Analysis & Interpretation of Phosphorus in Soils & Residuals

UMass Extension Symposium:
Managing Phosphorus in Organic Residuals Applied to Soils

November 2, 2016

John T. Spargo
Director, Agricultural Analytical Services Laboratory

Penn State **Extension**

Soil fertility testing

Measure of the ability of a soil to supply nutrients required for healthy plant growth.

Predict the probability of a profitable response to nutrient addition

Soil fertility testing

Routine soil fertility tests are empirically related to plant response.

Soil test methods are developed for specific soil and climate conditions present within a given region.

By design, they are rapid and inexpensive, so that they are practical.

RECOMMENDED SOIL TESTING PROCEDURES FOR THE NORTHEASTERN UNITED STATES

3RD Edition

Northeastern Regional Publication No. 493

Agricultural Experiment Stations of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

Revised

July, 2011

Soil fertility testing

Standardized methods

Recommended Soil Testing Procedures for the Northeastern United States

Prepared by: NEC-1012

Northeast Coordinating Committee for Soil Testing

Available on-line

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Soil fertility testing

Four key components:

1) Sampling
2) Extraction & analysis
3) Interpretation of results
4) Recommendations

Nutrients in soil

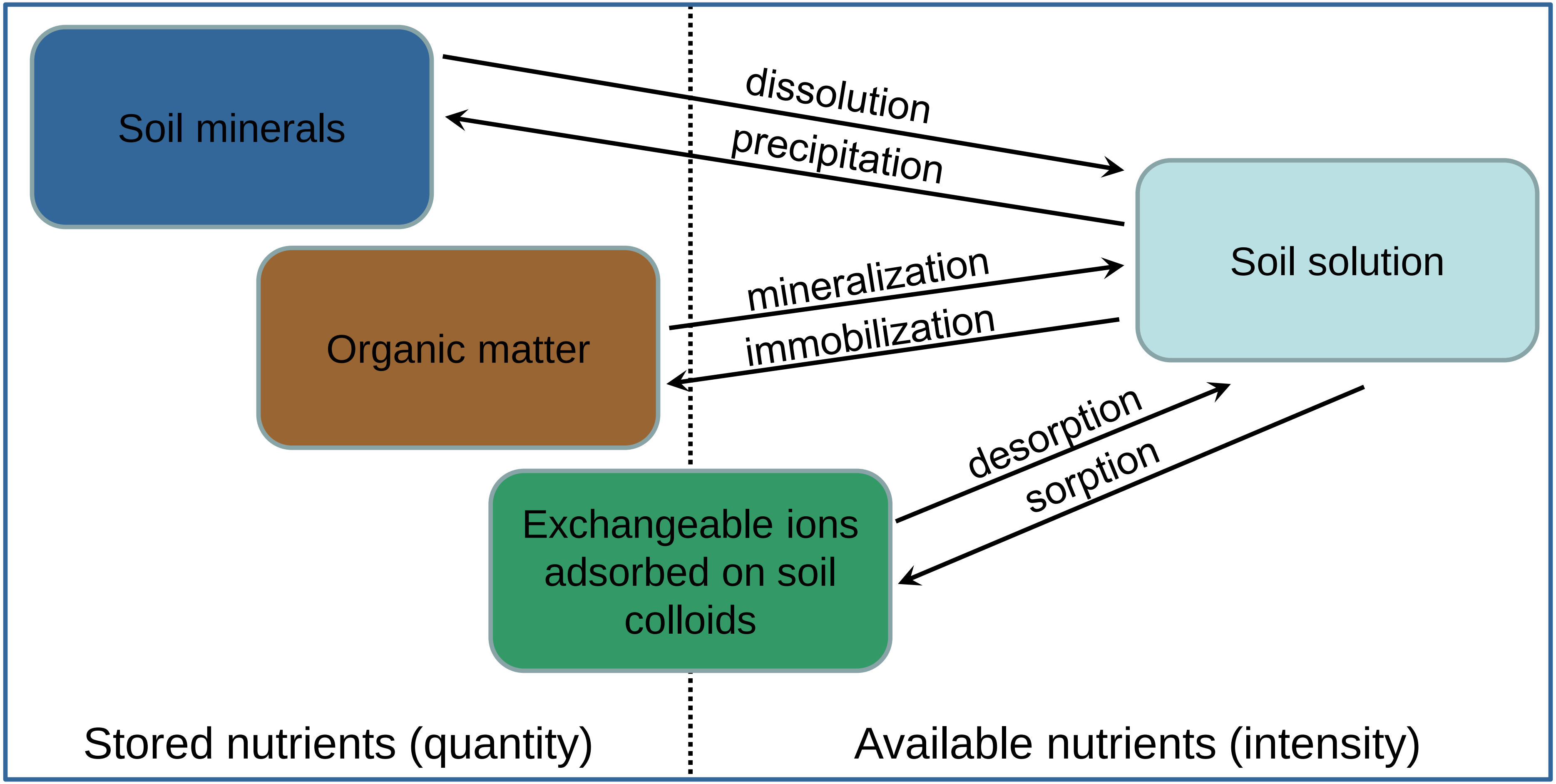
Plants absorb nutrients dissolved in soil solution.

Our focus is often on the total amount or ‘quantity’ of nutrients present in soil, but the ability of a soil to supply nutrients is determined by the release those nutrients into the soil solution, ‘intensity’

Land Institute, Salina Kansas.
http://ngm.typepad.com/our_shot/january-3-2008.html

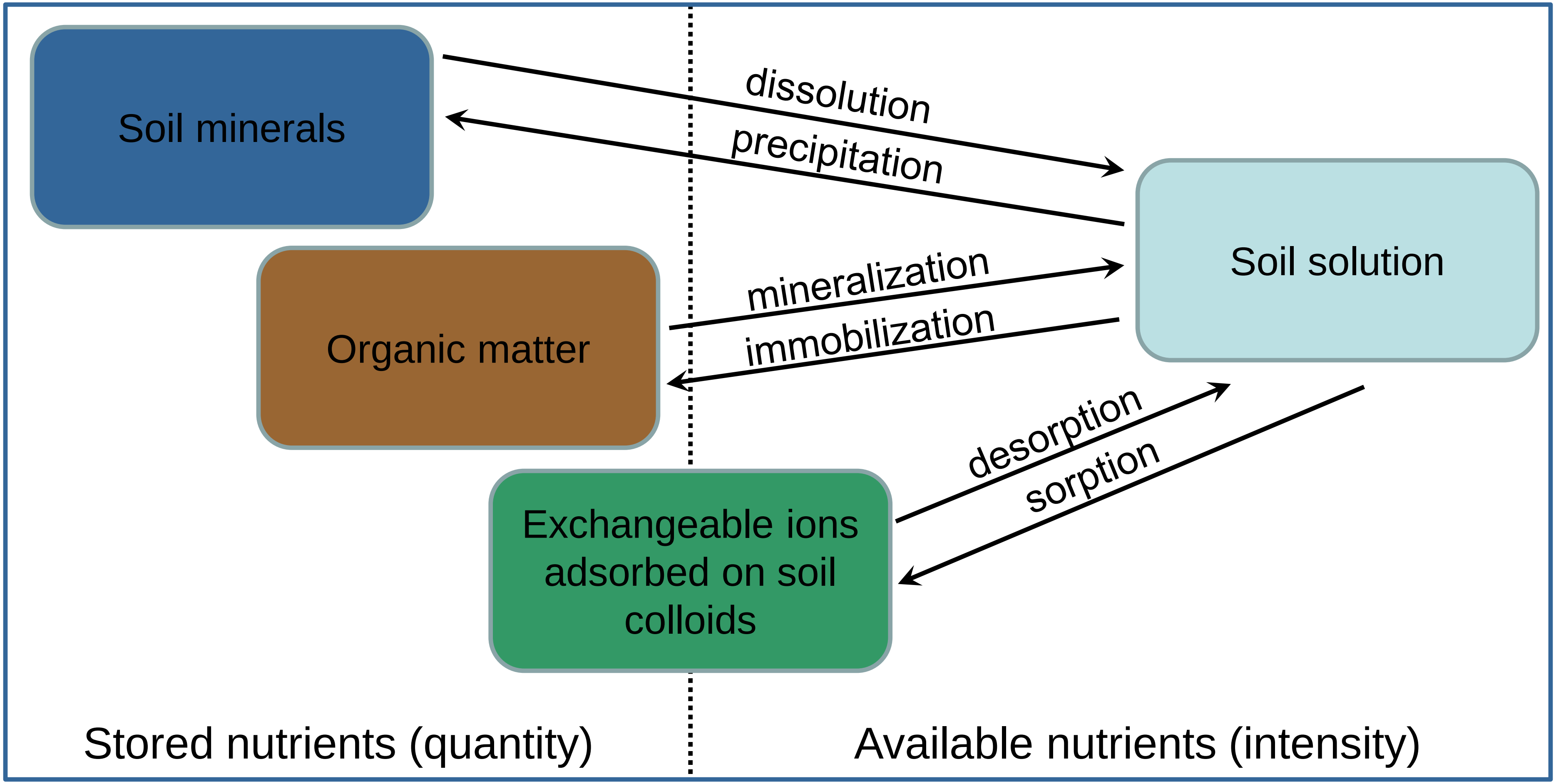
Nutrients in soil

Quantity–intensity relationship describes the ability of a soil to store and supply a given nutrient.

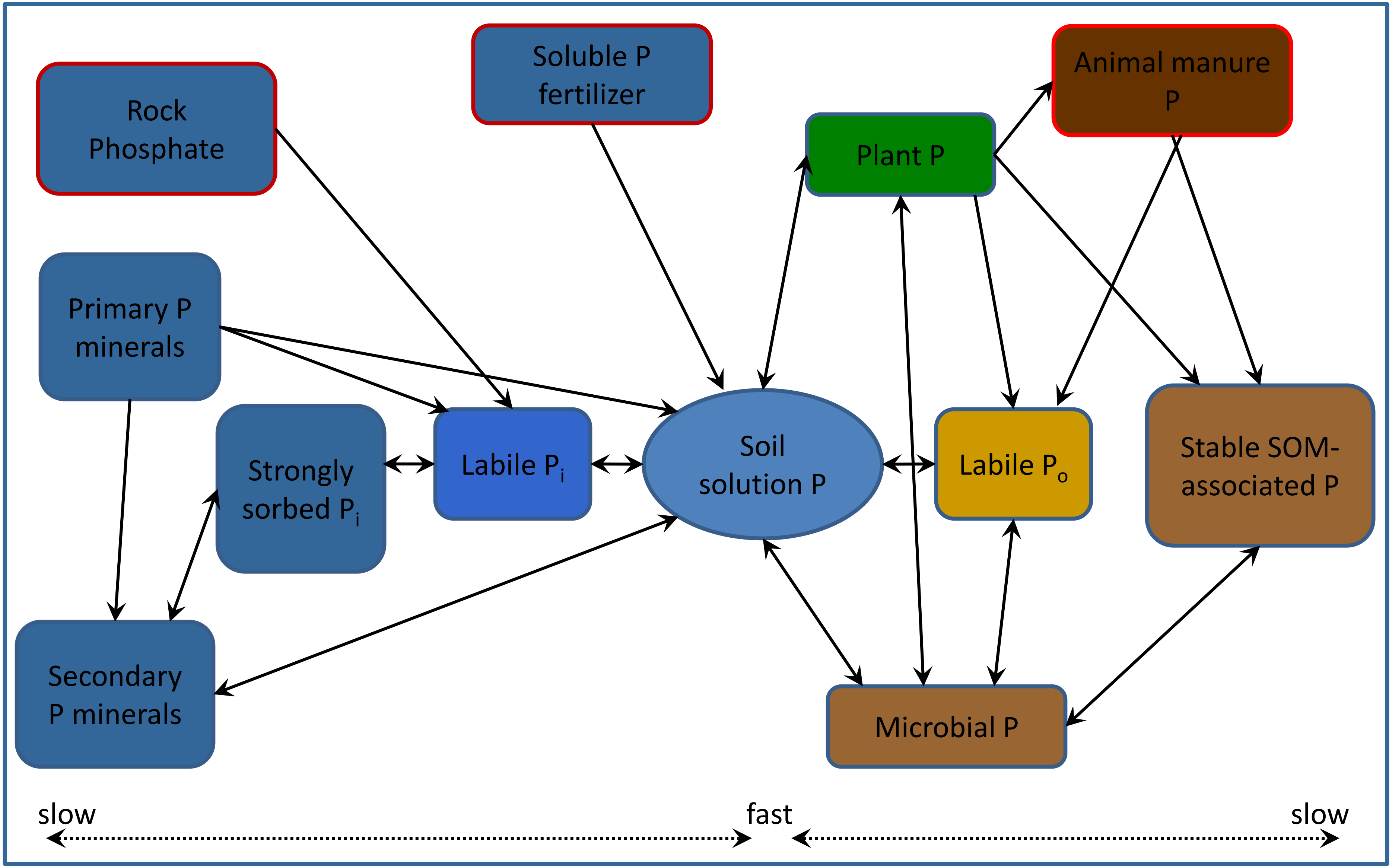


Nutrients in soil

An ideal soil test would provide a measure of nutrients in soil solution (intensity), in stored pools (quantity), and buffering capacity (change in intensity with respect to quantity).



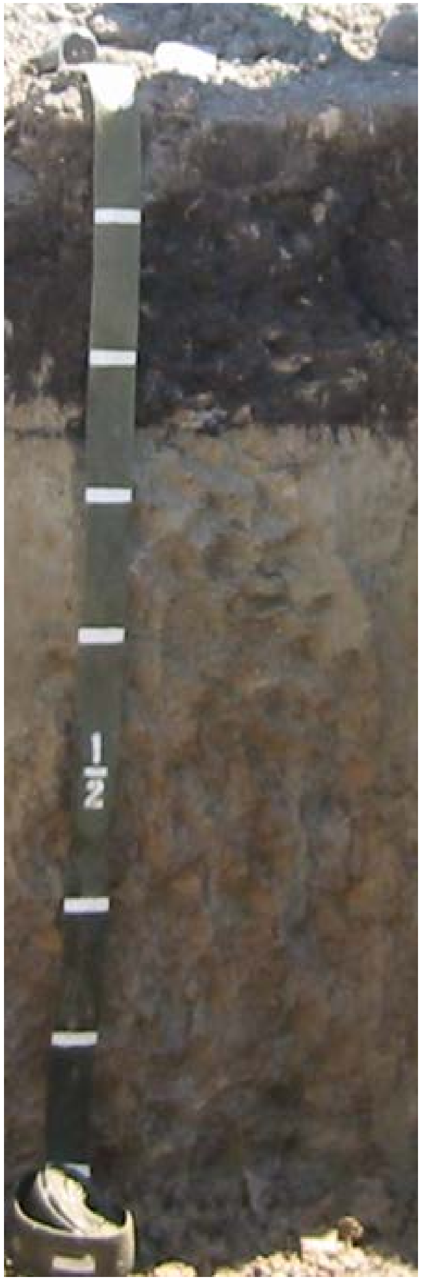
Conceptual illustration of phosphorus pools



Nutrients in soil

Number of factors influence the quantity-intensity relationship

- pH/soil acidity
- soil texture & mineralogy
- soil organic matter
- temperature/moisture regime

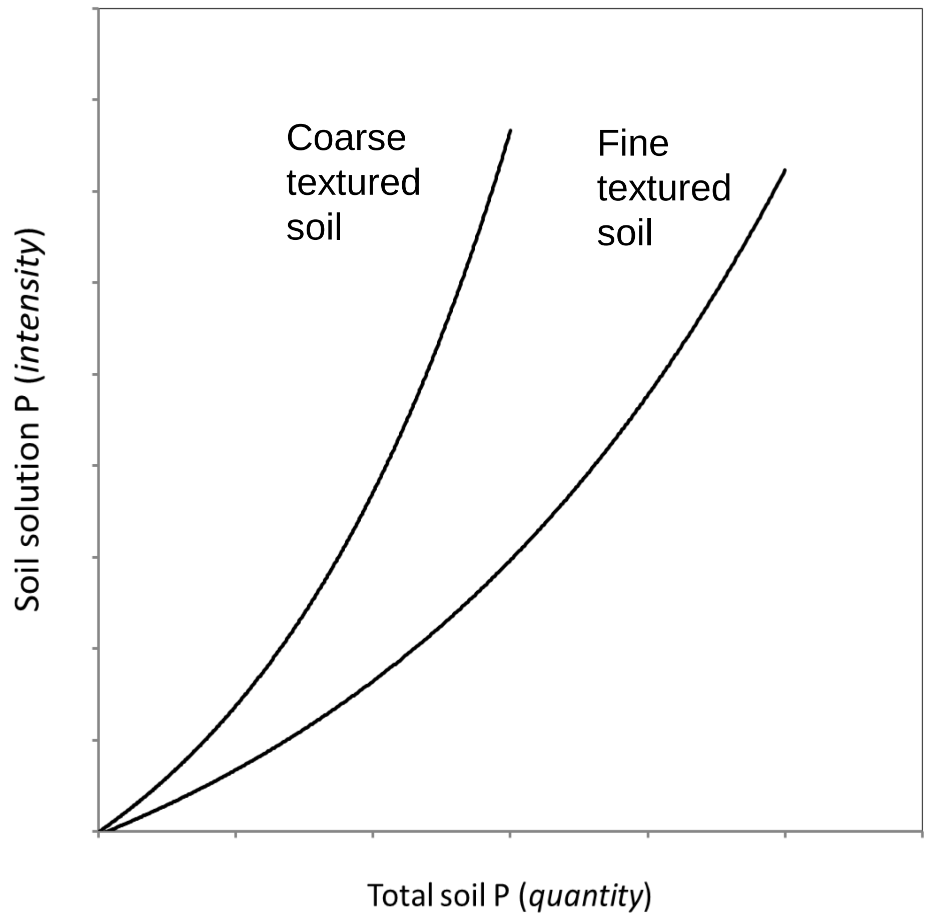


Nutrients in soil

Q/I curve describes the ability of the soil to maintain nutrients in solution, available to plants.

Not feasible to determine Q/I relationship in every case where a nutrient recommendation is desired.

However, an appreciation of this relationship does inform routine soil analysis and interpretation.

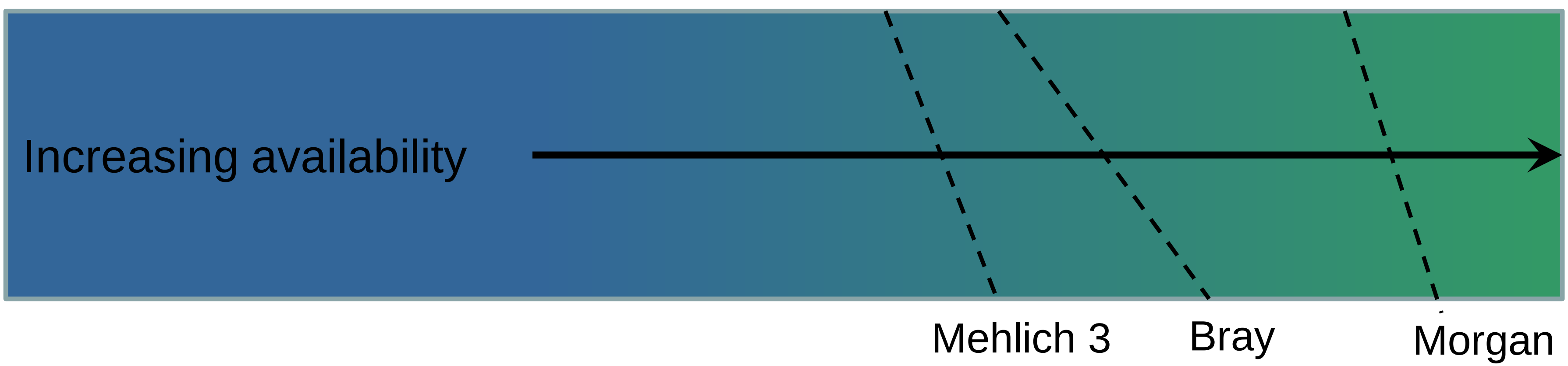


Conceptual quantity-intensity curves for phosphorus in a coarse vs. fine textured soil

Soil analysis

A discrete fraction of *available* nutrients does not exist,…

….rather, nutrient *availability* is more a continuum in soil based on specific conditions affecting solubility of different nutrient *pools*.



Soil analysis

Extraction solutions designed to remove immediately available nutrients plus a portion of that expected to become available.

Developed for specific conditions present within a given region.

The solution(s) used to extract nutrients in one region are often not appropriate for soils found in other regions.

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Common soil test P extractants

Extractant	Composition
Bray-P	0.03 M NH_4F + 0.025 M HCl
Mehlich 1	0.05 M HCl + 0.0125 M H_2SO_4
Mehlich 3	0.015 M NH_4F + 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.013 M HNO_3 + 0.001 M EDTA
Morgan	0.72 M NaOAc + 0.52 M CH_3COOH at pH 4.8
Modified Morgan	0.62 M NH_4OAc + 1.25 M CH_3COOH at pH 4.8
Olsen	0.5 M $NaHCO_3$ at pH 8.5

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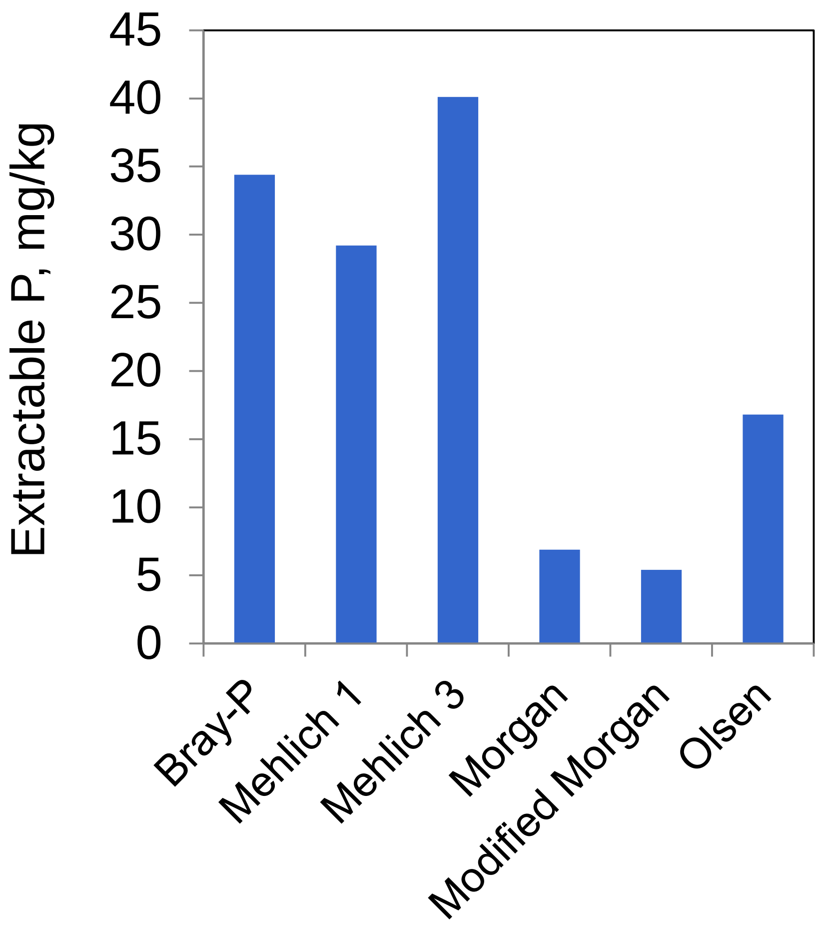
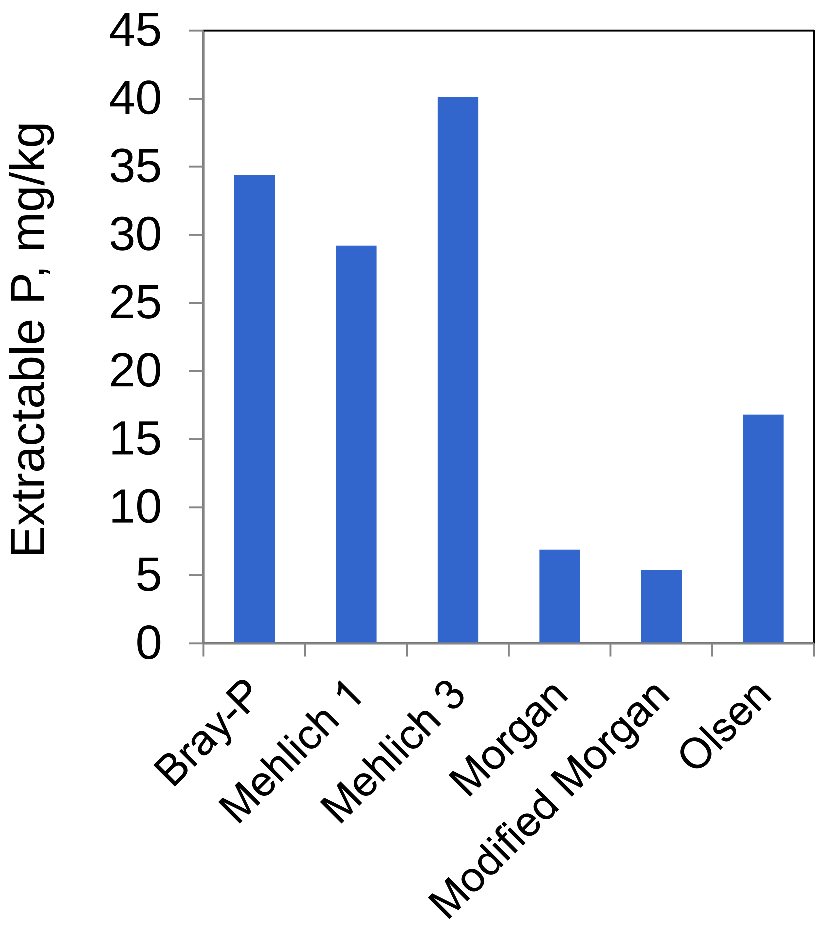


Soil test P determined by six common extraction solutions (North American Proficiency in Testing, *Soil 2014-101*)

Soil analysis

<u>Not</u> a quantitative measure of available nutrients; rather an *index* of soil nutrient supply.

Interpretation of results based on the empirical relationship between extractable nutrient levels and crop response to applied nutrient.



Soil test P determined by six common extraction solutions (North American Proficiency in Testing, *Soil 2014-101*)

Interpretation

Research, under local conditions, with representative soils ranging from deficient to adequate for given nutrient necessary to obtain meaningful soil test <u>correlation</u> and <u>calibration</u>.

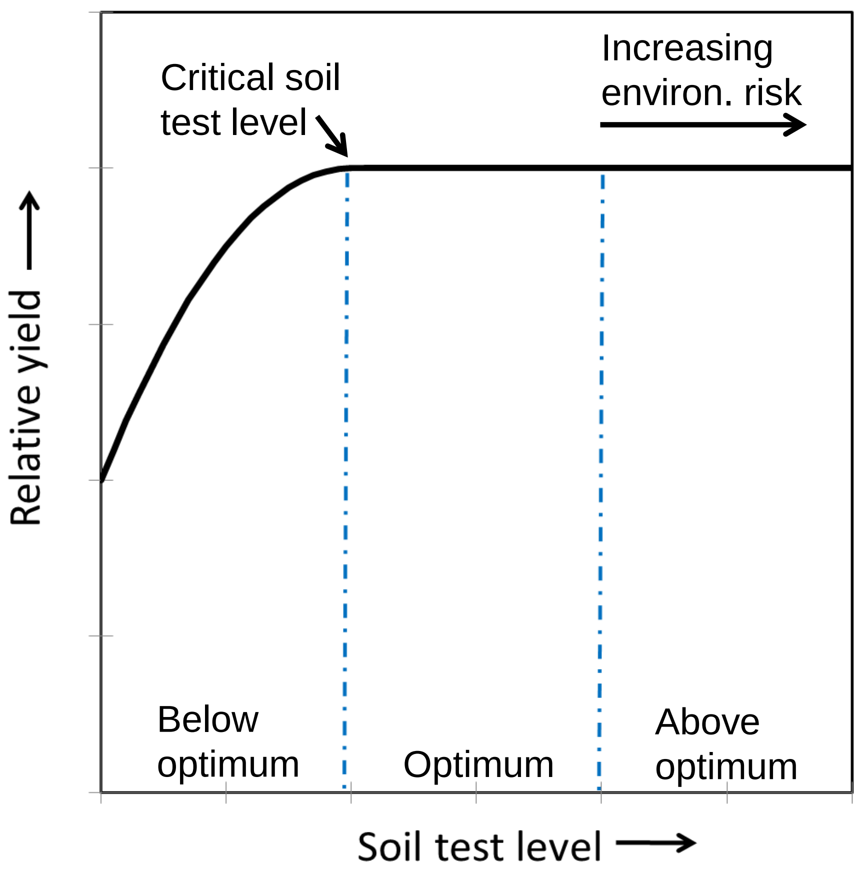
Interpretation

Soil test level

vs.

Relative yield $\left(\frac{yield\ without\ P_2O_5}{yield\ with\ P_2O_5.}\right)$

Define *critical soil test level* in order to identify responsive vs. non-responsive sites.



Generalized relationship between soil test level and crop response to nutrient applied

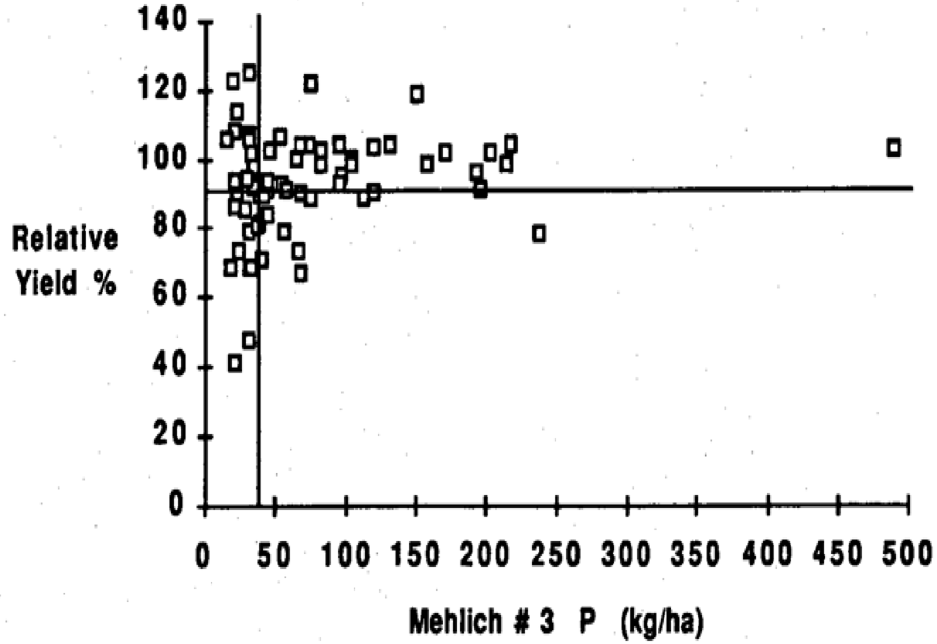
Interpretation

Soil test level

vs.

Relative yield $\left(\frac{yield\ without\ P_2O_5}{yield\ with\ P_2O_5.}\right)$

Define *critical soil test level* in order to identify responsive vs. non-responsive sites.



Mehlich 3 extractable P vs. relative yield of corn at 67 locations across PA. (Beagle and Oravec. 1990. Commun. Soil Sci. Plant Anal. 21:1025-1036)

Interpretation

Optimum Mehlich 3 extractable nutrient levels for agronomic crops in Pennsylvania

Soil test	Optimum range	Crops
Phosphorus	30-50 ppm	All agronomic crops
Potassium	100-150 ppm	Grain crops
	100-200 ppm	Forage crops
Magnesium	120-180 ppm	Grass forage crops
	60-120 ppm	Other agronomic crops

Interpretation

Optimum test ranges vary across different regions. Therefore, even when the same methods are used, the results may have a different meaning.

Optimum range of Mehlich-3 phosphorus* for field corn in selected states

State	Mehlich-3 P, ppm
Pennsylvania	30 to 50
Ohio, Indiana, Michigan	25 to 60
Iowa	26 to 35
Nebraska	10 to 20

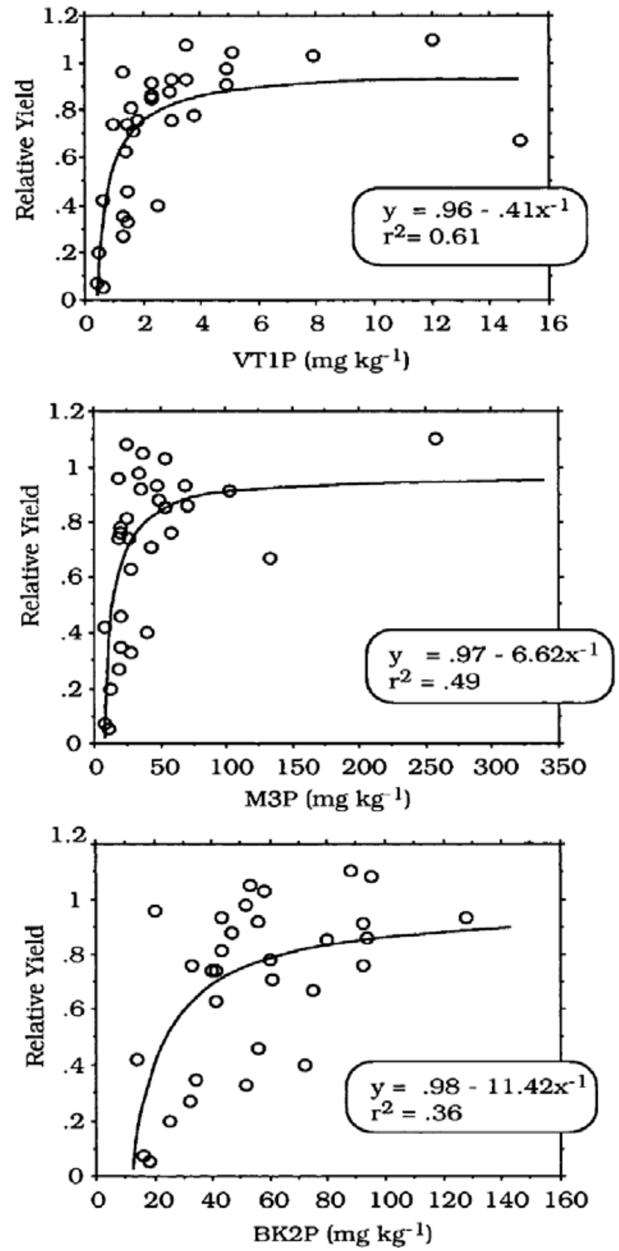
*determined by ICP-AES

Interpretation

Most New England LGU soil test recs are based field calibration of (modified) Morgan.

Work by Magdoff (UVM) showed that Modified Morgan was far better correlated with crop (alfalfa) response to P_2O_5 than either Mehlich 3 or Bray-Kurtz.

Other studies have found similar results for New England soils.



Magdoff et al., 1999. Soil Sci. Soc. Am. J. 63:999-1006

Interpretation

Optimum Modified Morgan extractable nutrient levels for all crops in Massachusetts

Soil test	Optimum range	Excessive
Phosphorus†	4-14 ppm	>40‡
Potassium	100-160 ppm	-
Calcium	1000-1500 ppm	-
Magnesium	50-120 ppm	-

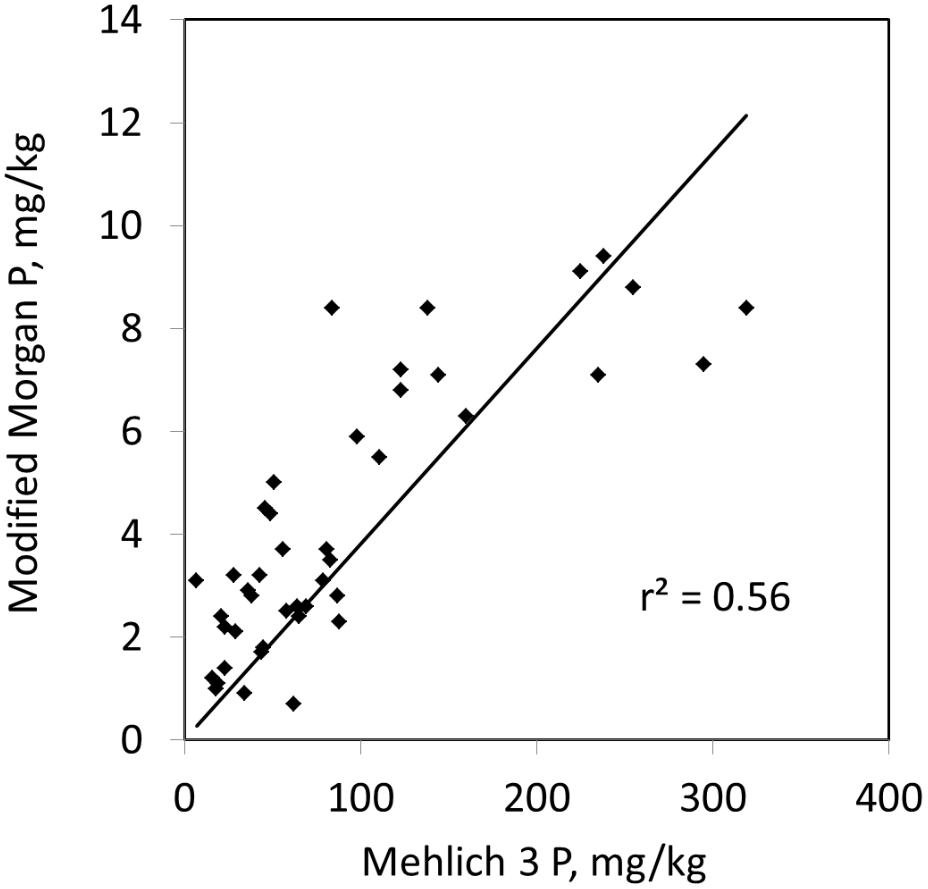
† Interpretation and recommendations for forage and grain crops based on extractable P and Al (Jokela et al., 1998).

‡ Has been shown to correspond to a P_{sat} of approximately 20% (Knight et al., 2012), the value proposed by the USEPA as a cutoff for manure and fertilizer applications in the Chesapeake Bay Watershed (USEPA, 2010)

Can we use Mehlich 3 extractable P to estimate (modified) Morgan P?

In this data set of 51 soils collected from the Northeast, Mehlich 3 extracted 2 to 90 times more P than modified-Morgan.

The two methods are not well correlated



Heckman et al., 2006. Soil Sci. Soc. Am. J. 98:280-288

Can we use Mehlich 3 extractable P to estimate (modified) Morgan P?

Ketterings et al. compared Morgan vs Mehlich 3 extractable P of 235 soil samples from NY.

They also found very poor correlation.

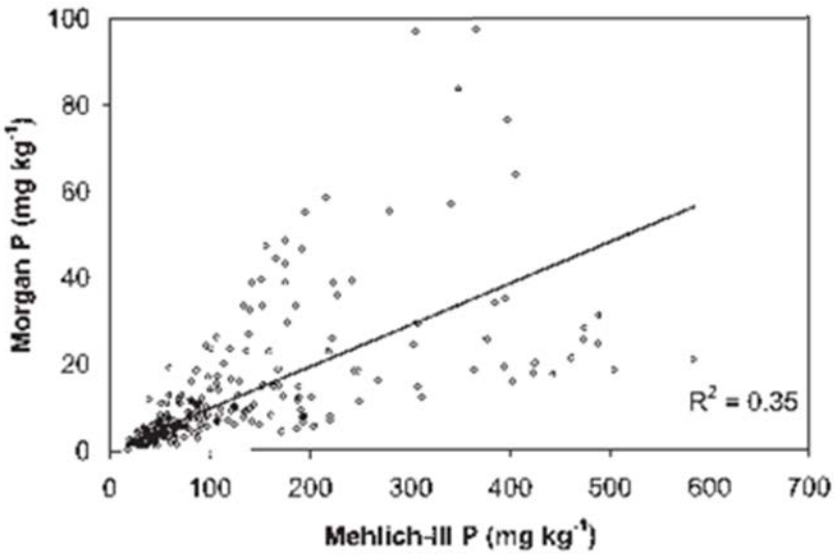


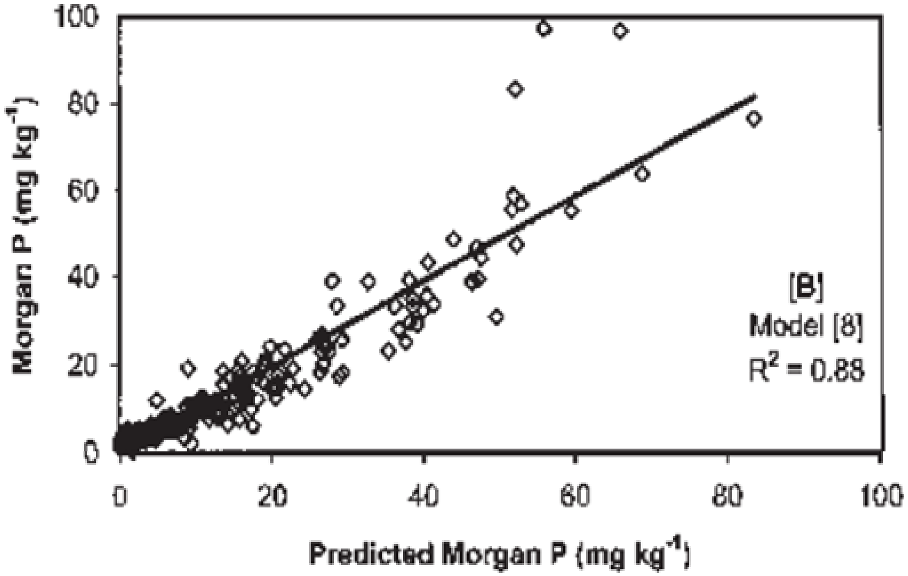
Fig. 2. Morgan and Mehlich-III extractable P for 235 New York State soil samples.

Ketterings et al., 2002. Soil Sci. 167:830-837

Can we use Mehlich 3 extractable P to estimate (modified) Morgan P?

Did find that Morgan P could be predicted using Mehlich 3 Al, Ca, and pH.

Important to recognize that conversion equations always add uncertainty.



$$\text{Morgan STP} = 1.62 + 0.56{*}\text{M3P} - 0.0018{*}\text{M3Ca} - 12.97{*}\text{pH} + 0.058{*}\text{M3Al} - 0.000027{*}\text{M3Al}^2 + 1.28{*}\text{pH}^2 + 0.000044{*}\text{M3P}{*}\text{M3Ca} - 0.00092{*}\text{M3P}{*}\text{M3Al} + 0.00000038{*}\text{M3P}{*}\text{M3Al}^2 \quad (r^2{=}0.88) \quad [8]$$

Ketterings et al., 2002. Soil Sci. 167:830-837

Interpretation

Units

Extractable nutrient levels can be expressed in different units.

Most labs report in ppm, but some use alternative units.

Some states (e.g., DE, MD, OK, NC) report results using a unit-less index system.

Soil test unit	To convert to ppm
P, lbs/A	$\frac{P, lbs/ac}{2}$
P_2O_5, ppm	$\frac{P_2O_5,\ ppm}{2.3}$
P_2O_5, lbs/A	$\frac{P_2O_5, lbs/ac}{4.6}$

Recommendations

Two basic philosophies:

Sufficiency approach (feed the crop)

When soil test level is below optimum, apply only enough nutrients to meet crop needs

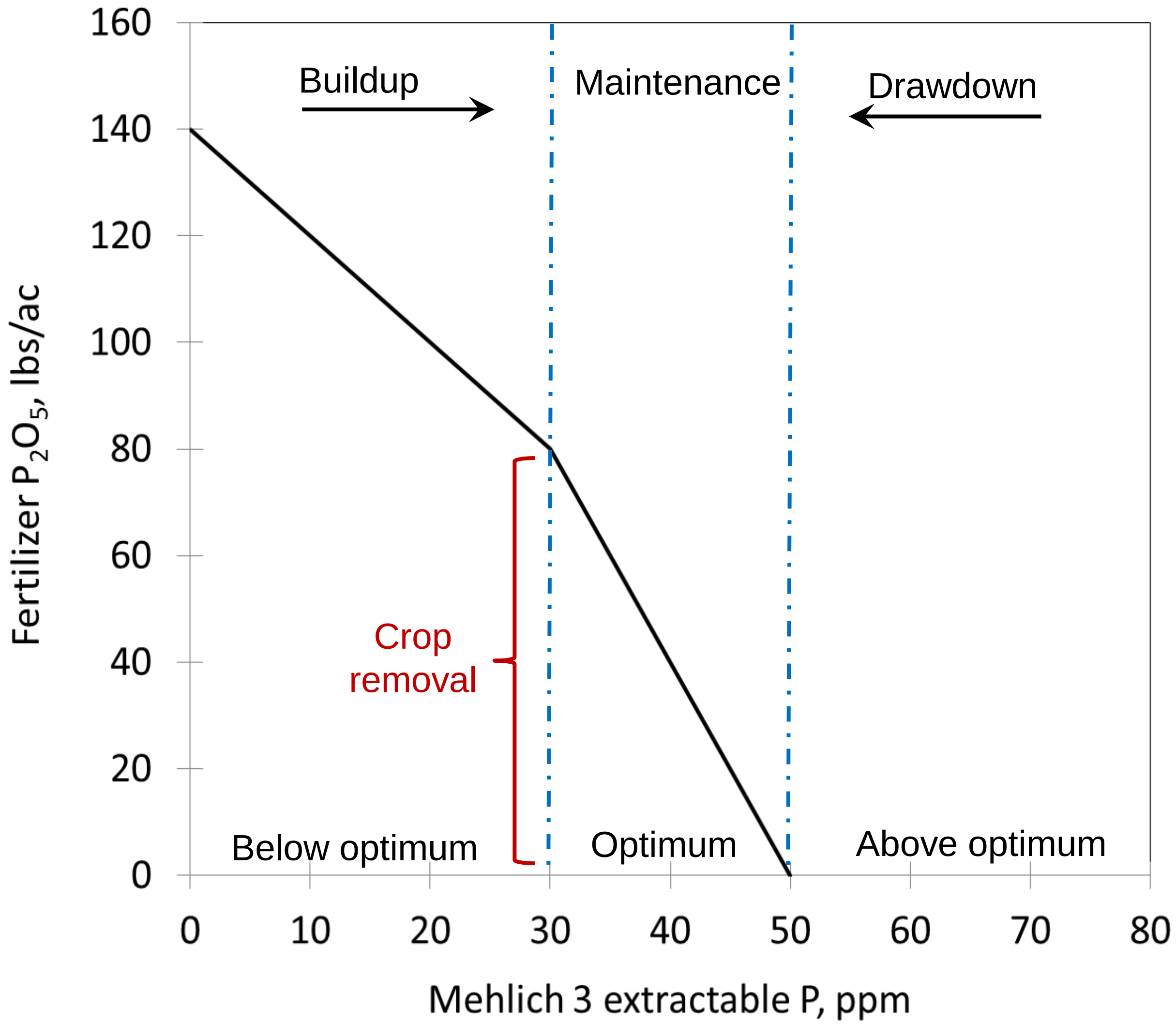
Buildup and maintenance approach (feed the soil)

Build soil test levels to optimum range over several years then replace nutrients removed by crop

Recommendations

Example of PSU *Build & Maintain* soil test recs for P_2O_5

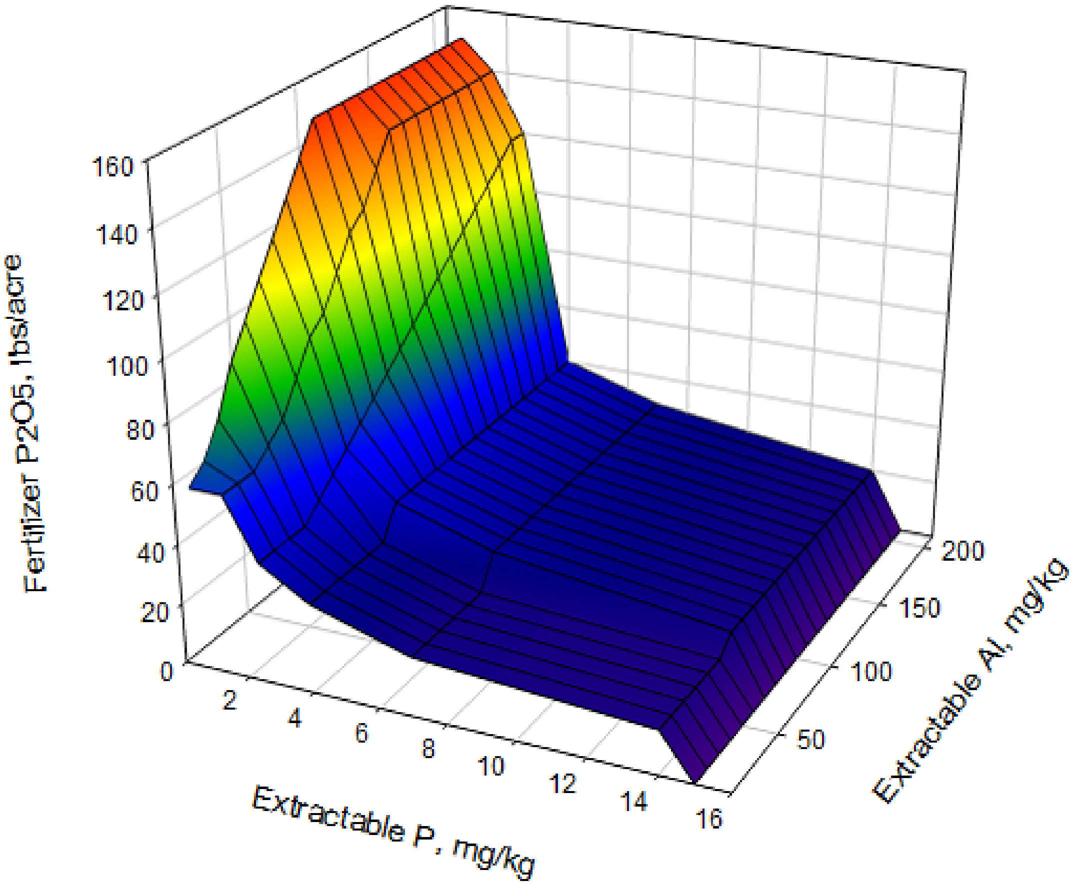
- Corn (grain), expected yield of 200 bu/A



Recommendations

University of Vermont, University of Massachusetts, and University of Connecticut recommendations consider both extractable P and soil P buffering capacity.

P_2O_5 recommendations are a function of Modified Morgan extractable P and Al, to account for P buffering capacity



Take-home message

We need to use relevant soil test methods and base our interpretation of results on local/regional field calibration in order to make sound nutrient management decisions.

Organic residuals testing

Key measurements for nutrient management

- Total solids (and volatile solids for compost)
- Ammonium-N
- Total N (and C for compost)
- **Total P** & K (plus other essential elements)
- **Water extractable P (WEP**)

Organic residuals testing

Reference Methods

<u>Biosolids</u>

Test Methods for Evaluating Solid Waste: Physical/Chemical Methods Compendium, EPA SW-846

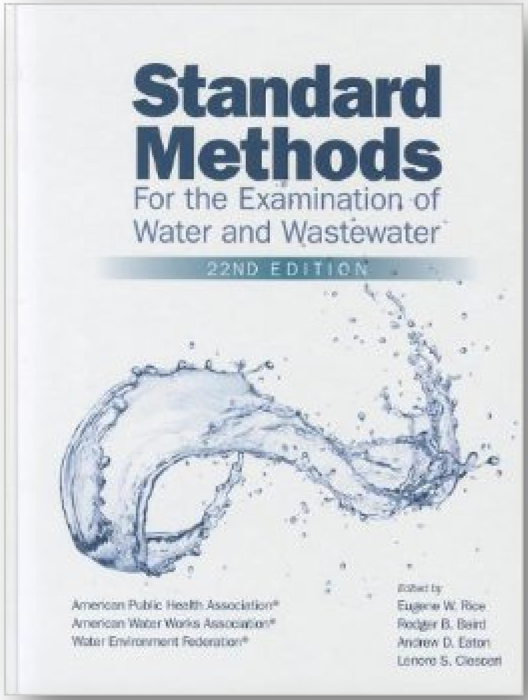
Standard Methods for the Examination of Water and Wastewater

<u>Compost</u>

Test Methods for the Examination of Composting and Compost

<u>Manure</u>

Recommended Methods of Manure Analysis



Organic residuals testing

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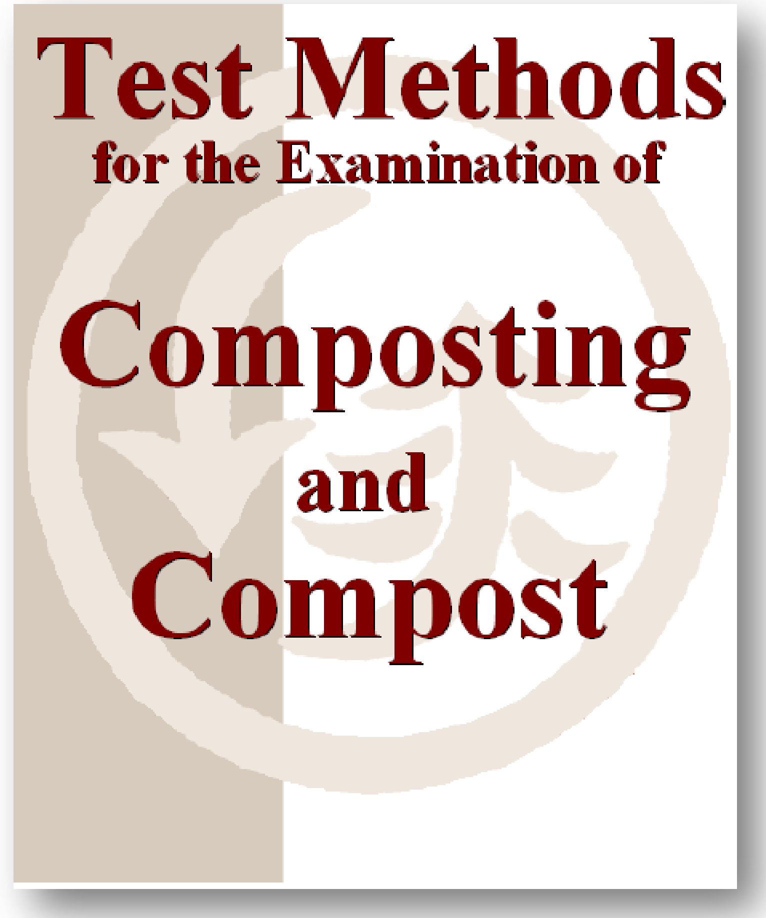

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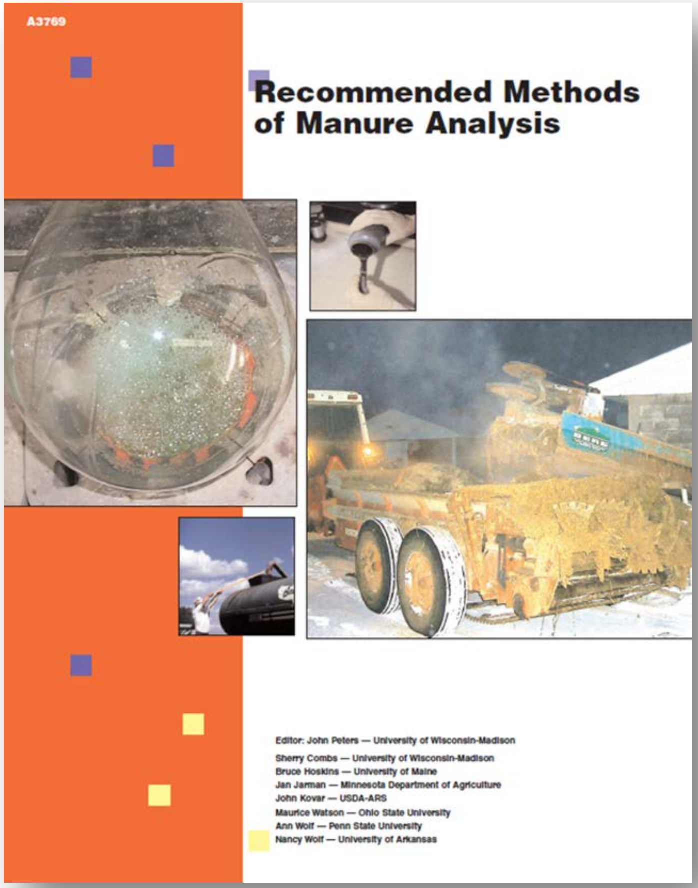

Organic residuals testing

Total Phosphorus

Several established reference methods give equivalent results

Generally subsample digested using conc. strong acid to bring P into solution which is analyzed by ICP-OES.

Includes soluble and insoluble organic and inorganic phosphorus.

Generally assumed to be 80 to 90% *fertilizer equivalent*, but this depends on nature of the material and the soil it is applied to…

Organic residuals testing

Water extractable P

Operationally defined.

Extensive work done by members of SERA-17 to develop standard method

- *Briefly,* subsample of as-received residual extracted using 1:100 ratio of solids:water, 60 min. equilibration time.

Measure of soluble inorganic, organic, and colloidal P.

Significantly influenced by characteristics of the residual (e.g., Fe, Al, Ca content)

Used to help predict risk of runoff P from recently amended soils – P source coefficient

Selection of a Water-Extractable Phosphorus Test for Manures and Biosolids as an Indicator of Runoff Loss Potential

Peter Kleinman* USDA-ARS
Dan Sullivan Oregon State University
Ann Wolf and Robin Brandt Pennsylvania State University
Zhengxia Dou University of Pennsylvania
Herschel Elliott Pennsylvania State University
John Kovar and April Leytem USDA-ARS
Rory Maguire Virginia Polytechnic University
Philip Moore and Lou Saporito USDA-ARS
Andrew Sharpley University of Arkansas
Amy Shober University of Florida
Tom Sims University of Delaware
John Toth University of Pennsylvania
Gurpal Toor University of Arkansas
Hailin Zhang Oklahoma State University
Tiequan Zhang Agriculture and Agri-Food Canada

The correlation of runoff phosphorus (P) with water-extractable phosphorus (WEP) in land-applied manures and biosolids has spurred wide use of WEP as a water quality indicator. Land managers, planners, and researchers need a common WEP protocol to consistently use WEP in nutrient management. Our objectives were to (i) identify a common WEP protocol with sufficient accuracy and precision to be adopted by commercial testing laboratories and (ii) confirm that the common protocol is a reliable index of runoff P. Ten laboratories across North America evaluated alternative protocols with an array of manure and biosolids samples. A single laboratory analyzed all samples and conducted a separate runoff study with the manures and biosolids. Extraction ratio (solution:solids) was the most important factor affecting WEP, with WEP increasing from 10:1 to 100:1 and increasing from 100:1 to 200:1. When WEP was measured by a single laboratory, correlations with runoff P from packed soil boxes amended with manure and biosolids ranged from 0.79 to 0.92 across all protocol combinations (extraction ratio, filtration method, and P determination method). Correlations with P in runoff were slightly lower but significant when WEP was measured by the 10 labs (r = 0.56–0.86). Based on laboratory repeatability and water quality evaluation criteria, we recommend the following common protocol: 100:1 extraction ratio; 1-h shaking and centrifuge 10 min at 1500 × g (filter with Whatman #1 paper if necessary); and determining P by inductively coupled plasma–atomic emission spectrometry or colorimetric methods.

Published in J. Environ. Qual. 36:1357–1367 (2007).
doi:10.2134/jeq2006.0450
Received 13 Oct. 2006.
*Corresponding author (Peter.Kleinman@ars.usda.gov).
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Accelerated freshwater eutrophication, the biological aging of surface waters related to anthropogenic enrichment of nutrients, is primarily controlled by inputs of phosphorus (P). Phosphorus-laden runoff from manure-amended soils is an important source of P in many eutrophic water bodies in North America (Carpenter et al., 1998). Application of livestock manures to soils can exacerbate P losses in runoff indirectly by augmenting soil P saturation and P desorption potential (Sibbesen and Sharpley, 1997) or directly through the transfer of recently applied manure P to runoff water (Preedy et al., 2001). As a result, there has been widespread implementation of P-based guidelines in the USA and Canada aimed at improving manure application practices to soils (USEPA, 2004; Hilborne and Stone, 2005), with a key strategy being the use of P site

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Mention of trade names does not imply recommendation or endorsement by USDA-ARS.

Abbreviations: ICP, inductively coupled plasma; P_{color}, phosphorus determined by colorimetry; P_{ICP}, phosphorus determined by inductively coupled plasma–atomic emission spectrometry; RSD, relative standard deviation; TP, total phosphorus; WEP, water-extractable phosphorus.

Kleinman et al., 2007. JEQ 36:1357-1367

Organic residuals testing

Units

Phosphorus expressed many ways

Generally expressed as P_2O_5 in units that are *ready to use*

lbs P_2O_5/cu yd (compost)
lbs P_2O_5/ton
lbs P_2O_5/1000 gal

Reported on an as-received and/or dry weight basis where appropriate.

PENNSTATE
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Analysis Report For:	Copy To:
Waylon Jennings Good Ol' Bolys Farm 18 Ramblin Rd. Springs Mills, PA 16875	Merle Haggard Poncho and Lefty CCA, LLC 1100 Muskogee Rd. Springs Mills, PA 16875

LAB ID:	SAMPLE ID:	REPORT DATE:	DATE SAMPLED:	COUNTY:	MATERIAL:	TYPE:	STORAGE SYSTEM:
M12587	Grassy Crest 10-12-2016	10/20/2016	10/12/2016	Allegheny			

MANURE ANALYSIS REPORT

Results on as sampled (wet weight) basis

Analyte	lb/ton	lb/1000 gal	Analyte	lb/ton	lb/1000 gal
Solids 11.46 %			Total Calcium (Ca)	13.66	56.96
Total Nitrogen (N)	6.72	28.02	Total Magnesium (Mg)	1.84	7.67
Ammonium N (NH_4-N)	2.52	10.50	Total Sulfur (S)	0.82	3.43
Calculated Organic N	4.20	17.52	Total Copper (Cu)	0.09	0.36
Total Phosphate (P_2O_5)	2.86	11.91	Total Zinc (Zn)	0.04	0.18
Total Potash (K_2O)	5.81	24.24	Total Manganese (Mn)	0.06	0.26
			Total Iron (Fe)	0.48	2.02
			Total Sodium (Na)	2.69	11.22
			Total Aluminum (Al)	0.13	0.55

Optional Test Results:	pH	Carbon (C) (%)	C:N Ratio	Ash (%)	Volatiles (%)	Nitrate Nitrogen (lb/ton)	Nitrate Nitrogen (lb/1000 gal)	Soluble Salts mmhos/cm	PSC*
									0.32

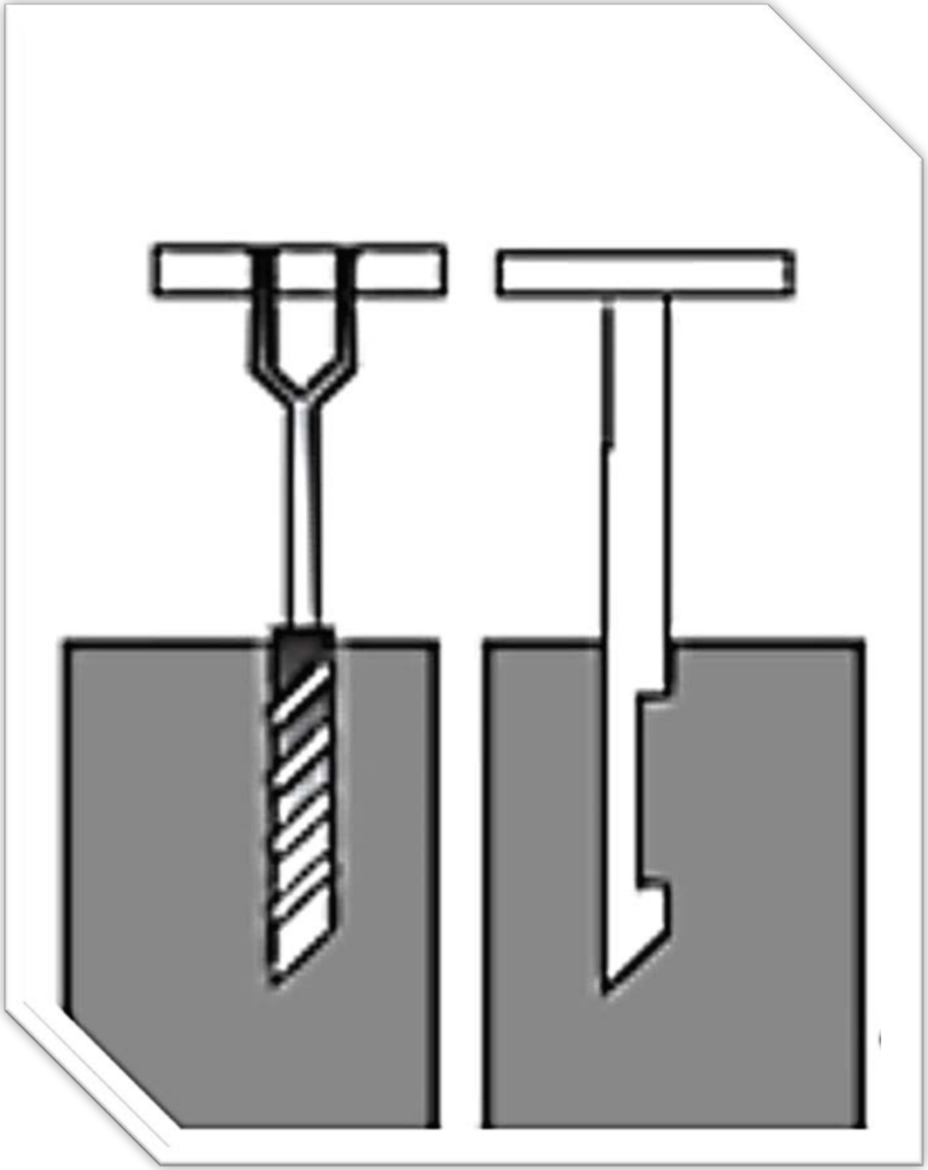
*P Source Coefficient for use in Pennsylvania P Index

Comments:

- The enclosed fact sheet "Using Your Manure Analysis Report" provides information to help you interpret this report and calculate appropriate manure application rates for your crops.
- Manure nutrients are not all equivalent to fertilizer nutrients. Phosphorus and potassium can be substituted directly for fertilizer to meet your soil test recommendation. Nitrogen (N) availability varies with handling. This must be accounted for in utilizing manure to meet soil test N recommendations. See the enclosed fact sheet "Using Your Manure Analysis Report"

Nutrient contents are presented as both "lb/ton" and "lb/1000 gal". Choose results with the units that are most convenient for you. An assumed manure density of 8.34 lbs per gal was used to calculate results on a lb/1000 gal basis.

Questions or Comments?



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