PHOSPHORUS GUIDELINES FOR FIELD CROPS IN NEW YORK

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Executive Summary

- Phosphorus (P) is an essential macro nutrient for crop growth. Both insufficient and excess P in agricultural systems can impact farm productivity, profitability, and environmental sustainability.

- This manual presents Land Grant University guidelines for P management of field crops, which considers the economic return of P fertilizer additions as well as the need to manage crops at an optimal soil test P (STP) range. This manual replaces Ketterings et al. (2003).

- Crops for which guidance is given include, among others, corn grown for grain, corn grown for silage, grass hay fields, mixed grass and alfalfa stands, sorghum sudangrass, forage sorghum, and small grains.

- Soil testing is key for P management of crops. A soil test will show if additional P from fertilizer or manure is likely to result in an increase in crop yield. The Cornell Morgan soil test (sodium acetate extraction followed by colorimetric determination of P in solution) is the basis for Cornell University guidelines for field crops. When other soil testing methods are used, results will need to be converted to a Cornell Morgan equivalent STP before they can be used to derive guidelines for various field crops.

- Equations were derived for converting Mehlich-3 and (Modified) Morgan soil test results from various laboratories into Cornell Morgan soil test P equivalents. These equations are included in this document.

- If STP suggests that P is not limiting crop production (agronomic STP threshold of >40 lbs P/acre for most crops in New York), no additional fertilizer P is recommended.

- An STP above the agronomic threshold does not mean that additional P in the form of fertilizer or manure directly contributes to loss of P to the environment. For P loss management, the New York Phosphorus Index 2.0 governs land application of manure. Information on the New York Phosphorus Index 2.0 can be found in the manual and user's guide (Czymmek et al., 2021).

Acknowledgments

Agronomic phosphorus (P) guidelines for field crops in New York were first developed by emeriti professors D.R. Bouldin, S.D. Klausner, D.J. Lathwell, and W.S. Reid. An earlier version of this document was co-authored in 2003 by S.D. Klausner and K.J. Czymmek, then Senior Extension Associates with the PRO-DAIRY program. Since then, field trials conducted as part of the Cornell On-Farm Research Partnership confirmed appropriateness of P guidelines for corn and other crops.

We thank K.J. Czymmek with whom many of the current guidelines were co-developed. We also thank G. Albrecht, B. Jordan, R. Bush (New York State Department of Agriculture and Markets, NYSAGM), J. Hornesky and D. Gates (Natural Resources Conservation Service, NRCS), and S. Latessa (New York State Department of Environmental Conservation, NYSDEC), for reviewing this document. We are grateful to the many New York Agricultural Environmental Management Certified Planners, Certified Crop Advisors, Cornell Cooperative Extension staff, Soil and Water Conservation District staff, Natural Resources Conservation Service staff, and farmers who worked with us to evaluate the need for P fertilizer for corn silage and grain, supplied yield data and gave valuable feedback as new guidance systems were being developed.

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1. Introduction

Phosphorus (P) is a macronutrient belonging to a group of 17 nutrients that are essential for plant growth and crop production. It is a key component of cell membranes and cellular compounds such as adenosine triphosphate (ATP, energy-rich compounds used as "fuel" for cell activity), deoxyribonucleic acid (DNA, the genetic code), and ribonucleic acid (RNA, essential in the production of proteins). Phosphorus is important for animals and humans as well. It is a component of bones, teeth, and shells and helps strengthen muscles in addition to being essential for production of ATP, DNA, RNA, and cell membranes. In plants, P plays an essential role in photosynthesis, respiration, N fixation, root development, maturation, flowering, fruiting, and seed production.

An adequate supply of P in early plant life is essential for the development of reproductive parts (seeds and fruits contain large quantities of P). A deficiency in P results in reduced plant growth, delay of maturity, and lower crop yields. Because P is mobile in the plant, deficiency symptoms are expressed in the older leaves. In corn and some other grass species, P deficiency symptoms can be recognized by a purple discoloration of the leaves or leave margins. For other crops, deficiency symptoms are less distinctive.

Phosphorus, like nitrogen (N), needs careful management to maximize economic returns and prevent losses to the environment. Phosphorus is the most limiting nutrient for the growth of algae and large aquatic plants in temperate lakes and, as a result, an overabundance of dissolved P in water can cause eutrophication resulting in oxygen deficiency and fish kills. The concentration of Morgan extractable soil P above which the loss of P is a concern, even when excellent management practices are followed, is unknown, but a reduction in surplus P in the soil will minimize the potential for loss.

2. Phosphorus Forms and Plant Availability

Phosphorus is least mobile of the major plant nutrients. It can exist as dissolved P or particulate P. Dissolved P includes PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, H_3PO_4 and some soluble organic compounds. Particulate P includes calcium phosphate minerals, P attached to clay minerals and to iron and aluminum oxides, incorporated into iron and aluminum oxides, or in soil organisms and active and stable organic matter.

Plants take up dissolved HPO_4^{2-}, $H_2PO_4^-$, and some soluble organic P compounds from the soil. The plant converts these forms of P into organic P forms. When plants die, this plant-P is returned to the soil through decomposition by microorganisms. Other pathways through which P can be made available include weathering of soil minerals, desorption from clay minerals, mineralization of and desorption from manure and plant residues, or inorganic fertilizer.

The various forms of P are continually undergoing change with the general tendency towards less soluble or less available forms. When relatively soluble P is added to the soil in fertilizer or manure, the soluble fractions increase, but with time these transform to less soluble and therefore less plant available forms. Phosphorus is in its most available

form in near neutral soils. At pH 7.2, the amount of $H_2PO_4^-$ and HPO_4^{2-} are approximately equal. At low pH, soluble forms of iron, aluminum, manganese, and their hydrous oxides fix inorganic P. At high pH, P is mostly fixed as calcium phosphates.

3. Phosphorus Guidelines for Field Crops

Cornell University P guidelines for field crops are derived from the Cornell Morgan soil test P (STP; Morgan, 1941). A Cornell Morgan STP equivalent needs to be determined if other tests are used (Section 4). At Cornell University, soil test P levels are classified as "Low", "Medium", "Optimum", "High" and "Very High". These classifications may differ depending on the crop. For example, for corn, STP levels of <3 lb P/acre (Morgan extractable P) are considered "Low", 4-8 lbs P/acre constitute "Medium", 9-19 lbs P/acre is classified as optimum, 20-39 lbs P/acre is categorized "High", and ≥40 lbs P/acre are "Very High" (Table 1).

Table 1: Classification of phosphorus status using the Cornell Morgan P soil test.

Morgan P	Classification*	Likeliness of an economic yield response to P addition
lbs P/acre		
<3	Low	High
4-8	Medium	Medium
9-19	Optimum	Low
20-39	High	Very low
≥40	Very High	None

*Classifications differ for winter grains (high=9-19 lbs P/acre; very high ≥20 lbs P/acre).

Yield benefits from applied P are only expected when the STP is very low, low, or medium. Once an optimal STP reading is reached, only minimal P fertilization, from any source, is needed to support yields. For most field crops, Cornell University guidance suggests little or no P fertilizer additions to fields with STP levels of 40 lbs P/acre or higher for two reasons: (1) P addition is not likely to result in yield gains; and (2) over-application may lead to P accumulation and contribute to losses to surface and ground waters.

Standard soil sampling practice for nutrient management planning involves collecting and combining multiple soil cores. It is recommended to take at least 10 cores per 10–15-acre field or management unit within a field.

To best capture the variability in fields, higher density soil sampling, where more cores are taken and combined into one sample, will improve the accuracy of the sampling result as a representation of the sampled area. However, a more meaningful approach in such fields is to conduct grid sampling or zone-based sampling. Grid sampling (to obtain detailed information about nutrient distribution within a field) can better inform management decisions as it allows for identification of low versus high soil test P areas *within* fields. Grid size typically ranges from 0.5 to 2.5 acres but grids as large as 5 or 6 acres in size can be justified based on field variability, equipment size, and capacity to manage at within-field scale. To determine the average STP for a zone within a field, based on grid sample results, the STP levels of individual grids can be converted to an area-

weighted average for a zone within a field. If all grids in a zone are the same size, a simple average is sufficient. For irregular grid sizes, an acre-weighted approach best represents the zone's STP; this requires knowing both the STP and the size of each grid.

As grid sampling is expensive to do, strategies for future sampling rounds for fields with grid maps could include (1) regular whole-field sampling along a zig-zag pattern through the field), or (2) zone-based sampling where samples are taken from each STP interpretation category, at an intensity that targets an average sampling density per category of two soil cores per acre.

In the following sections, Cornell University guidelines for P management of agronomic field crops in New York are presented. Guidelines are in lbs of P_2O_5/acre. Application rates need to be adjusted based on the nutrient content of the fertilizer source at hand. For example, a fertilizer blend characterized as "10-20-20" contains 10% N, 20% P_2O_5 and 20% K_2O on a weight basis. Thus, when 200 lbs/acre of this fertilizer is applied, the actual application rate is 20 lbs of N (200*10%), 40 lbs of P_2O_5 (200*20%), and 40 lbs of K_2O (200*20%). One lb of P equals 2.3 lbs of P_2O_5. One lb of P_2O_5 equals 0.44 lb of P.

3.1 GRAIN CORN AND CORN SILAGE

Phosphorus guidelines for grain corn (COG) and corn silage (COS) on soils with STPs <50 lbs P/acre are presented in Figure 1. These guidelines can also be derived from the following equation (STP is the Cornell Morgan soil test P results expressed in lbs P/acre):

$$\text{P recommendation (lbs } P_2O_5\text{/acre)} = 65 - (5 * \text{STP}) \quad [1]$$

The absence of a yield or quality increase with P fertilizer addition to corn grown on soils testing >40 lbs P/acre (without manure) or >9 lbs P/acre (manure applied) was documented in a statewide study on starter P use for corn (Ketterings et al., 2005).

Morgan soil test P (lbs P/acre)	Recommendation (lbs P_2O_5/acre)
<1	65
1	60
2	55
3	50
4	45
5	40
6	35
7	30
8	25
9-19	20
20-39	10
>40	0

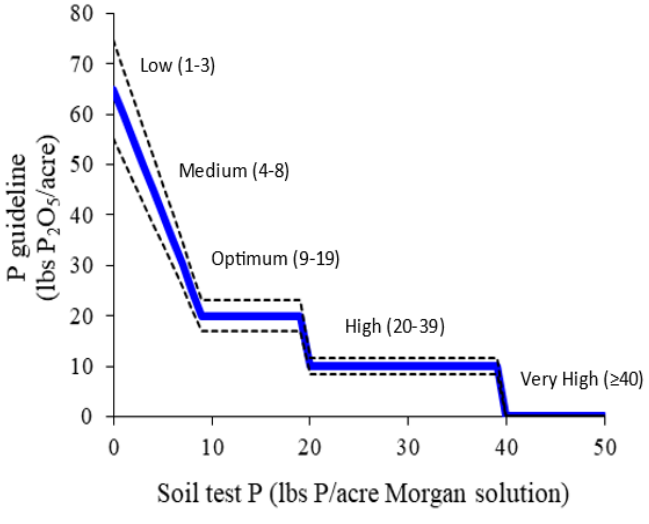

Figure 1: Phosphorus guidelines for grain corn (COG) and silage (COS) in New York. Soil test P is the Cornell Morgan soil test P.

3.2 ALFALFA, ALFALFA BIRDSFOOT-TREFOIL, ALFALFA GRASS

Guidelines for alfalfa (ALE, ALT), alfalfa/birdsfoot-trefoil (ABE, ABT), and alfalfa/grass (AGE, AGT) are given in Table 2. Once an alfalfa stand is established, P guidelines are reduced by approximately 30 lbs of P_2O_5 per acre for a given STP level. These guidelines can also be derived using the following set of equations:

For ALE, ABE and AGE:

If STP ≥ 80, P recommendation = 0 lbs P_2O_5/acre
If STP ≥ 40 but <80, P recommendation = 10 lbs P_2O_5/acre
If STP ≥ 20 but <40, P recommendation = 20 lbs P_2O_5/acre
If STP ≥ 10 but <20, P recommendation = 40 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 85 - (5 * STP) [2]

For ALT, ABT and AGT:

If STP ≥20, P recommendation = 0 lbs P_2O_5/acre
If STP ≥9 but <20, P recommendation = 10 lbs P_2O_5/acre
If STP <9, P recommendation (lbs P_2O_5/acre) = 55 – (5 * STP) [3]

For topdressing, the P in broadcasted manure is as efficient as P in fertilizer. For establishment, optimum results can be achieved by applying the first 25 lbs of the recommendation in a band-placed fertilizer. Manure can be used to supply the rest.

Table 2: Phosphorus guidelines for alfalfa (ALE, ALT), alfalfa/birdsfoot-trefoil (ABE, ABT), and alfalfa/grass mixtures (AGE, AGT).

Morgan soil test P	Recommendation (lbs P_2O_5/acre)	
(lbs P/acre)	Establishment (ALE, ABE, AGE)	Established (ALT ABT, AGT)
<1	85	55
1	80	50
2	75	45
3	70	40
4	65	35
5	60	30
6	55	25
7	50	20
8	45	15
9	40	10
10-19	40	10
20	20	10
21-39	20	0
40-79	10	0
80 or more	0	0

3.3 BIRDSFOOT-TREFOIL, BIRDSFOOT-TREFOIL/GRASS, BIRDSFOOT-TREFOIL/CLOVER, BIRDSFOOT-TREFOIL SEED, CROWNVETCH

Phosphorus guidelines for birdsfoot trefoil, birdsfoot trefoil grass, birdsfoot trefoil clover, birdsfoot trefoil seed, and crownvetch are listed in Table 3. As with alfalfa stands, guidelines are lowered by approximately 30 lbs P_2O_5/acre once stands are established. These guidelines can also be derived using the following set of equations:

For BTE, BGE, BCE, BSE, and CVE:

If STP $\geq$ 50, P recommendation = 0 lbs P_2O_5/acre
If STP $\geq$ 40 but <50, P recommendation = 10 lbs P_2O_5/acre
If STP $\geq$ 30 but <40, P recommendation = 20 lbs P_2O_5/acre
If STP $\geq$ 20 but <30, P recommendation = 30 lbs P_2O_5/acre
If STP $\geq$ 10 but <20, P recommendation = 40 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 85 - (5 * STP) [4]

For BTT, BGT, BCT, BST, and CVT:

If STP $\geq$ 10, P recommendation = 0 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 50 - (5 * STP) [5]

Table 3: Phosphorus guidelines for birdsfoot-trefoil (BTE, BTT), birdsfoot-trefoil/grass (BGE, BGT), birdsfoot-trefoil/clover (BCE, BCT), birdsfoot-trefoil seed (BSE, BST), and crownvetch (CVE, CVT).

Morgan soil test P (lbs P/acre)	Recommendation (lbs P_2O_5/acre)	
	Establishment (BTE, BGE, BCE, BSE, CVE)	Established (BTT, BGT, BCT, BST, CVT)
<1	85	50
1	80	45
2	75	40
3	70	35
4	65	30
5	60	25
6	55	20
7	50	15
8	45	10
9	40	5
10-20	40	0
21-29	30	0
30-39	20	0
40-49	10	0
50 or more	0	0

The P in broadcasted manure is typically used as efficient as P in broadcasted fertilizer so for topdressing (established fields), the guidelines can be met with either

manure or fertilizer P. For establishment of these field crops, if P is deficient, banded applications are more efficient and thus more likely to result in a yield response.

3.4. SPRING OR WINTER BARLEY WITH LEGUMES, OATS WITH LEGUMES, WHEAT WITH LEGUMES

Phosphorus guidelines for spring barley with legumes (BSS), winter barley with legumes (BWS), oats with legumes (OAS), wheat with legumes (WHS), and triticale/peas (TRP) are shown in Table 4. This guidance can also be derived using these equations:

If STP $\geq$ 50, P recommendation = 0 lbs P_2O_5/acre
If STP $\geq$ 40 but <50, P recommendation = 10 lbs P_2O_5/acre
If STP $\geq$ 30 but <40, P recommendation = 20 lbs P_2O_5/acre
If STP $\geq$ 20 but <30, P recommendation = 30 lbs P_2O_5/acre
If STP $\geq$ 10 but <20, P recommendation = 40 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 85 - (5 * STP) [6]

Table 4: Phosphorus guidelines for spring barley (BSS), winter barley (BWS), oats (OAS), wheat (WHS) with legumes (mixture), and triticale/peas (TRP).

Morgan soil test P (lbs P/acre)	Recommendation (lbs P_2O_5/acre)
<1	85
1	80
2	75
3	70
4	65
5	60
6	55
7	50
8	45
9	40
10-20	40
21-29	30
30-39	20
40-49	10
50 or more	0

3.5 BUCKWHEAT, OATS, SORGHUM FORAGE, SOYBEANS, SORGHUM SUDANGRASS, SUDANGRASS

Phosphorus guidelines for buckwheat (BUK), oats (OAT), sorghum forage (SOF), soybeans (SOY), sorghum/sudan hybrids (SSH), and sudangrass (SUD) are in Table 5. These guidelines can also be derived using these equations:

If STP $\geq$ 40, P recommendation = 0 lbs P_2O_5/acre
If STP $\geq$ 6 but <40, P recommendation = 20 lbs P_2O_5/acre
If STP <6, P recommendation (lbs P_2O_5/acre) = 50 - (5 * STP) [7]

Table 5: P recommendation for buckwheat (BUK), oats (OAT), sorghum forage (SOF), soybeans (SOY), sorghum/sudan hybrid (SSH), and sudangrass (SUD).

Morgan soil test P (lbs P/acre)	Recommendation (lbs P_2O_5/acre)
<1	50
1	45
2	40
3	35
4	30
5	25
6-39	20
40 or more	0

3.6 SPRING BARLEY, WINTER BARLEY, MILLET, SORGHUM GRAIN, WHEAT, SUNFLOWERS

Phosphorus guidelines for spring barley (BSP), winter barley (BWI), millet (MIL), sorghum grain (SOG), wheat (WHT), and sunflowers (SUN) are given in Table 6. These guidelines can also be derived using the following set of equations:

If STP $\geq$ 40, P recommendation = 0 lbs P_2O_5/acre
If STP $\geq$ 9 but <40, P recommendation = 20 lbs P_2O_5/acre
If STP <9, P recommendation (lbs P_2O_5/acre) = 65 - (5 * STP) [8]

Table 6: P recommendation for spring barley (BSP), winter barley (BWI), millet (MIL), sorghum grain (SOG), wheat (WHT), and sunflowers (SUN).

Morgan soil test P (lbs P/acre)	Recommendation (lbs P_2O_5/acre)
<1	65
1	60
2	55
3	50
4	45
5	40
6	35
7	30
8	25
9-39	20
40 or more	0

3.7 CLOVER, CLOVER GRASS, CLOVER SEED PRODUCTION

Guidelines for clover (CLE and CLT), clover grass (CGE and CGT), and clover seed production (CSE, CST) can be found in Table 7. These guidelines can also be derived using the following set of equations:

For CGE, CLE, and CSE:

If STP ≥ 40, P recommendation = 0 lbs P_2O_5/acre
If STP ≥ 20 but <40, P recommendation = 10 lbs P_2O_5/acre
If STP ≥ 10 but <20, P recommendation = 20 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 65 - (5 * STP) [9]

For CGT, CLT and CST:

If STP ≥10, P recommendation = 0 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 50 - (5 * STP) [10]

Table 7: Phosphorus guidelines for clover (CLE, CLT), clover grass (CGE, CGT), and clover seed production (CSE, CST).

Morgan soil test P	Recommendation (lbs P_2O_5/acre)	
(lbs P/acre)	Establishment (CGE, CLE, CSE)	Established (CGT, CLT, CST)
<1	65	50
1	60	45
2	55	40
3	50	35
4	45	30
5	40	25
6	35	20
7	30	15
8	25	10
9	20	5
10-19	20	0
20-39	10	0
40 or more	0	0

3.8 GRASSES, TEFF, PASTURE, PASTURES WITH IMPROVED GRASSES, INTENSIVELY GRAZED PASTURE, PASTURE WITH NATIVE GRASSES, PASTURES WITH LEGUMES

Table 8 lists the guidelines for intensively managed grasses (GIE and GIT), grasses (GRE and GRT), teff (TEF), pastures with improved grasses (PGE and PGT), intensively grazed pasture (PIE and PGT), and pasture with native grasses (PNT). These guidelines can also be derived using the following set of equations:

If STP ≥10, P recommendation = 0 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 50 - (5 * STP) [11]

Guidelines for establishing and topdressing pasture with legumes (PLE and PLT) are listed in Table 9. These guidelines can also be derived using these equations:

For PLE:

If STP ≥40, P recommendation = 0 lbs P_2O_5/acre

If STP ≥10 and <40, P recommendation = 40 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 85 - (5 * STP) [12]

For PLT:

If STP ≥10, P recommendation = 0 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 50 - (5 * STP) [13]

Table 8: Phosphorus guidelines for intensively managed grasses (GIE, GIT), grasses (GRE, GRT), teff (TEF), pastures with improved grasses (PGE, PGT), intensively grazed pasture (PIE, PIT), and pasture with native grasses (PNT).

Morgan soil test P (lbs P/acre*)	Recommendation (lbs P_2O_5/acre)
<1	50
1	45
2	40
3	35
4	30
5	25
6	20
7	15
8	10
9	5
10 or more	0

Table 9: Phosphorus guidelines for pasture with legumes (PLE, PLT).

Morgan soil test P (lbs P/acre)	Recommendation (lbs P_2O_5/acre)	
	Establishment (PLE)	Established (PLT)
0	85	50
1	80	45
2	75	40
3	70	35
4	65	30
5	60	25
6	55	20
7	50	15
8	45	10
9	40	5
10-39	40	0
40 or more	0	0

3.9 RYE SEED PRODUCTION

Guidelines for rye seed production (RYS) are given in Table 10. These guidelines can also be derived using this equation:

If STP ≥10, P recommendation = 40 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 85 - (5 * STP) [14]

Table 10: Phosphorus guidelines for rye seed production (RYS).

Morgan soil test P (lbs P/acre)	Recommendation (lbs P_2O_5/acre)
<1	85
1	80
2	75
3	70
4	65
5	60
6	55
7	50
8	45
9	40
10 or more	40

3.10 IDLE LAND, CHRISTMAS TREES, WATERWAYS

No P is needed for idle land. Guidelines for Christmas trees (TRE and TRT) and waterways (WPE and WPT) are given in Table 11. These guidelines can These guidelines can also be derived using these equations:

For Christmas trees:

For TRE: If STP ≥4, P recommendation = 0 lbs P_2O_5/acre
If STP <4, P recommendation (lbs P_2O_5/acre) = 100 - (25 * STP) [15]

For TRT: If STP ≥3, P recommendation = 0 lbs P_2O_5/acre
If STP <3, P recommendation (lbs P_2O_5/acre) = 75 - (25 * STP) [16]

Table 11: Phosphorus guidelines for Christmas trees (TRE,TRT), waterways (WPE,WPT).

Morgan soil test P	Recommendation (lbs P_2O_5/acre)			
(lbs P/acre)	Christmas Trees		Waterways	
	Establishment (TRE)	Established (TRT)	Establishment (WPE)	Established (WPT)
<1	100	75	85	90
1	75	50	80	85
2	50	25	75	80
3	25	0	70	75
4	0	0	65	70
5	0	0	60	65
6	0	0	55	60
7	0	0	50	55
8	0	0	45	50
9	0	0	40	45
10-39	0	0	40	40
40 or more	0	0	0	0

For waterways:

For WPE:

If STP ≥40, P recommendation = 0 lbs P_2O_5/acre
If STP ≥10 and <40, P recommendation = 40 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 85 - (5 * STP) [17]

For WPT:

If STP ≥40, P recommendation = 0 lbs P_2O_5/acre
If STP ≥10 and <40, P recommendation = 40 lbs P_2O_5/acre
If STP <10, P recommendation (lbs P_2O_5/acre) = 90 - (5 * STP) [18]

4. Soil Test Conversion Equations

Cornell University fertilizer guidelines are based on decades of field research in New York showing soil nutrients extracted by Morgan solution (sodium acetate buffered at pH 4.8) are correlated well with nutrient response for the vast array of soil types in New York. However, several university and private soil-testing laboratories that serve New York producers use the Mehlich-3 extraction solution (an unbuffered solution of acetate, ammonium nitrate, ammonium fluoride, and ethylenediaminetetraacetic acid) or modified Morgan (ammonium acetate) for STP derived guidance.

Compliance with USDA-NRCS Nutrient Management Conservation Practice Standard 590 requires that Comprehensive Nutrient Management Plans be based on land grant university guidance. In New York, this implies that Mehlich-3 and modified Morgan soil test results need to be converted to Cornell Morgan equivalents prior to use for deriving P guidelines.

Soil test results for the same soil sample analyzed for Mehlich-3 Ca, P, and Al differ among Brookside Laboratories Inc., Spectrum Analytic Inc., A&L Eastern Laboratories Inc., and Dairy One due to differences in analytical procedures. Thus, conversion equations are laboratory specific.

If STP results are converted from Mehlich-3 into Morgan P for nutrient management planning purposes, it is better to first derive the Morgan P equivalent per sample (using soil test P, Al, Ca, and soil pH), and then to use the equations in this document.

If a producer opts to use a soil test different from the Cornell Morgan test and rely on conversions, it is highly recommended to split a few samples each year to evaluate if the conversions are reliable for the fields on the farm. Use of conversion equations will always add uncertainty to the STP estimate and the conservation planner’s nutrient recommendations based on the converted soil test.

4.1 MEHLICH-3: BROOKSIDE LABORATORIES INC.

Mehlich-3 STP data from Brookside Laboratories Inc. can be used to estimate Morgan P equivalents in lbs/acre if Mehlich-3 P, Ca, Al, and the pH of the soil are known:

Morgan STP (lbs P/acre) =

$$3.3957 + (1.1705*B\_P) - (0.003799*B\_Ca) - (27.24*pH) + (0.1218*B\_Al) - (0.00005760*B\_Al^2) + (2.6867*pH^2) + (0.00009335*B\_P*B\_Ca) - (0.001940*B\_P*B\_Al) + (0.00000080*B\_P*B\_Al^2)$$

(r^2=0.88, n=235) [19]

In this equation *all input data are in ppm.* Morgan STP is Morgan extractable soil test P in lbs P per acre, B_P is Mehlich-3 extractable P, B_Al is Mehlich-3 extractable Al, B_Ca is Mehlich-3 extractable Ca, and pH is the soil pH in water (1:1). If the model predicts a negative Morgan equivalent, a value of 2 lbs/acre is assumed. This model predicted 86% of the dataset within 5 ppm (10 lbs/acre) of the measured value in a soil test conversion study conducted in 2000-2001 (Ketterings et al., 2002).

4.2 MEHLICH-3: SPECTRUM ANALYTIC INC.

Mehlich-3 STP data from Spectrum Analytic Inc. can be used to estimate Morgan P equivalents in lbs/acre if Mehlich-3 P, Ca, Al, and the pH of the soil are known:

Morgan STP (lbs P/acre) =

$$-49.2971 + (0.5495*Sp\_P) - (0.001631*Sp\_Ca) - (11.8281*pH) + (0.1350*Sp\_Al) - (0.00006742*Sp\_Al^2) + (1.5452*pH^2) + (0.0000218*Sp\_P*Sp\_Ca) - (0.000947*0.7*Sp\_P*Sp\_Al) + (0.000000399**Sp\_P*Sp\_Al^2)$$

(r^2=0.88, n=235) [20]

In this equation all input data are in lbs/acre except for Morgan extractable Al which is reported in ppm on a standard soil test report from Spectrum Analytic Inc. Morgan STP is Cornell University's Morgan extractable STP in lbs P per acre, Sp_P and Sp_Ca are soil test P and Ca in lbs/acre as reported by Spectrum Analytic and Sp_Al is Mehlich-3 extractable Al (ppm). At that time, Spectrum Analytic converted Mehlich-3 data back to their original Bray P1 and ammonium acetate reporting. This practice was discontinued in July of 2005, after which original Mehlich-3 were reported. Equation 21 is adjusted for use with soil samples analyzed after July 2005. If this model predicts a negative Morgan equivalent, a value of 2 lbs/acre is assumed.

4.3 MEHLICH-3: A&L EASTERN LABORATORIES INC.

Mehlich-3 STP data from A&L Laboratories Inc. can be used to estimate Morgan P equivalents in lbs/acre if Mehlich-3 P, Ca, Al, and the pH of the soil are known:

Morgan STP (lbs P/acre) =

$$45.52106614 + (1.44109538*AE\_P) - (0.00250878*AE\_Ca) - (42.04727550*pH) + (0.09744870*AE\_Al) - (0.00003732*AE\_Al^2) + (4.00344858*pH^2) + (0.00006744*AE\_P*AE\_Ca) - (0.00220826*AE\_P*AE\_Al) + (0.00000084*AE\_P*AE\_Al^2)$$

(r^2=0.88, n=235) [21]

In this equation *all input data are in ppm.* Morgan STP is Cornell Morgan extractable soil test P in lbs P per acre, AE_P is Mehlich-3 extractable P, AE_Al is Mehlich-3 extractable Al, AE_Ca is Mehlich-3 extractable Ca, and pH is the soil pH in water. If the model predicts a negative Morgan equivalent, a value of 2 lbs/acre is assumed. This model predicted 86% of the dataset within 5 ppm (10 lbs/acre) of the measured value.

4.4 MEHLICH-3: DAIRY ONE

Mehlich-3 soil test P data from Dairy One can be used to estimate Morgan P equivalents in lbs/acre if Mehlich-3 P, Ca, and Al of the soil are known:

Morgan STP (lbs P/acre) =

$$-16.814678414 + (1.189938196*DO\_P) + (0.000715708*DO\_Al) + (0.000873708*DO\_Ca) + (0.000007434*DO\_Al^2) + (0.000053416*DO\_P*DO\_Ca) - (0.001709930*DO\_P*DO\_Al) + (0.000000612*DO\_P*DO\_Al^2)$$

(r^2=0.88, n=223) [22]

In this equation *all input data are in ppm.* Morgan STP is Cornell Morgan extractable soil test P in lbs P per acre, DO_P is Mehlich-3 extractable P, DO_Al is Mehlich-3 extractable Al, DO_Ca is Mehlich-3 extractable Ca. If the model predicts a negative Morgan equivalent, a value of 2 lbs/acre is assumed.

4.5 (MODIFIED) MORGAN: ANALYTICAL LAB AND MAINE SOIL TESTING SERVICE, DAIRY ONE, SPECTRUM ANALYTIC INC., AND A&L EASTERN LABORATORIES INC.

Morgan analyses from the Analytical Lab and Maine Soil Testing Service ("New York Soil Test") can be used directly (no conversion needed). Similarly, Morgan analyses from Dairy One can be used directly without the need for a conversion by the user (Dairy One does the conversions in-house before submitting results to clients).

Modified Morgan P test results from Spectrum Analytic Inc. can be converted to Cornell Morgan equivalents according to the following equations (Sp_MP is the modified Morgan test result in lbs/acre):

For Sp_MP < 106 lbs P/acre:

Morgan STP (lbs P/acre) = (1.2*Sp_MP) – 8 (n=64, r^2=0.97)

For Sp_MP ≥ 53 lbs P/acre:

Morgan STP (lbs P/acre) = (1.5*Sp_MP) – 42 (n=18, r^2=0.65)

[23]

Modified Morgan P test results from Analytical Lab and Maine Soil Testing Service can be converted to Cornell Morgan equivalents according to the following equation (ME_MP is the modified Morgan test result in lbs/acre):

Morgan STP (lbs P/acre) = (1.0384*ME_MP) - 4.5108 (n=228, r^2=0.97)

[24]

Modified Morgan P extraction data from A&L Eastern Laboratories Inc. (AE_MP in ppm) should be multiplied by 1.8 to obtain Cornell Morgan soil test equivalents prior to deriving fertilizer guidelines:

Morgan STP (lbs P/acre) = 1.8*AE_MP (n=235, r^2=0.97)

[25]

5. Sources of Phosphorus

5.1 MANURE

Manure P is primarily in the organic form and must mineralize to an inorganic form before being available to a crop. It is recommended to soil sample at least once in three years to monitor STP levels over time. Placement of P is important when establishing a crop. If manure will be applied after the soil test was taken, the following P, K, and micronutrient guidelines are offered:

For crop establishment:

- If the P guidance is to use less than 25 lbs/acre, apply the entire amount as a band placed starter fertilizer.
- If the P guidance exceeds 25 lbs/acre, apply 25 lbs/acre as a band placed starter fertilizer and use manure to supply the rest.

For topdressing:

- If the P guidance is to use less than 30 lbs/acre, use fertilizer to supply the entire P requirement.
- If the P guidance 30 lbs/acre, apply 30 lbs/acre in a top-dressed fertilizer and use manure to supply the rest.

When manure is applied at a rate to supply the needed N, both P and K are likely to be applied in excess of crop needs. The excess can be used by a later crop in the rotation. Excessive inputs of P can result in a very high STP value where additions of fertilizer P are

not expected to lead to a yield increase; in such instances, the potential for P loss increases. The New York Phosphorus Index 2.0 has STP limits beyond which P application is restricted or prohibited (Czymmek et al., 2021).

5.2 PHOSPHORUS CONTAINING FERTILIZERS

Table 12 lists common P fertilizers. Single super and triple super phosphates contain P in the form of calcium orthophosphate. Ammoniated superphosphate is obtained by reacting superphosphates with anhydrous ammonium. Superphosphates are considered neutral because their application does not appreciably affect the soil pH. Both ammoniated superphosphates and monoammonium phosphate make excellent sources of N and P for band application.

Table 12: Phosphorus containing inorganic fertilizers.

	% N	% P_2O_5	% K_2O	% S
Single superphosphate (SSP)	0	20	0	14
Triple superphosphate* (TSP or CSP)	0	46	0	2
Ammonium polyphosphate	10	34	0	0
Ammoniated superphosphate	5	40	0	12
Monoammonium phosphate (MAP)	13	52	0	2
Diammonium phosphate (DAP)	18	46	0	0
Urea-ammonium phosphate (UAP)	28	28	0	0
Monopotassium phosphate	0	50	40	0

* Also referred to as concentrated superphosphate.

To avoid fertilizer injury, it is recommended that fertilizer band application rates remain lower than: (1) 30 lbs of P_2O_5 from diammonium phosphate; (2) 20-30 lbs of urea N plus N from diammonium phosphate; and (3) 30-40 lbs of ammonium N from all sources in combination with diammonium phosphate.

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Appendix

APPENDIX TABLE 1: CORNELL CROP CODES.

Crop code	Crop description
	Alfalfa
ABE	Alfalfa trefoil grass, Establishment
ABT	Alfalfa trefoil grass, Established
AGE	Alfalfa grass, Establishment
AGT	Alfalfa grass, Established
ALE	Alfalfa, Establishment
ALT	Alfalfa, Established
	Birdsfoot
BCE	Birdsfoot trefoil clover, Establishment
BCT	Birdsfoot trefoil clover, Established
BGE	Birdsfoot trefoil grass, Establishment
BGT	Birdsfoot trefoil grass, Established
BSE	Birdsfoot trefoil seed, Establishment
BST	Birdsfoot trefoil seed, Established
BTE	Birdsfoot trefoil, Establishment
BTT	Birdsfoot trefoil, Established
	Barley
BSP	Spring barley
BSS	Spring barley with legumes
BUK	Buckwheat
BWI	Winter barley
BWS	Winter barley with legumes
	Clover
CGE	Clover grass, Establishment
CGT	Clover grass, Established
CLE	Clover, Establishment
CLT	Clover, Established
CSE	Clover seed production, Establishment
CST	Clover seed production, Established
	Corn
COG	Corn grain
COS	Corn silage
	Grasses, pastures, covercrops
CVE	Crownvetch, Establishment
CVT	Crownvetch
GIE	Grasses intensively managed, Establishment
GIT	Grasses intensively managed, Established
GRE	Grasses, Establishment
GRT	Grasses, Established
PGE	Pasture, Establishment
PGT	Pasture improved grasses, Established

APPENDIX TABLE 1 (CONTINUED): CORNELL CROP CODES.

Crop code	Crop description
PIE	Pasture intensively grazed, Establishment
PIT	Pasture intensively grazed, Established
PLE	Pasture with legumes, Establishment
PLT	Pasture with legumes, Established
PNT	Pasture native grasses
RYS	Rye seed production
TEF	Teff
TRP	Triticale peas
	Small grains
MIL	Millet
OAS	Oats with legume
OAT	Oats
SOF	Sorghum forage
SOG	Sorghum grain
SOY	Soybeans
SSH	Sorghum sudangrass hybrid
SUD	Sudangrass
WHS	Wheat with legume
WHT	Wheat
	Others
SUN	Sunflower
TRE	Christmas trees, Establishment
TRT	Christmas trees, Established