
Galway	4	14	35.49	cd	32.63	7.87	27.30	53.86
Hogansburg	4	14	35.11	cd	35.18	5.14	23.35	43.93
Herkimer	3	10	34.23	d	31.71	4.96	28.11	41.67

Appendix C6: Molar sum of Mehlich-3 extractable Fe, Al, and Ca[15].

Soil Series	SMG[16]	N	Mean		Median	St Dev	Min	Max
Farmington	3	15	105.7	a	104.6	13.7	81.9	126.7
Galway	4	14	100.0	ab	100.1	13.6	77.2	118.7
Nellis	4	14	96.5	abc	92.8	13.4	81.4	125.5
Herkimer	3	10	95.9	abc	89.8	11.8	85.5	116.2
Kingsbury	1	15	94.4	bc	87.4	21.0	71.8	146.0
Muskellunge	3	15	94.3	bc	92.5	12.1	78.0	126.8
Croghan	5	4	88.8	c	90.3	5.1	81.4	93.1
Rhinebeck	2	12	86.9	c	85.9	9.3	77.4	106.5
Hogansburg	4	14	86.5	c	85.1	7.2	74.6	100.6
Collamer	3	14	85.8	c	86.8	6.1	75.3	100.9

[15] Means followed by the same letter are not significantly different at $\alpha = 0.05$.
[16] Soil Management Group

Appendix C7: Molar ratio of Mehlich-3 extractable Fe and Al (Fe/Al)[17].

Soil Series	SMG[18]	N	Mean		Median	St Dev	Min	Max
Rhinebeck	2	12	0.111	a	0.105	0.029	0.074	0.155
Herkimer	3	10	0.109	ab	0.108	0.028	0.070	0.149
Hogansburg	4	14	0.097	abc	0.089	0.022	0.072	0.162
Muskellunge	3	15	0.096	abc	0.091	0.024	0.066	0.151
Kingsbury	1	15	0.093	abc	0.096	0.020	0.061	0.129
Nellis	4	14	0.089	bc	0.081	0.037	0.044	0.190
Galway	4	14	0.085	cd	0.073	0.031	0.050	0.166
Collamer	3	14	0.079	cd	0.080	0.013	0.056	0.101
Farmington	3	15	0.067	d	0.061	0.017	0.050	0.110
Croghan	5	4	0.066	d	0.060	0.026	0.043	0.103

[17] Means followed by the same letter are not significantly different at $\alpha = 0.05$.
[18] Soil Management Group