UNIVERSITY OF GEORGIA
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Soil Test Extractants: Principles, Applications, and Implications

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Soil test extractants are chemical solutions used to dissolve or exchange nutrients in soil samples. They are used when performing soil analyses to determine nutrient recommendations. The nutrient concentrations obtained from using soil test extractants are commonly termed ***available nutrients***, ***exchangeable nutrients***, or ***extractable nutrients***. These terms indicate that the nutrient concentration reported for the soil samples is not equal to the total nutrient content.

Common examples of soil test extractants are Mehlich-1 (pronounced Mel-lick; rhymes with [Tom] Selleck), Mehlich-3, Morgan-Wolf, and Olsen. Mehlich-1 is the recommended soil test extractant by University of Georgia Cooperative Extension. However, some Georgia growers are showing interest in the Mehlich-3 soil test extractant, and some growers already have switched from using Mehlich-1 to Mehlich-3.

Common reasons provided by the growers for this change, based on interactions with Extension agents and specialists, include: "I have heard the Mehlich-3 is a better test," "My grower friends in other states use Mehlich-3 so I decided to switch to Mehlich-3," "I like the Mehlich-3 test because it generally provides higher nutrient levels, allowing me to reduce fertilizer applications," just to name a few. Some of these explanations reflect a lack of understanding of the principles of soil test extractants.

This publication should increase your understanding by providing a general overview of soil test extractants and considerations for choosing specific ones. After reading this publication, you should be able to explain the significance of using soil test extractants; differentiate between extractable soil nutrients and total soil nutrients; determine how soil test extractants are correlated and applied; and describe single-nutrient and multi-nutrient extractants along with their advantages and limitations.

Why Test Your Soil?

Crops require adequate and balanced nutrient levels to complete their life cycles and produce optimal yields and quality. Soil testing gives growers a snapshot of the crop-nutrient requirements that can be supplied from the soil. Growers can then supplement the shortfall of nutrients, if applicable, with fertilizers or other nutrient sources. In the absence of soil testing, growers may not supply enough nutrients, which could lead to poor plant health and crop failure. In contrast, growers applying too many nutrients could increase production costs, reduce profit margins, and negatively affect the environment.

It is important to note that routine soil test analyses do not measure the total amount of nutrients in the soil but instead provide an index of the nutrient-supplying capacity of the soil. In other words, a soil test predicts the amount of nutrients that will be made available from the soil. This prediction is achieved by using soil test extractants. Typically, soils have higher amounts of nutrients than reported in routine soil test analyses. Total nutrient concentrations can be obtained through sample digestion, but there are poor correlations between total nutrient concentration and plant uptake—which is why total nutrients are not used to indicate plant-available nutrients.

Table 1 shows the nutrient values of different soil samples for Mehlich-1 extraction compared to nitric acid-hydrogen peroxide digestion. Nutrient values after soil digestion are consistently greater than Mehlich-1 for all of the soil samples. In fact, a grower may assume that their soil does not need an application of fertilizer based on the nutrient values produced when the test is performed with soil digestion. However, some of these nutrients may be held too tightly by the soil or are associated with organic materials and microbial biomass and cannot be accessed by plants. This is why soil test extractants are used to predict the amount of nutrients that will be made available from the soil and will be accessible to plants.

Table 1. Nutrient Values of Soils Sampled in Georgia Compared to Commercial Standard Soil and Silica Sand.

Extraction method	**Nutrient value in lb/acre**									
	P	**K**	**Mg**	**Ca**	**B**	**Zn**	**Mn**	**Fe**	**Cu**	
Tift County soil										
Mehlich-1	55.7	103	105	1,038	0.40	4.07	103	44.0	0.57	
Digested	338	352	342	1,233	6.30	15.9	675	9,430	4.87	
Sumter County soil										
Mehlich-1	31.0	122	217	964	0.90	3.87	196	53.0	0.63	
Digested	621	608	732	1,260	3.94	43.2	1,124	44,762	13.6	
Standard soil										
Mehlich-1	71.0	430	430	4,051	1.08	3.23	226	181.5	1.35	
Digested	1,835	6,893	10,140	7,906	14.1	139	1,731	70,960	36.9	
Silica sand										
Mehlich-1	2.71	11.4	18.1	118	0.17	0.45	1.78	10.8	0.19	
Digested	6.10	39.7	33.6	173	3.31	2.11	5.39	421	2.01	

Note. Nitric acid and hydrogen peroxide were used for digestion, which also provides partial nutrient levels because they do not completely dissolve the soil. Hydrofluoric acid, a highly corrosive acid, is required to completely dissolve the soil for total nutrient analyses.

Nutrient Release From Soil

Soil test extractants are intended to mimic the actions of roots in the uptake of nutrients. The interaction of several physical, chemical, and biological properties in soils controls the availability of nutrients to plants. Figure 1 shows how nutrients are supplied to plants through a dynamic interaction between plant roots, the surface of soil particles, and the ***soil solution***, which is the water surrounding the soil particles that contains dissolved minerals and salts.

As plant nutrients are absorbed from the soil solution by the plant roots, the decrease in nutrient concentration in the soil solution triggers the release of nutrients from the soil surface. This process will resupply the soil solution until concentrations of nutrients on the soil surface and within the solution reach equilibrium. This process continues until the remaining nutrients on the soil surface are held too tightly to be released into the soil solution. Appreciable amounts of nutrients are in organic forms, such as in organic matter or the biomass of soil microbes. These nutrients are not readily accessible by plants until the organic compounds are broken down, usually by microbes, in a process called mineralization.

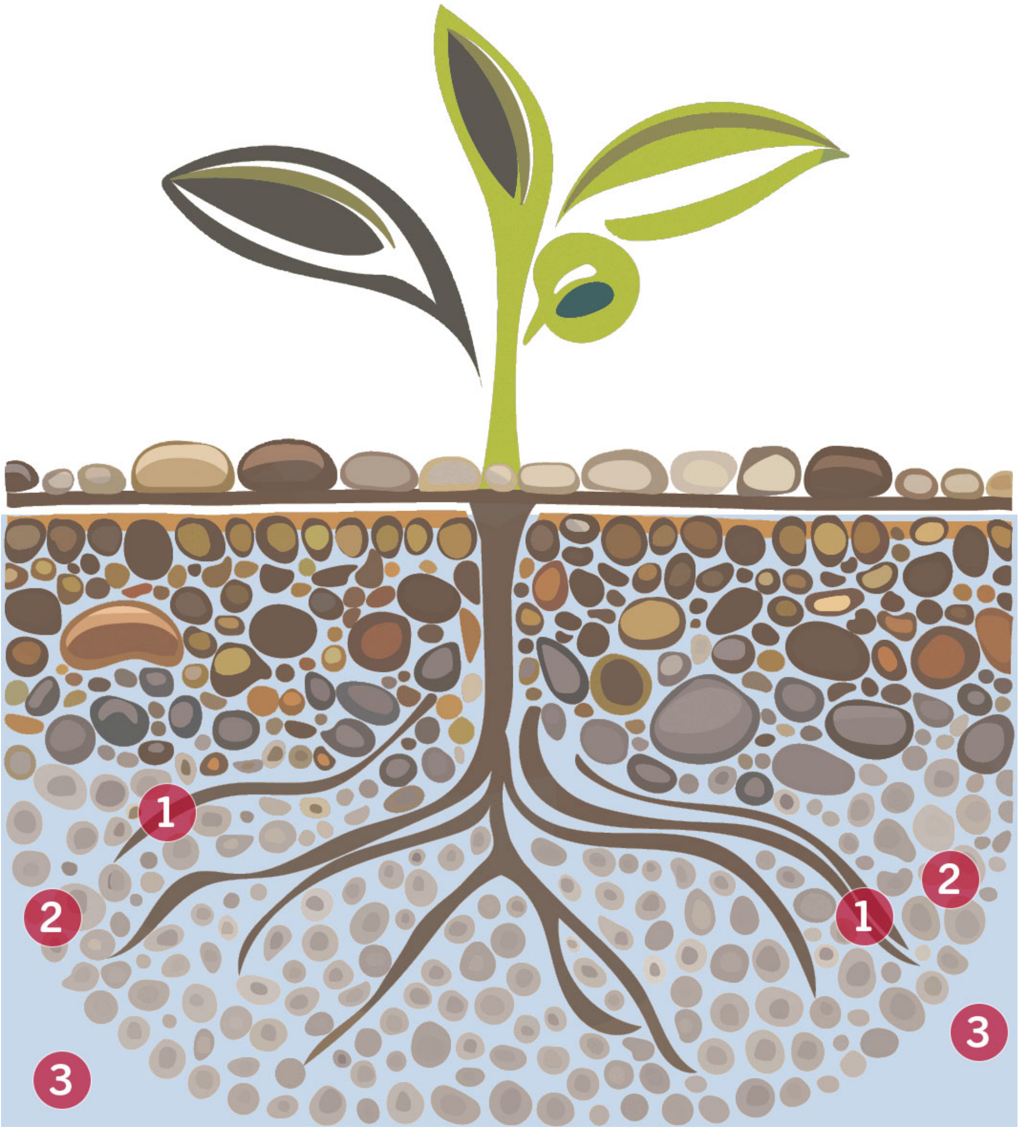


Figure 1. Ion Exchange for Nutrient Uptake. As plant roots (1) absorb nutrients, biochemical reactions cause ions to be exchanged from the soil surface (2) to resupply (or buffer) the soil solution (3).

Evaluating Soil Test Extractants

Nutrient uptake is controlled by several factors, and when it comes to soil testing, **the amount of nutrients extracted** by a particular soil test extractant is not as important as the **extractant's ability to provide a reliable index of nutrient availability**. In other words, the results you see from soil testing should strongly correlate with actual nutrient uptake by crops.

Correlation is the process of establishing a relationship or connection between two or more measures. ***Soil test correlation*** is the process of determining the relationship between plant nutrient uptake or yield and the amount of nutrients extracted by a particular soil test extractant. A correlated soil test will be able to determine whether crops will respond to the application of nutrients—these are results that will help growers make sound decisions.

In traditional soil fertility research, two sets of correlation experiments are carried out. The first is a preliminary study, especially if several soils and extractants are being assessed. The extractants are first used to determine the nutrient concentration of soils. This is followed by growing different crops in a greenhouse or growth chamber and quantifying the total nutrients taken up by the crops. Correlation analyses are then performed statistically to determine the best extractant based on the correlation coefficient. A scatter diagram of nutrient uptake and soil nutrient concentration can also provide a visual assessment of the different extractants.

Low nutrient uptake and poor plant growth should correspond with a low soil test, and high nutrient uptake and better crop growth should correspond with a high soil test. Figure 2 shows an example of a scatter diagram of phosphorus uptake and soil phosphorus determined after extraction with two extractants (A and B). As shown in the figure, Extractant A correlates better with phosphorus uptake than Extractant B; the dots representing test results are much more closely aligned with each other. This is because the phosphorus uptake increased along with an increase in the extractable phosphorus. There is considerable variation in phosphorus uptake with extractable phosphorus of Extractant B; the dots representing the soil test results are scattered farther from each other.

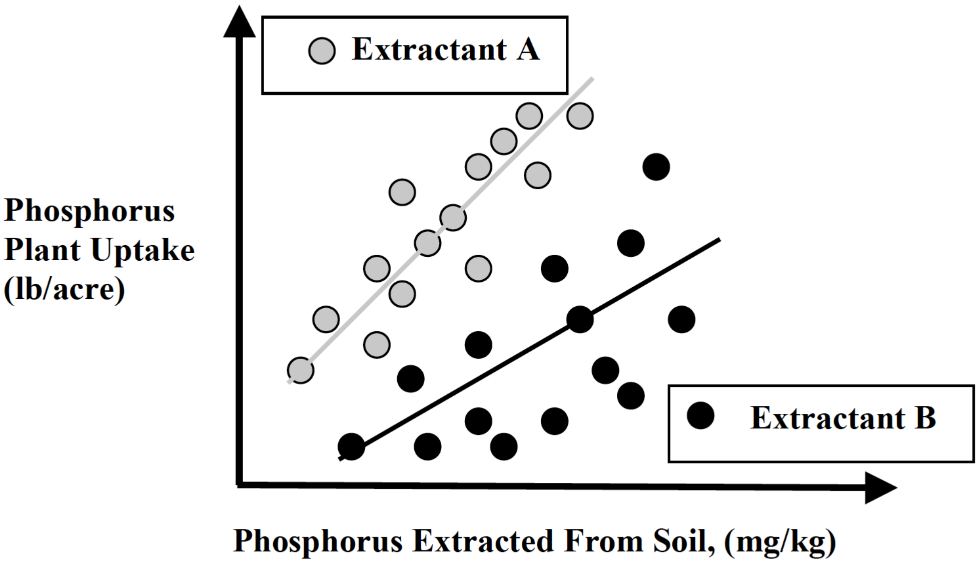


Figure 2. Correlation of Phosphorus Extracted from Soil and Corresponding Phosphorus Uptake by Plants. From "Understanding Soil Tests for Plant-Available Phosphorus," by M. Watson & R. Mullen, 2007, The Ohio State University Extension, p. 2 (https://agcrops.osu.edu/sites/agcrops/files/imce/fertility/Soil_Tests_Plant_Avail.pdf).

The second correlation experiment is usually conducted in the field to establish the crop's response. Typically, the experiment is carried out across multiple locations to derive crop yield as a function of the soil test nutrient concentration (Figure 3). The response curve is then partitioned into different groups or indices, commonly referred to as ***soil test ratings***.

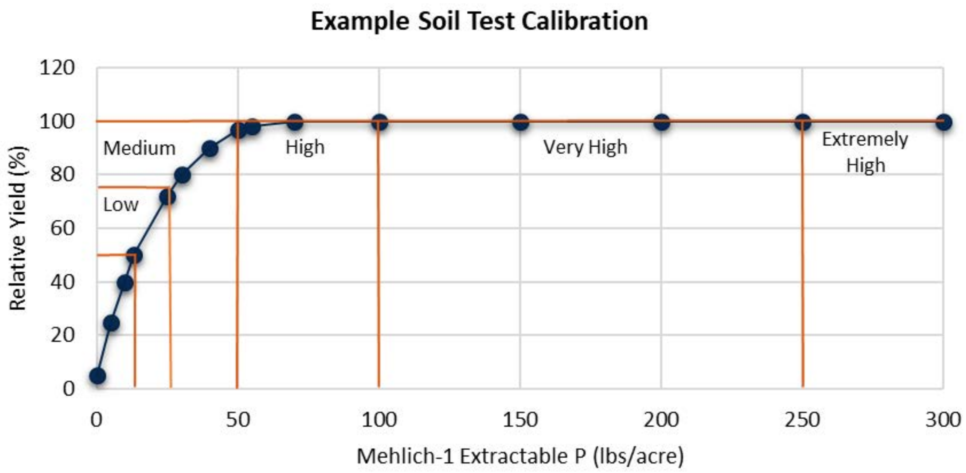


Figure 3. Response Curve of Relative Yield to Mehlich-1 Extractable Phosphorus (P). The response curve has been partitioned into soil test ratings labeled low, medium, high, very high, and extremely high. From "Nutrient Recommendations for Alabama Row Crops," by P. Paterson, 2020, Auburn University Extension, p. 8 (https://www.aces.edu/wp-content/uploads/2020/06/AlabamaRowCropsPDF_final.pdf).

Soil test ratings are interpreted differently by various analytical labs or university Extension services. For instance, Tables 2 and 3 are the interpretation of phosphorus and potassium indices by UGA Extension and Auburn University Extension, respectively. The UGA Extension interpretation is based on the percent probability that phosphorus or potassium application will cause a yield response. However, the Auburn University Extension interpretation is based on expected yield potential.

Interpretation based on probability tends to be more appropriate for crops that are less responsive to nutrient application, whereas interpretation based on yield potential is better suited for crops that are very responsive to nutrient application.

Table 2. Interpretation of Soil Test Ratings for Phosphorus and Potassium by University of Georgia Extension.

Soil test ratings	Description
Low	Soil is deficient and yield response to applied phosphorus or potassium fertilizer should occur 80% or more of the time.
Medium	Soil test level is sufficient to prevent a deficiency from occurring with expected yield response to applied phosphorus or potassium fertilizer about 50% of the time.
High	Soil test level is sufficient for most crops without the application of phosphorus or potassium fertilizer. Certain agronomic and horticultural crops may benefit from fertilization at this level. Expected response to applied fertilizer is generally less than 10% of the time.
Very high	Soil test level may be approaching or at an excessive level. Generally, no additional fertilizer is to be recommended or applied. Continued application can result in a nutrient imbalance and may impact water quality. Continued application of phosphorus fertilizer can induce zinc deficiency, and continued application of potassium fertilizer can induce magnesium deficiency.

Table 3. Interpretation of Soil Test Ratings for Phosphorus and Potassium by Auburn University Extension.

Soil test ratings	Description
Very Low (VL)	Soil will yield less than 50% of its potential. Large applications for soil-building purposes usually are recommended. Some of the fertilizer should be placed in the drill for row crops.
Low (L)	Soil will yield 50% to 75% of its potential. Some fertilizer should be placed in the drill for row crops.
Medium (M)	Soil will yield 75% to 100% of its potential. Continued annual applications should be made in this range.
High (H)	Nutrient is adequate/optimum/sufficient for the crop, and none is recommended for field and forage crops. Where this recommendation is followed, the soil should be resampled each year.

Soil test ratings	Description
	considered adequate. Application of this nutrient is wasteful.
Extremely High (EH)	The nutrient is at least five times the amount considered High. The level is excessive and further additions may be detrimental to the crop and may contribute to pollution of ground and surface waters.

Adapted from "Nutrient Recommendations for Alabama Row Crops," by P. Paterson, 2020, Auburn University Extension, p. 4 (https://www.aces.edu/wp-content/uploads/2020/06/AlabamaRowCropsPDF_final.pdf).

The next step after soil test correlation is ***soil test calibration***. Soil test calibration is the process of establishing the nutrient requirements of a crop at different soil test values. While the second phase of soil test correlation establishes soil test ratings, **soil test calibration provides the actual nutrient recommendation**.

Single- Versus Multi-Nutrient Extractants

Single-nutrient extractants are those designed and well-suited for soil test analyses of one nutrient based on the specific characteristics of that element. For instance, available phosphorus can be extracted with a solution consisting of diluted hydrochloric acid (0.025 N) and ammonium fluoride (0.03 N), referred to as Bray-1. As another option, a solution of sodium bicarbonate (0.5 M) can be used for available phosphorus analyses—this is commonly referred to as the Olsen method. The Bray-1 method is well-suited for available phosphorus analyses of acidic to neutral pH, whereas the Olsen method is suited for neutral to alkaline pH soils.

As single-nutrient extractants are well-suited for just one nutrient element, other extractants are required to analyze different nutrients. This makes the analyses of several nutrient elements cumbersome and costly. In contrast, ***multi-nutrient extractants*** are well-suited for the analyses of several nutrient elements. Mehlich-1 and Mehlich-3 extractants are typical examples of multi-nutrient extractants. The Mehlich-1 extractant is composed of hydrochloric and sulfuric acids (specifically, 0.05 M HCl and 0.0125 M H_2SO_4), whereas the Mehlich-3 extractant is composed of acetic acid, ammonium fluoride, nitric acid, ethylenediaminetetraacetic acid (EDTA), and ammonium nitrate (specifically, 0.2 M CH_3COOH, 0.015 M NH_4F, 0.013 M HNO_3, 0.001 M EDTA, and 0.25 M NH_4NO_3).

Mehlich-1 Versus Mehlich-3 Extractants

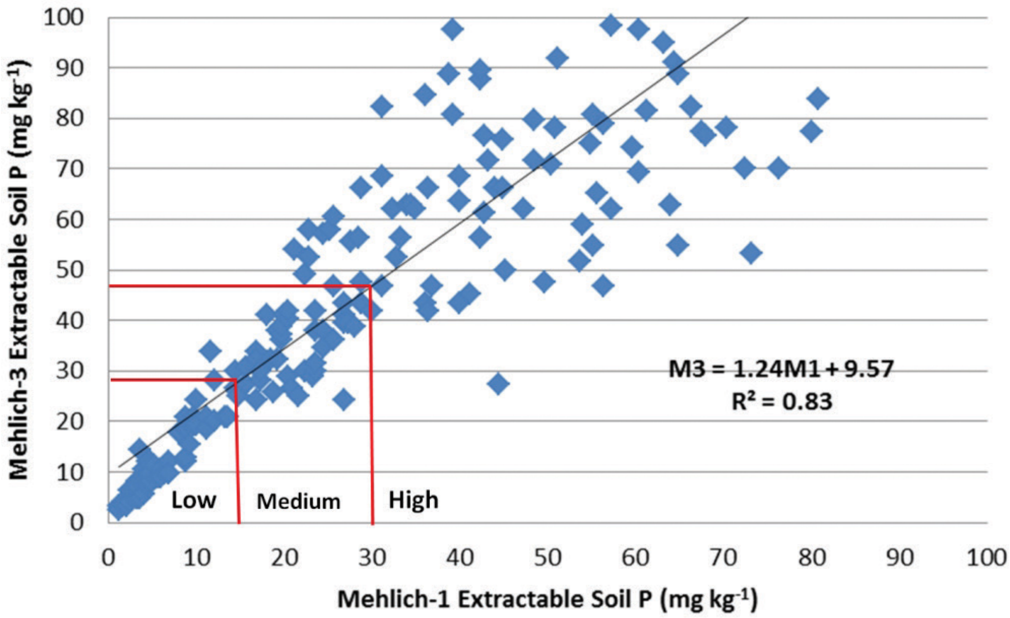
Previously, the Mehlich-1 extractant was considered ideal for soils low in organic matter and pH, and Mehlich-3 for soils high in organic matter and pH. The Mehlich-1 extractant is not ideal for high-pH soils because the two dilute acids are neutralized during the extraction process.

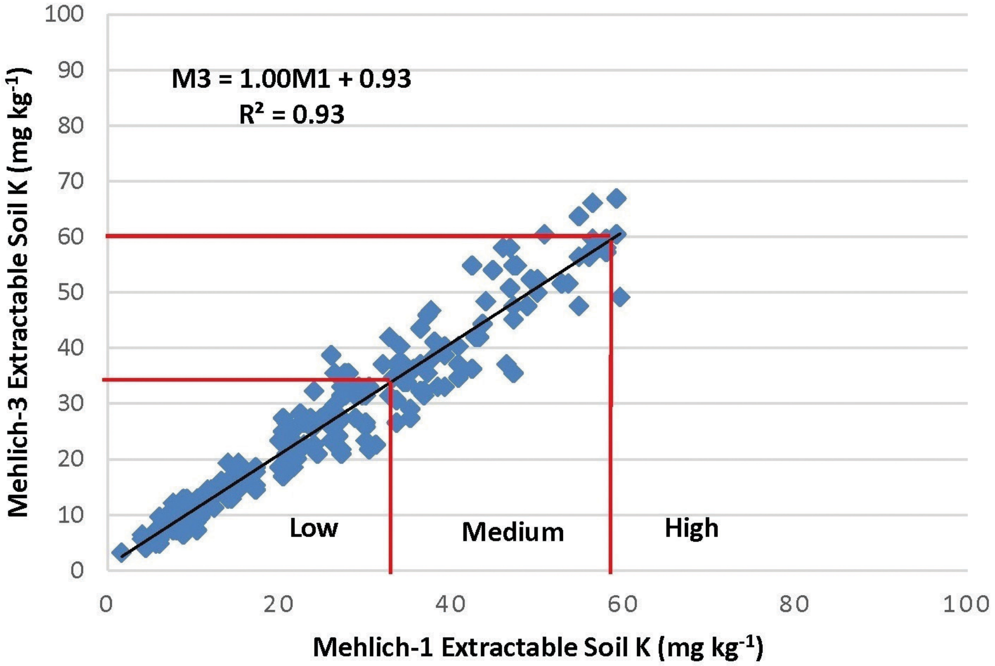
The EDTA present in Mehlich-3 reportedly helps to enhance the extraction of micronutrients. Thus, some state Extension laboratory services in the southern U.S. have switched to using the

Mehlich-3 extractant, but Mehlich-1 is UGA Extension's recommended soil test extractant. It is used for routine analyses of available phosphorus, potassium, magnesium, calcium, zinc, and manganese for nutrient guidelines of several row crops and forages.

For most soils, the concentration of extracted nutrients by Mehlich-3 tends to be higher than those extracted by Mehlich-1, especially cations. Remember, however, that the amount of nutrients extracted by a particular soil test extractant is not as important as its **ability to provide a reliable index of nutrient availability**, which is generated through a series of soil test correlation and calibration experiments across multiple locations and over several years. The process is quite tedious, time-consuming, and costly.

Extensive effort was put into establishing soil test indices and nutrient recommendations for Mehlich-1, with periodic updates. However, similar efforts have not been invested in developing soil test indices and nutrient recommendations for Mehlich-3 in Georgia. Some analytical laboratories rely on the correlation between Mehlich-1 and Mehlich-3 to develop conversion equations. Figure 4 shows the correlations and conversion equations between Mehlich-1 and Melich-3 for soil test indices of phosphorus, potassium, and magnesium.





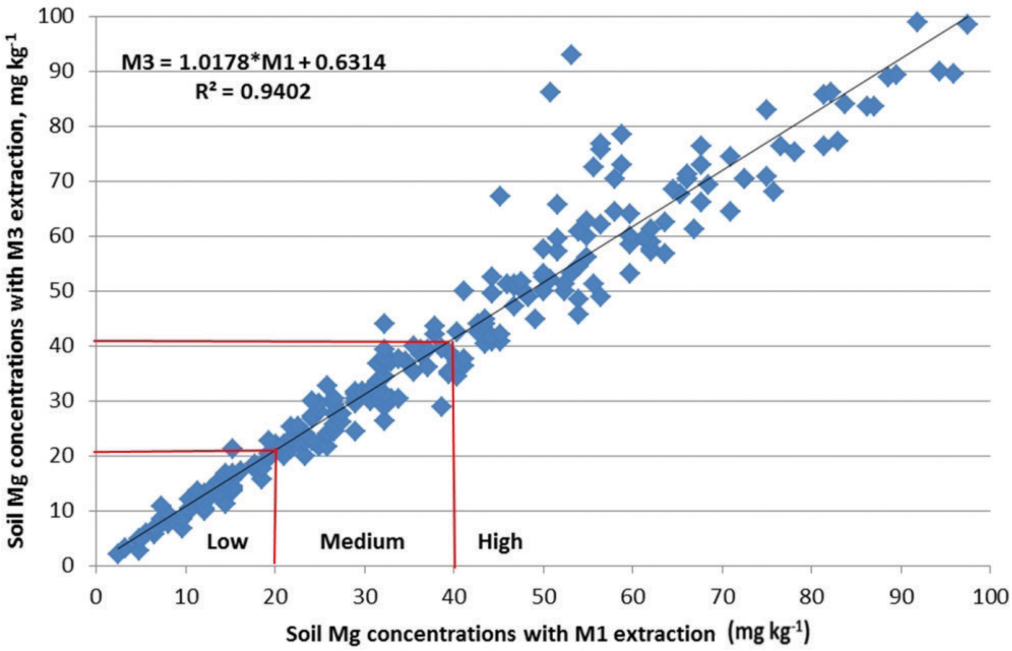


Figure 4. Correlations Between Mehlich-1 and Mehlich-3 for Soil Test Indices of Phosphorus (P), Potassium (K), and Magnesium (Mg). The correlation was based on the analyses of 280 soil samples from different soil series in Florida. A coefficient of correlation (R^2) of 1 indicates a perfect correlation, 0 indicates no correlation, and -1 indicates a perfect inverse correlation (as one measure increases, the other decreases). From "Extraction of Soil Nutrients Using Mehlich-3 Reagent for Acid-Mineral Soils of Florida," by R. Mylavarapu, T. Obreza, K. Morgan, G. Hochmuth, V. Nair, and A. Wright, 2023, University of Florida IFAS Extension, pp. 4–5 (https://edis.ifas.ufl.edu/publication/SS620).

The correlations between Mehlich-1 and Mehlich-3 extracted nutrients are not perfect, with the correlation for phosphorus being relatively lower compared to that derived for potassium and magnesium. This highlights the differences between the two methods.

A grower **should not** use soil test indices and nutrient recommendations for Mehlich-1 if the soil samples were analyzed using the Mehlich-3 extractant. Doing so may result in the undersupply of nutrients and potentially reduce yields and net revenue.

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