UPDATING PHOSPHORUS RECOMMENDATIONS FOR ILLINOIS

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ABSTRACT

Phosphorus (P) is a key fertility input essential to maintain the high productivity of North Central cropping systems. An important aspect of fertilizer recommendations is knowing when soil tests indicate a profitable yield response to P fertilization. To this end, critical soil test values (CSTV) are essential to informing agronomic and economic optimum rates for crop production. To improve profitable use of P inputs, as well as to explain field-specific variation in CSTV that enable context-specific adjustment, soil P contribution to crop uptake is also necessary. Two sources of soil-derived P are inorganic P stocks, conceptualized as “soil P supply power”, and organic P that can be mineralized to crop-available orthophosphate. Though no longer used by neighboring states, the Illinois Agronomy Handbook still recommends interpretation of CSTV based on subsoil P supply power, a qualitative (e.g., high vs low supply power regions) assessment based on loess thickness, loess age and drainage. Quantifying P stocks at fine spatial and their contribution P to crop uptake through on-farm trials will provide a basis for assessing the utility of the soil P supply power concept. Apart from inorganic P stocks, soils contain large reserves of P in organic forms, bound to carbon in organic matter. Like nitrogen, organic P in soil organic matter must first be mineralized via microbes, specifically from the catalytic action of enzymes known as phosphatases. Using radioisotopic dilution to estimate potentially mineralizable P, we find evidence for agronomically relevant magnitudes of potential P credits from soil organic matter. Active and forthcoming work on improving P recommendations for Illinois corn-soybean production systems are reviewed.

INTRODUCTION

<u>Updating P CSTV for Illinois</u>.

Soil tests are a simple but powerful approach to nutrient management: a soil sample is extracted using a chemical solution (e.g., Bray or Mehlich-3) that is calibrated to relative crop yield. The relationship between the increasing concentration of the nutrient extracted from the soil (“soil test” value) and relative yield (% of maximum obtainable) is then derived (Figure 1). Ensuring that soil tests are interpreted with correctly calibrated CSTV is essential to keep pace with agricultural management and soil testing practices that change over time.

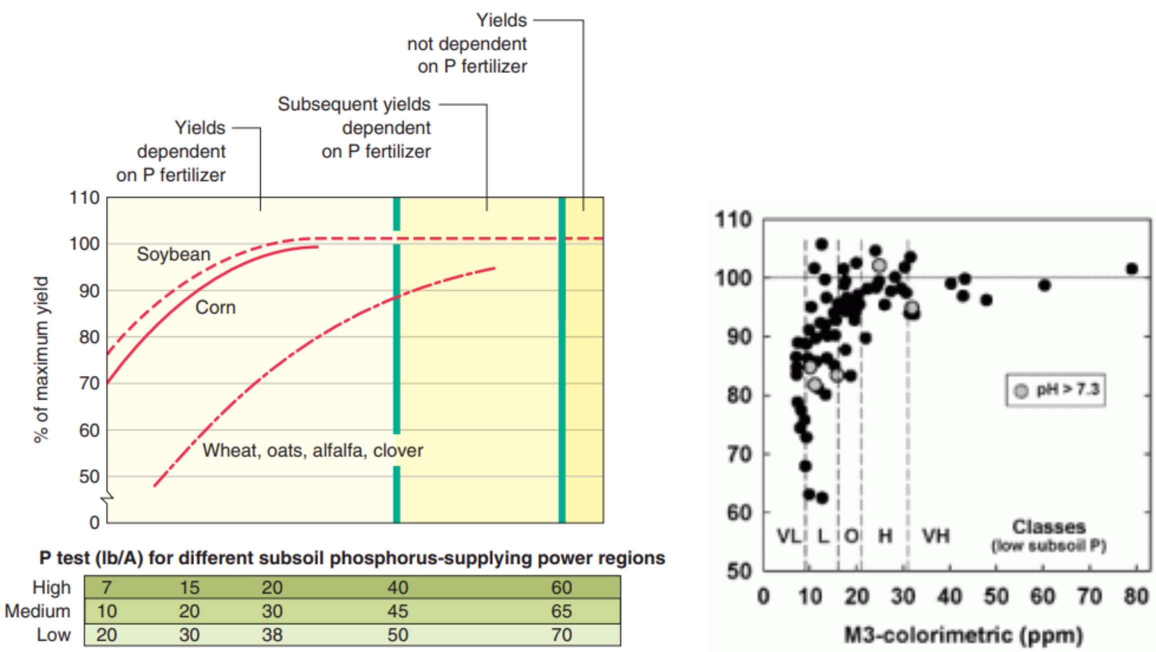
There are at least **<u>six reasons</u>** why the soil test P recommendations for Illinois agriculture are in need of updating:

1. Changes in how we test for soil P. Commercial labs have largely shifted from Bray for P to Mehlich-3 as a universal extractant [1]. Facilitated by inductively coupled plasma (ICP) optical emission spectroscopy (OES), which measures all nutrient elements except N in the same extract, Mehlich-3 ICP values are now the norm [2]. This is reflected in Mehlich-3 being the recommended soil test for P (and other macronutrients and micronutrients) in the North Central region according to the UDSA

NCERA-13 committee [3]. Due to the nature of extractants differing in chemical composition, soil test P values based on Bray or Mehlich-3 colorimetric values do not give the same numerical values as Mehlich-3 ICP that is used by most commercial soil labs. In other words, Illinois recommendations are out-of-date with the method of testing for soil P, and this can lead to misinterpretation of soil test results. In general, Mehlich-3 extracts more P than Bray, so using soil test P values based on Bray to interpret Mehlich-3 soil test results could lead to underapplication of P. However, universal conversions between soil tests are not possible, and require soil- or region-specific corrections.

2. Crop-specific needs. The Illinois Agronomy Handbook does not currently distinguish CSTV among crops (Figure 1), but it has been shown that corn or soybean vs wheat can have different CSTV for P [2, 4]. For example, wheat can have up 2x lower P Mehlich-3 CSTV compared to soybean [4].

Figure 1. Example of CSTV for P from (left) the Illinois Agronomy Handbook and (right) Iowa State University Extension CSTV, developed by Dr. Antonio Mallarino [5, 6].



3. Changes in crop management. Higher plant populations, modern hybrids with changes in root systems, tillage practices, and fertilizer placement have all clearly changed in the >50 years since the Illinois CSTV were developed for P and K. However, these CSTV assume broadcast application with conventional tillage for full incorporation. Each of these changes could impact the CSTV based on crop uptake efficiencies, root densities, and nutrient stratification.

4. Changes in how we model the soil test data. Selecting a method for soil test correlations (i.e., model) to be used for determining CSTV is important because the model selected can change the resulting CSTV, even for the same dataset. Thus, it is important to evaluate multiple models for the same dataset. The Illinois Agronomy Handbook does not specify the original model(s) used to determine CSTV. Recent advances in CSTV calculation enable additional models to be evaluated for conference and for quantification of uncertainty inherent to CSTV estimations [7, 8].

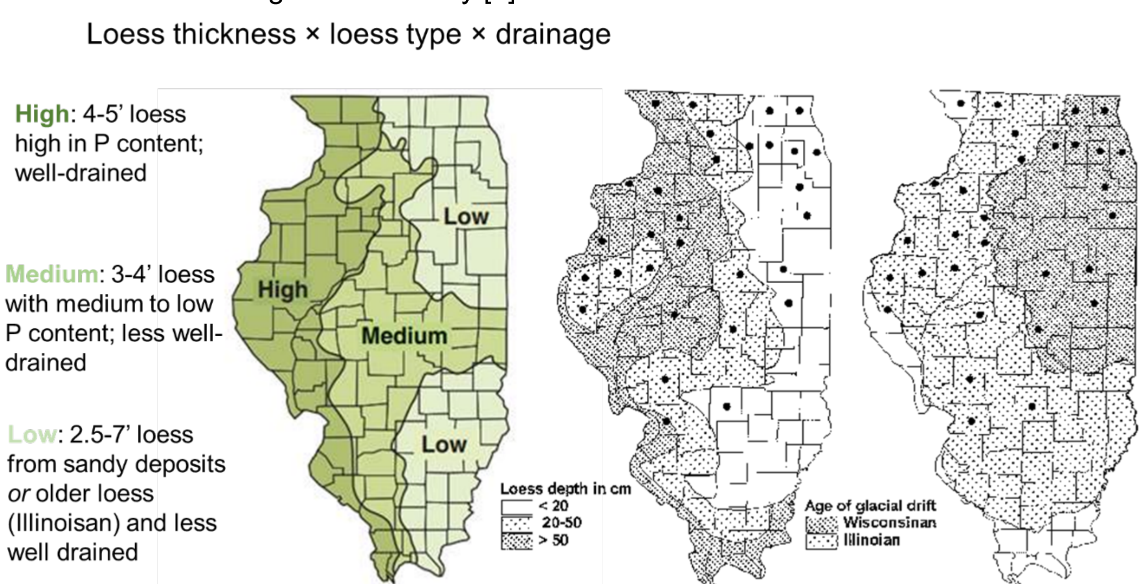
5. Changes in other North Central region and Corn Belt states. It is estimated that 80% of states have CSTV that are outdated by at least 20 years [7]. The economics of fertilizer and environmental stewardship pressures have led many states to update soil test P recommendations. For example, the Tri-States region of Indiana, Michigan and Ohio recently updated >25 year old CSTV for P for corn, soybean and wheat [2]. Nationally, the Fertilizer Recommendation Support Tool (FRST) effort is working to consolidate CSTV and soil testing recommendations across state borders [7, 8].

6. Transparency and open-access of data. To our knowledge, the original data and methods of modeling these for CSTV in Illinois are not available. The issue of transparency in CSTV can challenges users' interpretation of recommended CSTV [7].This lack of transparency should be addressed by making all data fully available *and* interactive, much like the North Central region's Mean Return to Nitrogen (MRTN) tool, and as exemplified by the FRST effort [7, 8].

Revisiting soil P supply power concept.

The concept of soil P supplying capacity that forms the basis of Illinois and many other Midwestern state recommendations on P management, including P application rates, are qualitative (e.g., low vs medium vs high) and not refined beyond broad regions (Figure 2). The Illinois Agronomy Handbook categorizes soils in Illinois and thus P application rates by "P supply power" (Figure 1) based on loess type and thickness, with soils developed on deeper and younger loess deposits considered to have higher P supply power. However, this is qualitative, and not useful at fine scales. Quantifying soil P stocks and test P to substantial depth (0-36") by loess region and soil types can help evaluate whether this concept can improve P application recommendations.

Figure 2. Phosphorus supply power regions in the Illinois Agronomy Handbook, compared to loess thickness and age described by [9].



Potentially mineralizable P as the basis for a soil P credit.

In constructing nitrogen (N) recommendations for farmers, N credits from organic matter mineralization are typically considered. These N credits are developed by combining the size of the soil organic matter “bank account” with inherent soil properties (e.g., clay content) to predict the total release of plant-available N. Currently, no such credit exits for P, though soils contain large reserves of P in organic matter. Though the amount of organic P stored in soils of Illinois or the US is largely unknown, like N it is likely to be substantial. Recent work by the Margenot Lab on soil P cycling at the Monmouth Research and Demonstration Center in northwestern Illinois reveal that at 0-6” depth alone, soils had 440 to 600 lb per acre of organic P that could be mineralized [10]. With recent advances in cost-effectiveness, instrumentation, and safety [11, 12], the use of radioisotopic (^{32}P or ^{33}P) pool dilution can provide an estimate of potentially mineralizable P (lbs/ac).

MATERIALS AND METHODS

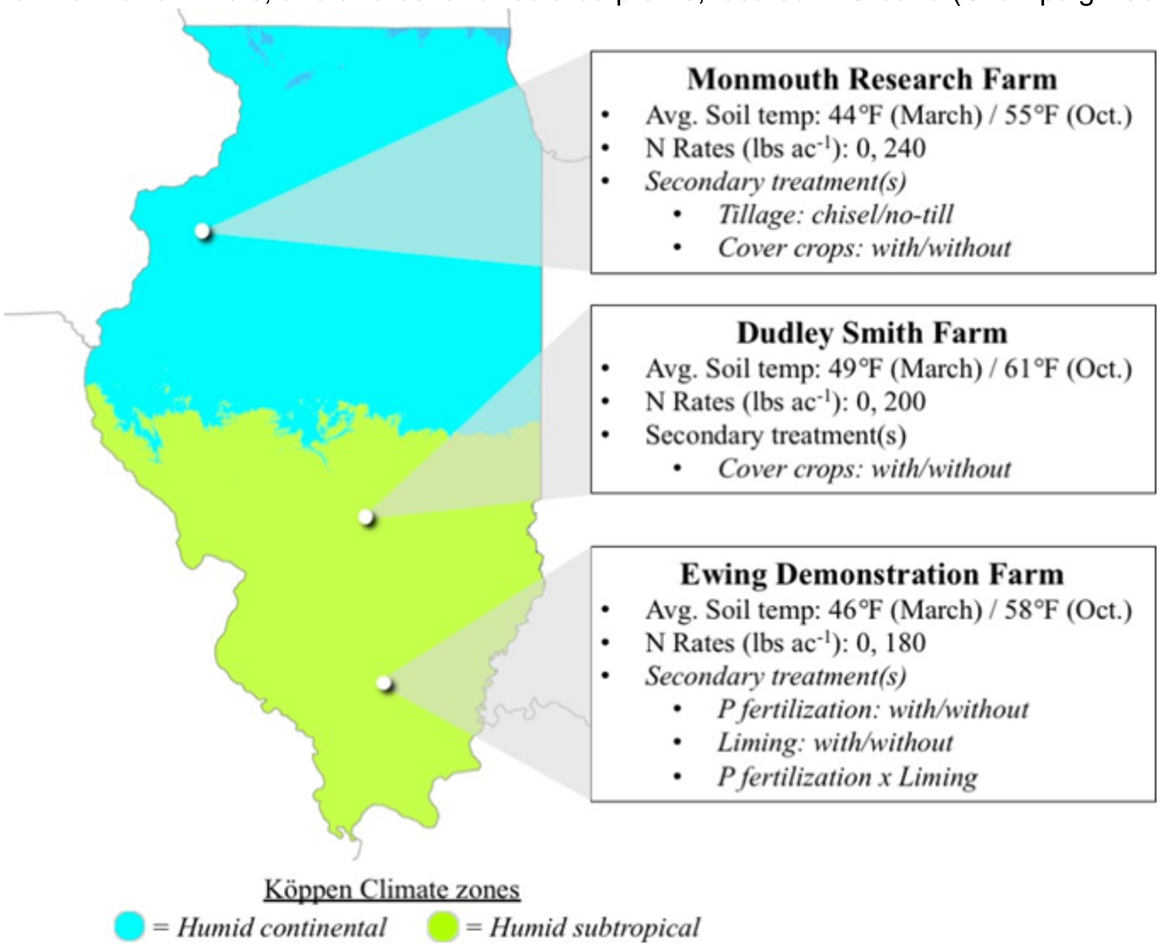
Updating P CSTV for Illinois.
To determine P CSTV for corn, soybean and wheat and specific to Illinois regions and soil types, we are employing historical datasets from private commercial labs as well as an estimated n=80-90 on-farm trial locations for several years starting in the 2023 growing season. Specific objectives will be to (1) establish P CSTV for major soil types of Illinois, specific to corn, soybean and wheat; (2) account for (i) soil type, (ii) nutrient stratification by tillage management (conventional, strip, no-till) and (iii) soil sampling depth to fine-tune CSTV interpretations, as well as (iv) recent advances in modeling CSTV; and, (3) develop conversion factors among P tests to account for new tests being used in the 21st century (e.g., Bray P to Mehlich-3 P).

Revisiting soil P supply power concept.
To verify the value of including the soil P supply power concept in interpretation of CSTV, soils from (1) an archive of pedons sampled in the Illinois state survey from 1904-2010 and (2) on-farm soil cores to 36” depth (n=1200 cores across n=140 fields) that capture geographic diversity of loess and soil types of the state are being analyzed for total P. A subset will be analyzed for available, potentially available (organic P, exchangeable P) and apatite P.

Potentially mineralizable P as the basis for a soil P credit.
Soil P mineralization rates at 5, 10, 15 and 20ºC were determined for n=18 soils [11, 13] encompassing soil-climate conditions of Illinois and agricultural mangaement treatments (Figure 3). Though complex and laboratory-intensive (hence the low sample size), this approach is the sole method in existence for estimating P mineralization rates in soil. Both gross and net (crop-available) P mineralization were quantified in a two-part experimental approach. First, a short-term (100 min) isotopic exchange kinetics (IEK) experiment was used to exclusively model physicochemical processes that must be controlled for in determining P mineralization. Second, a 28 d incubation experiment was performing to account for biological and/or biochemical processes. In both experiments, preincubated moist soil spiked with ^{33}P-phosphate tracer solution. Subsamples over the 28 d incubation were analyzed for radioactivity and water soluble

P. Data obtained from IEK was fit using empirical power function to extrapolate abiotic controls in 100 min over 28 d. The difference in the measured and extrapolated isotopically exchanged P was gross P mineralized. Microbial P uptake of mineralized P was corrected by fumigating the ^{33}P labeled soil. The specific radioactivity of the water extracts of fumigated soil and non-fumigated soil, together with the fumigant-labile P content, was measured to calculate the microbial P immobilization rates. By subtracting microbial P immobilization from gross P mineralization rates, net P mineralization rates were derived.

Figure 3. Subset of experimental sites and associated treatments being used to furnish soil samples with gradients of soil organic matter used to evaluate radioisotopic pool dilution based estimation of potentially mineralizable P. Soil temperatures indicate the 5 year-average (2014-2019). An additional site was included from contrast crop rotation and input treatments in year 145 of the Morrow Plots, and a forest and restored prairie, located in Urbana (Champaign Co.),



RESULTS & DISCUSSION

Updating P CSTV for Illinois.

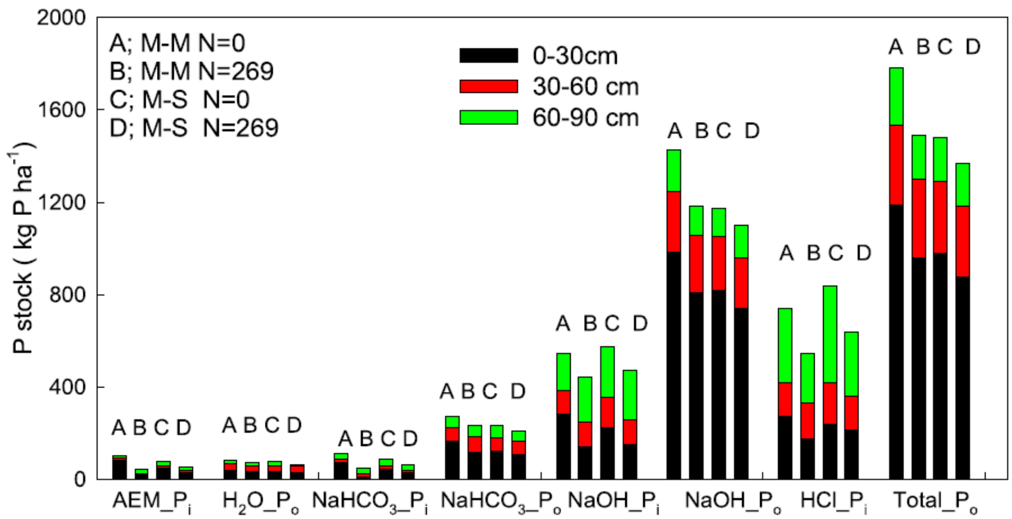
Results are anticipated starting in early 2024, with project deliverables in 2027. A series of project updates will be delivered at future NCSFC and other outreach venues in Illinois and the North Central region.

Revisiting soil P supply power concept.
Preliminary results on soil P stocks to depth indicate that the loess parent material of Illinois that blankets much of the North Central region contains appreciable P (250-400 mg/kg), which is largely in apatite forms of non-extractable forms (known as "occluded" or "residual") that is not thought to be crop-available [14] (Figure 4). Thus, we find that there is substantial P stocked in subsoils developed on loess parent material. However, how much this subsurface P can contribute to crop P uptake remains unknown, and will be the subject of field trials (on-farm) that will initiated in the 2024 growing season. Additional results will be anticipated starting in early 2025, with assessments finalized in 2026. A series of project updates will be delivered at future NCSFC and other outreach venues in Illinois and the North Central region.

Potentially mineralizable P as a basis for a soil P credit.
Based on the diverse soils evaluated in Illinois, including Mollisols and Alfisols, there is reason to anticipate agronomically relevant P credits across the North Central region. Though the amount of organic P stored in soils of Illinois and the greater North Central region is largely unknown, it is thought to far exceed the pool of immediately available soil P that is proxied as "soil test" P [10]. At 0-6" depth alone, soils had 440 - 600 lb/ac of P in organic forms that could be mineralized, and at 0-36" depth contained 1,100 - 1,700 lb/ac [10] (Figure 4).

Figure 4. Stocks of soil P across operationally defined chemical fractions that correspond to pools of significant, including organic P ("Total P_o") and apatite P from the loess parent material ("HCl P_i"). To convert from kg/ha to lb/ac, multiply by 0.892. From [10]. Additional fractions

include crop available P (AEM-P_i), sub-fractions of organic P extractable by water (H_2O P_o), sodium bicarbonate ($NaHCO_3$ P_o) and sodium hydroxide (NaOH P_o), labile inorganic P extractable by sodium bicarbonate ($NaHCO_3$ P_i) and mineral-associated sodium hydroxide (NaOH P_i). Fractions are meant to *approximate* pools of varying availability [15, 16]. Different letters indicate significant differences among 36 year crop rotation treatments of corn-corn (M-M) vs corn-soybean (M-S), with or without N (269 kg/ha = 240 lb/ac) applied to corn.



The soils evaluated ranged widely in organic C from 1.0 – 5.9%, which entailed large variation in organic P of 190-1247 mg/kg, representing 59 – 94% of total P (Table 1). In soils under corn and soybean cropping, organic P ranged from 190 – 592 mg/kg, encompassing the same range of total P that was present as organic P.

Table 1. Properties of soils used to evaluate potentially mineralizable P across four agricultural trials (n=16 soils) and two non-agricultural soils used as a reference (n=2). Abbreviations: CC, cover crop.

Trial	Soil type	Treatment	Organic C (%)	C:N	pH	Total P (mg/kg)	Organic P	
							(mg/kg)	(% of total)
Ewing	Alfisol	No lime, - P	1.0	9.4	4.6	233	190	81
Ewing	Alfisol	No lime, +P	1.1	9.3	4.7	556	488	88
Ewing	Alfisol	Lime, - P	1.0	8.7	5.3	203	192	94
Ewing	Alfisol	Lime, +P	1.3	9.4	5.0	568	497	87
Dudley-Smith	Alfisol	- CC, +N	1.7	11.3	5.8	666	419	63
Dudley-Smith	Alfisol	+CC, +N	1.8	12.0	5.9	732	444	61
Dudley-Smith	Alfisol	-CC, -N	1.8	11.7	5.8	762	452	59
Dudley-Smith	Alfisol	Pasture	2.0	11.1	6.3	546	376	69
Morrow	Mollisol	Corn-corn, -NPK	1.5	11.7	6.2	530	411	78
Morrow	Mollisol	Corn-corn, +NPK	2.1	11.3	7.4	654	479	73
Morrow	Mollisol	Corn-soy, -NPK	2.0	12.5	6.5	486	430	88
Morrow	Mollisol	Corn-soy, +NPK	2.7	12.8	7.1	796	512	64
Monmouth	Mollisol	Till, +N	2.3	12.8	6.9	638	501	79
Monmouth	Mollisol	No-till, +N	2.5	12.4	5.5	629	592	94
Monmouth	Mollisol	corn-soy, -N	2.7	12.4	6.9	636	539	85
Monmouth	Mollisol	corn-soy, +N	2.3	13.5	7.2	603	446	74
n/a	Mollisol	Forest	5.9	13.7	7.3	1358	1247	92
n/a	Mollisol	Prairie	3.3	13.9	7.2	702	540	77

Interpreted as a pool of potentially mineralizable P (mg/kg or lb/ac), assessments support the hypothesis of a soil P credit that is agronomically appreciable.

At 0-6” depth, potentially mineralizable P ranged from 24 to 201 lb/ac in soils under agricultural management and up to 304 lb/ac in forest (Table 2). Notably, mineralizable P in prairie soils (94 lb/ac) was nearly the same as the average potentially mineralizable P in agricultural soils of 95 ± 43 lb/ac.

Assuming that half of this pool of potentially mineralizable P is actually mineralized in a growing season, this would entail a P credit of 12 to 100 lb/ac, which could meet from two-thirds to all the P needs of high-yielding corn and soybean [17, 18]. Clearly, how much P is actually mineralized – likely to depend on weather, as for N mineralization – will vary. Additionally, timing of P mineralization and synchrony of P release from organic matter with crop need will determine contributions of soil organic P to crop uptake.

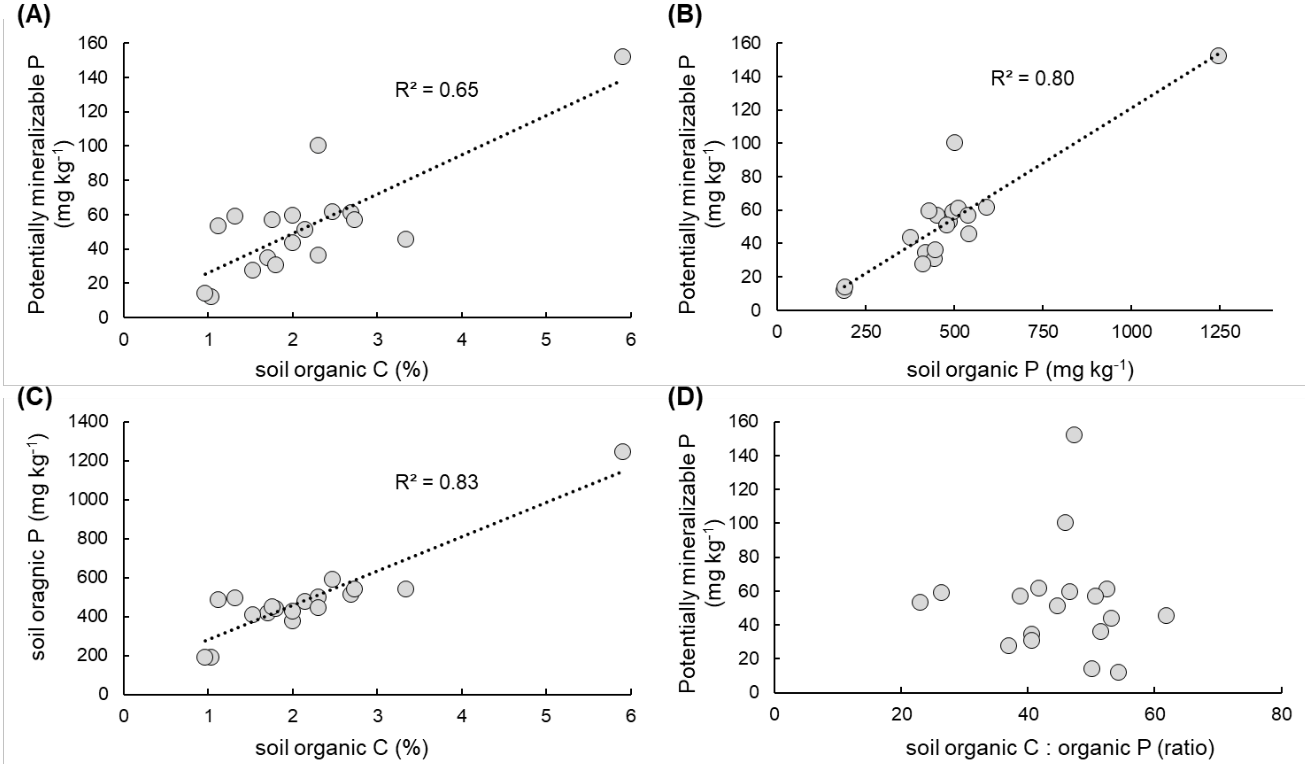
Table 2. Potentially mineralizable P at 0-6" depth across a range of agriculturally managed (n=16) and non-agriculturally managed (n=2) soils.

Trial	Soil type	Treatment	Potentially min. P (mg/kg)	(lb/ac)
Ewing	Alfisol	No lime, - P	12.1	24
Ewing	Alfisol	No lime, +P	53.3	107
Ewing	Alfisol	Lime, - P	14.1	28
Ewing	Alfisol	Lime, +P	59.2	118
Dudley-Smith	Alfisol	- CC, +N	34.8	70
Dudley-Smith	Alfisol	+CC, +N	30.9	62
Dudley-Smith	Alfisol	-CC, -N	56.9	114
Dudley-Smith	Alfisol	Pasture	43.9	88
Morrow	Mollisol	Corn-corn, -NPK	27.8	56
Morrow	Mollisol	Corn-corn, +NPK	51.2	102
Morrow	Mollisol	Corn-soy, -NPK	59.7	119
Morrow	Mollisol	Corn-soy, +NPK	61.3	123
Monmouth	Mollisol	Till, +N	100.6	201
Monmouth	Mollisol	No-till, +N	61.5	123
Monmouth	Mollisol	corn-soy, -N	57.0	114
Monmouth	Mollisol	corn-soy, +N	36.3	73
n/a	Mollisol	Forest	152.2	304
n/a	Mollisol	Prairie	45.8	92

Across soils and management treatments, potentially mineralizable P was 5- to 7-fold greater at 68°F vs 50-41°F soil temperatures, indicating that the temperature sensitivity of this process is robust across managements (data not shown).

Potentially mineralizable P was strongly related to total soil organic P and less so to total soil organic C (Figure 5), reflecting variation in organic C: organic P ratios from 23 to 62 (data not shown), well below the threshold of P immobilization of 200 [19, 20]. Potentially mineralizable P was unrelated to the organic C: organic P ratio.

Figure 5. Relationships of potentially mineralizable P at 0-6" depth in soils across a range of agriculturally managed (n=16) and non-agriculturally managed (n=2) soils. To convert from mg/kg to lb/ac, multiply by 2. To convert from lb P/ac to lb P_2O_5/ac, multiply by 2.29.



CONCLUSIONS

Updating P recommendations in Illinois requires revisiting current but multidecade-old recommendations in the Illinois Agronomy handbook, specifically CSTV and soil P supply power, while also considering a potential "soil P credit" to help refine application rates. A combination of on-farm field trials, soil archives, and lab-based assessments will continue through 2026 to provide much needed data to transparently update the basis for CSTV and soil P supply power thresholds and concepts, respectively, while also exploring the potential of crediting P from organic matter mineralization. Active and forthcoming work on improving P recommendations for Illinois corn-soybean production systems relevant to the greater North Central region will be presented at future NCSFC events.

ACKNOWLEDGEMENTS

This work was supported by the Illinois Farm Bureau, a University of Illinois College of ACES Dudley-Smith Initiative DSynergy award, Illinois Nutrient Research and Education Council awards # 2021-4-360731-469 and #2022-(tbd), and National Science Foundation (NSF) Smart & Connected Communities award #2125626.

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