UF IFAS Extension UNIVERSITY of FLORIDA

UF/IFAS PEER REVIEWED SL545
doi.org/10.32473/EDIS-SS761-2026

Iron Oxide Strip as an Innovative Diagnostic Tool for Soil Phosphorus Management[1]

Lilit Vardanyan and Vimala D. Nair[2]

This publication is part of the ***Soil Phosphorus Storage Capacity (SPSC) for Phosphorus Risk Assessment and Management*** series. The series targets soil scientists, environmental consultants, state agency personnel, UF/IFAS Extension faculty, and others interested in improving phosphorus (P) management in agricultural and environmental contexts. This publication introduces the innovative iron oxide strip (FeO-P) method and presents new site-specific approaches for assessing plant-available phosphorus and environmental risk, thus supporting more accurate fertilizer recommendations and sustainable nutrient management across diverse soil types.

Summary

Purpose: Phosphorus (P) management in agroecosystems relies on soil test methods that may not always accurately estimate plant-available P. Inaccurate soil test results lead to inefficient fertilizer use and an increased risk of environmental P loss. This study evaluates the iron oxide strip-P (FeO-P) technique as an alternative P extraction method. The iron oxide strip method is more reliable than conventional Mehlich extraction methods since it can extract plant-available P across diverse soil conditions.

Methods: Laboratory and field evaluations were conducted across major Florida soil orders (Alfisols, Entisols, Spodosols, and Ultisols) and multiple cropping systems using a dataset of over 1,000 soil samples. The FeO-P values were compared with traditional Mehlich 1-P (M1-P) and Mehlich 3-P (M3-P) extractions for their ability to predict crop yield.

Results: The strength and consistency of the relationships between FeO-P and traditional soil P tests differed among locations and soil orders.

Implications: The FeO-P threshold of 21 mg P kg^{-1} effectively distinguishes soils requiring P fertilization from those where P could be withheld without yield loss. Integration of FeO-P with the Soil P Storage Capacity (SPSC) index further improves an environmental risk assessment by identifying soils vulnerable to P loss. These findings demonstrate that the FeO-P method offers a more reliable, site-specific approach for guiding agronomic P recommendations while supporting environmental protection goals.

Introduction

Challenges in Phosphorus Management

Phosphorus management remains one of the toughest issues that farmers face today. While phosphorus is essential for healthy crops, excessive fertilizer application has contributed to environmental degradation. When too much fertilizer is applied, it does not just stay in the field. Through runoff and leaching into waterways, P fuels algal blooms and accelerates eutrophication, harming water quality and aquatic life.

Limitations of Traditional Soil Tests

Traditionally, M1-P and M3-P have been widely used to guide fertilizer recommendations in Florida and many other regions. The problem is that these methods do not always give an accurate picture of how much P is actually available to plants, especially in soils with diverse mineralogy or strong P sorption capacity. This inaccuracy can result in suboptimal P fertilization, leading to either underapplied P, which limits crop yields, or overapplied P, which increases the risk of environmental contamination.

The FeO-P Technique

Unlike M1-P and M3-P, which rely on chemical extractants that may mobilize both labile (plant available) and non-labile (plant unavailable) forms of P, FeO-P focuses specifically on the P fraction that plants can actually take up. As a result, the FeO-P method offers a more reliable indicator of P availability, particularly in soils where traditional extractions fail to capture the dynamics of plant-soil interactions. By mimicking the absorptive activities of plant roots, FeO-P links the gap between soil testing protocols and actual crop nutrient demand. Therefore, FeO-P provides an improved diagnostic tool for both agronomic and environmental applications.

The FeO-P technique, first described by Sissingh (1983) and then modified by Sharpley (1991), measures bioavailable P in soil by using FeO-coated filter paper. This paper mimics a plant root and acts as an "infinite sink" for labile P. It offers consistent performance across a wide range of soil types, including both calcareous and non-calcareous. This makes FeO-P suitable for highly diverse Florida soils, where traditional methods fail to accurately predict soil P levels (Nair et al. 2026). By adsorbing the bioavailable and weakly bound P ions that plants access (i.e., binding P to the strip surface), the FeO-P strips measure the amount of P that more closely estimates the bioavailable fraction.

Advantages of FeO-P Extraction over Traditional Soil Tests

Compared with other soil P tests, including Florida's currently recommended M3 extraction, the FeO-P approach provides several advantages:

- Minimizes overestimation of available P by excluding non-labile pools that are chemically extractable but unavailable for plant uptake.
- Aligns closely with plant nutrient acquisition.
- Serves as a quantitative indicator both for agronomic P recommendations and for assessing potential environmental P losses.

A disadvantage of this technique is that it does not allow the determination of other nutrients and micronutrients, unlike the M1 and M3 procedures.

How Is FeO-P Determined?

FeO-impregnated filter paper acts as a strong P sink by attracting phosphate from the soil solution through electrostatic and ligand-exchange reactions (Figure 1). Phosphate binds to FeO(OH) surfaces, forming stable Fe-P complexes during shaking in 0.01 M $CaCl_2$.This process selectively extracts labile phosphorus from soil into the FeO-P phase. Later, the P is extracted from the FeO-P by treating it with 0.1 M H_2SO_4. See Appendix 1 for an overview of the laboratory procedure.

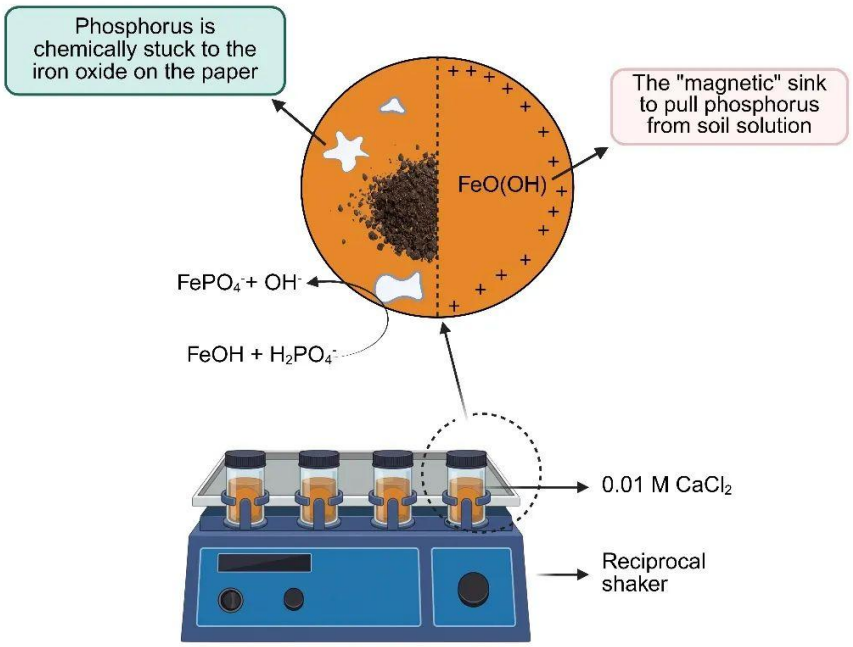

Figure 1. Iron oxide impregnated filter paper (FeO-P) test illustrating how an FeO(OH) (iron oxyhydroxide) coated paper strip acts as a sink for phosphate, removing plant-available P from a soil 0.01 M $CaCl_2$ suspension during shaking by sorbing (i.e., adhering) H_2PO_4- onto the FeO(OH) coating of the filter paper.
Credit: Created in BioRender by D. Phuyal, https://biorender.com/zevjgkp.

Has the FeO-P Procedure Been Tested for Florida Soils?

Assessing the FeO-P Procedure for P Availability in Florida's Major Soil Orders

To evaluate its applicability in Florida, the FeO-P procedure was tested across three major soil orders representative of the state's agricultural landscapes: Entisols, Spodosols, and Ultisols. Field trials were conducted at satellite UF/IFAS facilities, located in the north central peninsula in Gainesville (Beef Research Unit [BRU]), central peninsula in Citra (Plant Science Research and Education Unit [PSREU]), and northwest panhandle in Marianna and Quincy (North Florida Research and Education Center [NFREC]). At each location, composite surface samples (0–15 cm depth) were collected during silage corn (*Zea mays* L.) harvest by combining three soil samples from each plot to create a representative sample. The following near-identical treatments were replicated six times at each study site: i) N fertilizer applied according to UF/IFAS recommendations with other nutrients, including P, corresponding to crop needs; or ii) N and other nutrients as previously described but excluding P. Preliminary results indicated that silage corn yield was positively correlated with FeO-P values across the two-year continuous cropping cycle of rye (*Secale cereale* L.), corn, and sorghum (*Sorghum bicolor* L.). Notably, differences in FeO-P were most pronounced at NFREC (Ultisols), where higher values corresponded with greater yield responses despite identical fertilizer treatments (Rodriguez et al. 2025).

FeO-P Procedure Validation in Florida: Multi-Location and Multi-Crop Assessment

This research was made possible through the support of the Florida Legislature, which has provided annual funding to UF/IFAS since 2021 to study optimal fertilizer application rates and management strategies for various crops. As part of this initiative, the co-principal investigators and other collaborators collected over 1,000 surface soil samples (0–15 cm depth) from 11 agricultural locations across the following Florida regions: north Florida (NF), central Florida (CFL), south Florida (SFL), and southwest Florida (SWFL). Several crops are grown at these locations, such as tomato, potato, green bean, corn, artichoke, and citrus. The FeO-P was plotted against M1-P (Figure 2) and M3-P (Figure 3).

What Is the Relationship Between FeO-P and Traditional Soil Tests for Florida?

Figure 2 illustrates the relationship between M1-P and FeO-P across a large, statewide dataset representing diverse soil types and cropping systems. The linear relationship between M1-P and FeO-P is site-specific and valid only at lower M1-P values. The FeO-P value corresponding to the UF/IFAS-recommended critical M1-P threshold of 30 mg P kg^{-1} is 21 mg P kg^{-1}, supporting FeO-P as a biologically meaningful indicator of plant-available P (Nair et al. 2026).

The relationship between M3-P and FeO-P across multiple locations and soil orders in Florida shows that M3-P values increase with FeO-P (Figure 3). Highly scattered data were observed, especially at higher M3-P concentrations. This non-linear relationship indicates that M3-P may include both plant-available and non-labile P fractions. Notably, some soils exhibit high M3-P levels (up to 150 mg kg^{-1}) but FeO-P values below the threshold of 21 mg P kg^{-1} (Figure 2), suggesting that plants may still respond to P fertilization despite elevated M3-P concentration. Other locations have soils with values >20 mg kg^{-1} but low M3-P concentrations. These soils are likely to get P from the subsurface or via continuous P release from weak P associations if satisfactory yields are obtained.

Several studies have identified FeO-P levels below 21 mg P kg^{-1} as the threshold for plant-available P (Sims et al. 2002; Rodriguez et al. 2025; Nair et al. 2026). Therefore, thresholds above 21 mg P kg^{-1} could lead to P loss from the soil. These results highlight the limitations of relying solely on M3-P and reinforce the need to calibrate conventional soil tests against FeO-P to improve both agronomic recommendations and environmental risk assessments.

Figures 2 and 3 demonstrate that the strength and consistency of the relationships between FeO-P and traditional soil P tests vary widely across locations and soil orders. While both M1-P and M3-P show general positive associations with FeO-P, the increasing scatter at higher values suggests that these extractants often capture non-labile P pools that are not directly relevant to plant uptake. This is quantitatively confirmed in Table 1, which presents correlation coefficients among FeO-P, M1-P, and M3-P across major Florida soil orders. The table reveals strong correlations in Alfisols and Spodosols but weaker, more variable relationships in Entisols and Ultisols. This reinforces the conclusion that soil mineralogy and P sorption capacity strongly influence the reliability of conventional soil tests. FeO-P is a more robust and site-sensitive diagnostic tool for phosphorus management than either M1-P or M3-P alone.

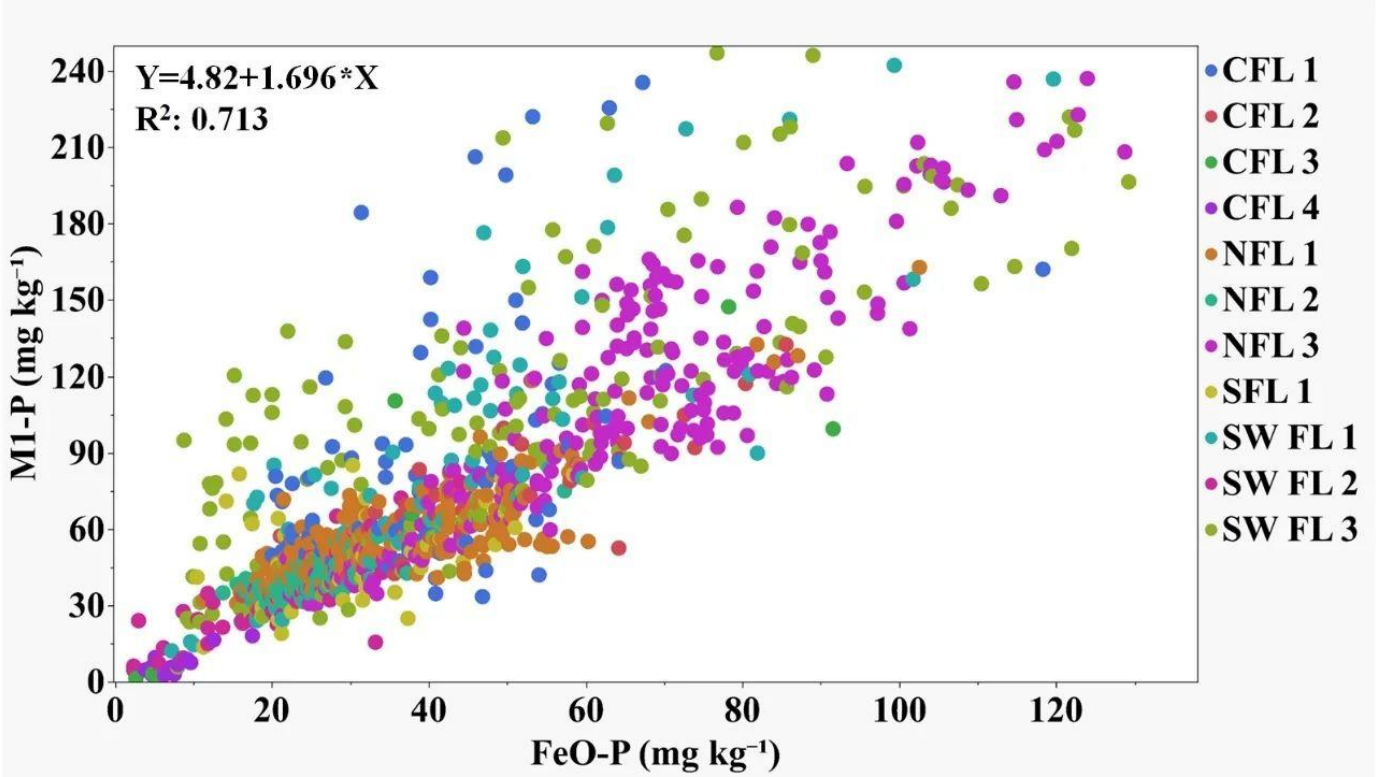

Figure 2. Relationships between M1-P (mg kg^{-1}) and FeO-P (mg kg^{-1}). Samples represent 11 locations across the following Florida regions: central Florida (CFL1=78, CFL2=32, CFL3=7, CFL4=16); north Florida (NFL1=238, NFL2=125, NFL3=212); south Florida (SFL=39); and southwest Florida (SWFL1=65, SWFL2=40, SWFL3=144). (See the data tables in Appendix 2 for alternative viewing.)

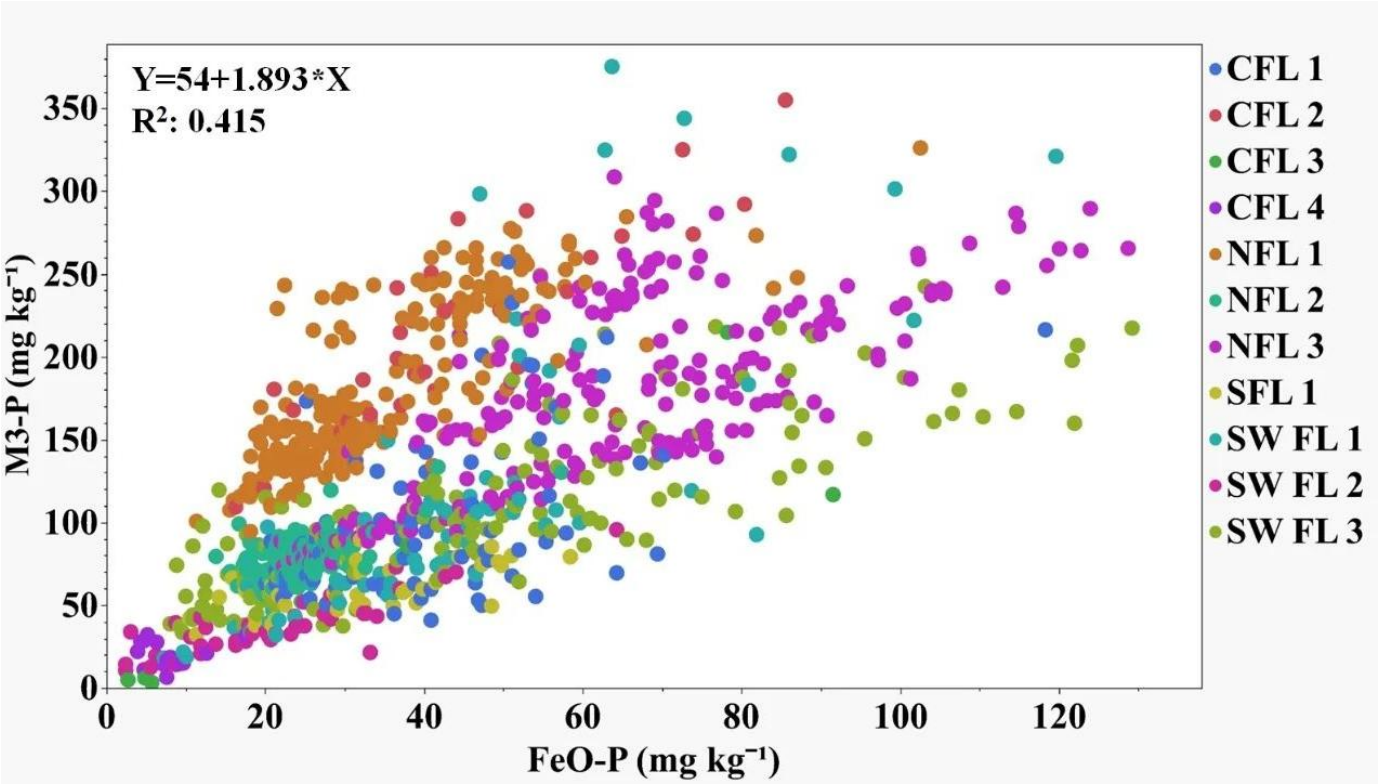

Figure 3. Relationships between M3-P (mg kg^{-1}) and FeO-P (mg kg^{-1}). Samples represent 11 locations across the following Florida regions: central Florida (CFL1=78, CFL2=32, CFL3=7, CFL4=16); north Florida (NFL1=238, NFL2=125, NFL3=212); south Florida (SFL=39); and southwest Florida (SWFL1=65, SWFL2=40, SWFL3=144). (See the data tables in Appendix 2 for alternative viewing.)

Table 1. Correlation coefficients (r) among FeO-P, M1-P, and M3-P across major Florida soil orders: Alfisols, Entisols, Spodosols, and Ultisols. P<0.001 for all the correlation analyses.

		FeO-P (mg kg^{-1})	M3-P (mg kg^{-1})	M1-P (mg kg^{-1})
Alfisols (N=337)	FeO-P (mg kg^{-1})	1.00	0.91	0.94
	M3-P (mg kg^{-1})	0.91	1.00	0.97
	M1-P (mg kg^{-1})	0.94	0.97	1.00
Entisols (N=85)	FeO-P (mg kg^{-1})	1.00	0.58	0.56
	M3-P (mg kg^{-1})	0.58	1.00	0.65
	M1-P (mg kg^{-1})	0.56	0.65	1.00
Spodosols (N=302)	FeO-P (mg kg^{-1})	1.00	0.79	0.83
	M3-P (mg kg^{-1})	0.79	1.00	0.92
	M1-P (mg kg^{-1})	0.83	0.92	1.00
Ultisols (N=270)	FeO-P (mg kg^{-1})	1.00	0.79	0.84
	M3-P (mg kg^{-1})	0.79	1.00	0.68
	M1-P (mg kg^{-1})	0.84	0.68	1.00

These results are general observations derived from surface soil samples and simple linear regressions across a wide range of P concentrations. Typically, the relationships are stronger at lower P concentrations, where soil P is more closely associated with Fe and Aluminum (Al) in acid-mineral soils. At higher P concentrations, however, P may originate from anthropogenic sources, leading to greater variability among locations within the same soil order (Nair et al. 2026).

What Are the Implications of Using Mehlich 3-P as a Soil Test?

Current UF/IFAS recommendations define M3-P values with a low P threshold of 27 mg kg^{-1} and a high threshold of 47 mg kg^{-1} (Mylavarapu et al. 2014). However, these thresholds have posed challenges for many landowners, with several reporting reduced yields when P is applied at the maximum recommended level of 47 mg kg^{-1}. This issue may stem from the nature of M3-P analysis, which is typically conducted using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) at most soil testing laboratories. The resulting measurement includes all forms of P extracted by M3, not just the bioavailable fraction that plants can utilize.

Can M3-P Be Used as a Soil Test for Phosphorus?

M3-P can be a useful soil test if it is calibrated against FeO-P, which specifically measures plant-available P. This calibration should be conducted on a locational basis as it is likely influenced by the soil order prior to the break point under site-specific conditions. After the break point, the proportion of M3-P representing plant-available P may vary due to anthropogenic (human) influences and soil components other than Fe and Al. Once properly calibrated, M3-P values can be accurately interpreted for that location. However, this approach may be less reliable in soils with underlying calcareous materials or in muck soils, where the calibration may not hold.

Can We Use FeO-P as an Indicator of Environmental Phosphorus Loss?

The Soil P Storage Capacity (SPSC) Concept

The SPSC concept, introduced by Nair and Harris (2004) and detailed in the Ask IFAS publication SL336, is a quantitative measure used to estimate the amount of additional P a soil can absorb before reaching a threshold. The SPSC index is derived from the P Saturation Ratio (PSR) and indicates a soil's capacity to retain P. Negative SPSC values suggest a heightened risk of P loss (Nair 2014). The surface soil across Florida has a threshold PSR of 0.10, with a 95% confidence interval of 0.05–0.15. PSR marks the point where soil changes from being a "P sink" to a "P source" (Dari et al. 2018).

Integrating SPSC and FeO-P for Fertilizer Recommendations and Environmental Protection

The relationship between FeO-P (an agronomic indicator) and SPSC (an environmental risk indicator) was evaluated in soils from 11 locations in Florida (Figure 4).

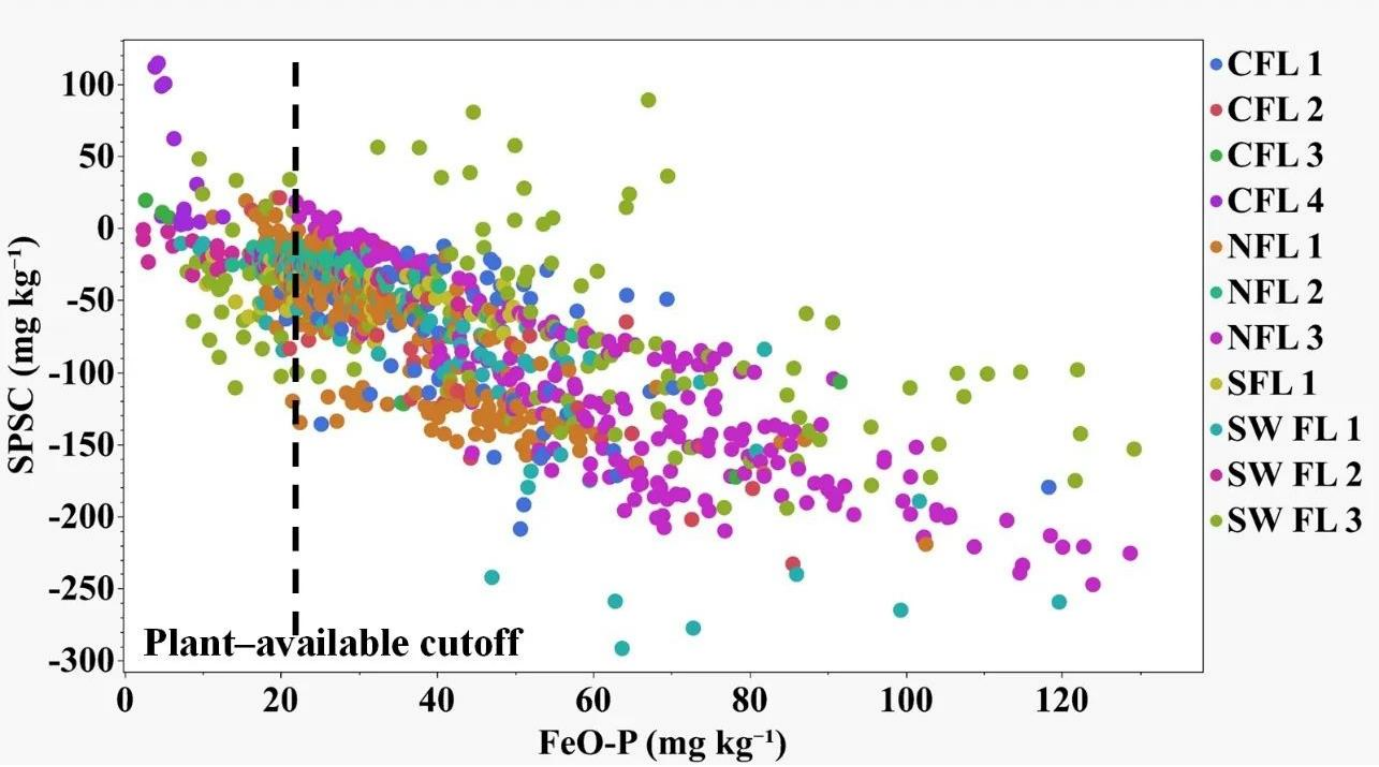

Figure 4. Relationship between FeO-P (mg kg^{-1}) and SPSC (mg kg^{-1}) across Florida soils. Samples represent 11 locations across the following Florida regions: central Florida (CFL1=78, CFL2=32, CFL3=7, CFL4=16); north Florida (NFL1=238, NFL2=125, NFL3=212); south Florida (SFL=39); and southwest Florida (SWFL1=65, SWFL2=40, SWFL3=144). (See the data tables in Appendix 2 for alternative viewing.)

When SPSC is positive (PSR of the soil is below the threshold), the soil is a P sink; when SPSC is negative (PSR of the soil is above the threshold), the soil becomes a P source. A negative SPSC indicates a soil is at risk of P loss, while a positive value suggests that the soil can still retain additional P.

Detailed location-specific descriptive statistics, including sample numbers, mean, minimum, maximum, and standard error values for FeO-P, M1-P, M3-P, and SPSC, are presented in Appendix 2, Tables 2–5.

Implications for Fertilizer Management

Soils from SWFL3 exhibit insufficient plant-available P, with FeO-P values falling below the critical threshold of 21 mg P kg^{-1} and SPSC values slightly below -100 mg kg^{-1}. These indicators suggest that P fertilization will be necessary to achieve optimal crop yields. In contrast, soils from SWFL1 show adequate levels of bioavailable P and negative SPSC values, indicating that P can be mined from the soil without additional fertilization, as supported by findings from Nair et al. (2020). This study establishes a framework for integrating FeO-P and SPSC metrics into fertilizer recommendations that balance agronomic needs with environmental protection. The next step is to validate that crop yields remain unaffected in these soils when P fertilization is withheld and FeO-P is above the plant-available threshold. The threshold of 21 mg kg^{-1} for FeO-P was established across multiple soil orders and cropping systems. As demonstrated by Nair et al. (2026), the relationship between bioavailable P and crop yield can be developed for a specific location. Additionally, the absolute negative SPSC required at a given site to sustain yield should be incorporated into yield predictions.

Conclusion

The FeO-P technique provides a more reliable and site-specific assessment of plant-available P than traditional M1 and M3 soil tests. This test is particularly helpful in Florida soils with high P sorption capacity or variable mineralogy. Field and laboratory evaluations across multiple soil orders and crops demonstrated strong relationships between FeO-P and crop yield responses, with a critical threshold near 21 mg P kg^{-1}. This provides a "safe threshold value" for farmers to apply P fertilizer.

Integration of FeO-P with the SPSC index provides a comprehensive framework for balancing agronomic productivity with environmental protection. This addresses crop nutrient needs and P-loss risk. Future research should focus on expanding calibration across additional soil orders and cropping systems, validating long-term yield responses, and refining site-specific fertilizer recommendations to support sustainable P management statewide.

Acknowledgment

The authors would like to acknowledge the support of the Florida Department of Agriculture and Consumer Services (FDACS, Award ID: AWD17077) and thank Michael Dukes for his leadership as principal investigator of the UF/IFAS Fertilizer Rate and Nutrient Management Studies. Special thanks are extended to the following project managers and collaborators for generously providing soil samples for this study: Shinsuke Agehara, Jay Capasso, Evelyn Fletcher, Davie Kadyampakeni, Kelly Morgan, Sanjay Shukla, and Lincoln Zotarelli. The assistance of Aaron Portmess and Johnathan Ballou with laboratory analyses is also gratefully acknowledged.

References

Dari, B., V. D. Nair, A. Sharpley, P. Kleinman, D. Franklin, and W. Harris. 2018. "Consistency of the Threshold Phosphorus Saturation Ratio Across a Wide Geographic Range of Acid Soils." *Agrosystems, Geosciences & Environment* 1 (1): 1–8. https://doi.org/10.2134/age2018.08.0028

Murphy, J., and J. P. Riley. 1962. "A Modified Single Solution Method for the Determination of Phosphate in Natural Waters." *Analytica Chimica Acta* 27: 31–36. https://doi.org/10.1016/S0003-2670(00)88444-5

Mylavarapu, R., T. Obreza, K. Morgan, G. Hochmuth, V. Nair, and A. Wright. 2014. "Extraction of Soil Nutrients Using Mehlich-3 Reagent for Acid-Mineral Soils of Florida: SL407/SS62, 5/2014." *EDIS* 2014 (7). https://doi.org/10.32473/edis-ss620-2014

Nair, V. D. 2014. "Soil Phosphorus Saturation Ratio for Risk Assessment in Land Use Systems [Mini Review]." *Frontiers in Environmental Science* 2. https://doi.org/10.3389/fenvs.2014.00006

Nair, V. D., and W. G. Harris. 2004. "A Capacity Factor as an Alternative to Soil Test Phosphorus in Phosphorus Risk Assessment." *New Zealand Journal of Agricultural Research* 47 (4): 491–497. https:/doi.org/10.1080/00288233.2004.9513616

Nair, V. D., D. Phuyal, and L. Vardanyan. 2026. "Bioavailable Phosphorus Across Florida's Diverse Soil Orders: Implications for Crop Productivity and Environmental Protection." *Frontiers in Environmental Science* 14. https://doi.org/10.3389/fenvs.2026.1748291

Nair, V. D., L. E. Sollenberger, W. G. Harris, et al. 2020. "Mining of Soil Legacy Phosphorus Without Jeopardizing Crop Yield." *Agrosystems, Geosciences & Environment* 3 (1): e20056. https://doi.org/10.1002/agg2.20056

Rodriguez, A. N., V. D. Nair, A. M. Freitas, G. Maltais-Landry, and L. E. Sollenberger. 2025. "Site-Specific Mehlich 3-P Recommendations for Florida's Sandy Soils." *Communications in Soil Science and Plant Analysis* 56 (6): 841–855. https://doi.org/10.1080/00103624.2024.2433151

Sharpley, A. N. 1991. "Soil Phosphorus Extracted by Iron-Aluminum-Oxide-Impregnated Filter Paper." *Soil Science Society of America Journal* 55 (4): 1038–1041. https:/doi.org/10.2136/sssaj1991.03615995005500040025x

Sims, J. T., R. O. Maguire, A. B. Leytem, K. L. Gartley, and M. C. Pautler. 2002. "Evaluation of Mehlich 3 as an Agri-Environmental Soil Phosphorus Test for the Mid-Atlantic United States of America." *Soil Science Society of America Journal* 66 (6): 2016–2032. https://doi.org/10.2136/sssaj2002.2016

Sissingh, H. 1983. "Estimation of Plant-Available Phosphates in Tropical Soils. A New Analytical Technique." Report No. 235. The Institute for Soil Fertility Research.

Appendix 1. An Overview of the Laboratory Procedure to Determine Phosphorus by the FeO-P Method

The FeO-P method involves several laboratory steps, including preparing reagents, developing FeO-coated filter papers, extracting P from soil samples, and analyzing the extracted P using colorimetric techniques. Each step is critical to ensuring the test's reproducibility and accuracy. This methodological sensitivity depends on the integrity of the FeO coating and the consistency of soil-solution interactions during extraction.

Step 1: Preparation of Chemical Solutions

Multiple chemical solutions are required for the FeO-P procedure, including calcium chloride ($CaCl_2$) as a background electrolyte, sulfuric acid (H_2SO_4) for desorption, ferric chloride ($FeCl_3$) as the precursor for iron oxide coating, and ammonium hydroxide (NH_4OH) to precipitate hydrated iron oxides onto the filter surfaces.

0.01 M Calcium Chloride ($CaCl_2$) (2 L)

a. Fill a 2 L volumetric flask halfway with double deionized water (DDI).
b. Measure 2.94 g $CaCl_2$ into a plastic weigh boat quickly.
c. Thoroughly rinse all the $CaCl_2$ from the weigh boat into the flask and bring to volume.
d. Cover with parafilm and invert the volumetric flask prior to use.

0.1 M Sulfuric Acid (H_2SO_4) (2 L)

a. In a fume hood, fill a 2 L volumetric flask halfway with DDI.
b. Add 11.22 mL concentrated H_2SO_4 using a calibrated pipette.
c. Bring up to 2 L with DDI.

0.65 M Ferric Chloride ($FeCl_3$) (0.5 L)

a. Grind $FeCl_3$ hexahydrate into a fine powder using a mortar and pestle.
b. Weigh 87.8475 g into a 250 mL beaker using a ceramic scoop, add DDI, and mix with a glass stir rod.
c. Wedge the glass stir rod against the neck of an empty 500 mL volumetric flask and slowly pour in the $FeCl_3$ solution.
d. The solid $FeCl_3$ will often take time to dissolve, so it is important to stir and progressively rinse the beaker with DDI.
e. Bring up to 500 mL with DDI, use parafilm to cover the top, invert, and transfer into a 1 L beaker.

2.7 M Ammonium Hydroxide (NH_4OH) (1.5 L)

a. In a fume hood, measure 278.7 mL of 25% NH_4OH in a graduated cylinder.
b. Fill a 1 L volumetric flask halfway with DDI.
c. Add NH_4OH, mix, and bring the volumetric flask to 1 L with DDI.
d. Transfer into a 2 L beaker containing an additional 500 mL DDI (1.5 L solution in total).

Step 2: Preparation of FeO-Coated Filter Strips (3 Days)

The coating procedure spans three days and requires careful handling to produce uniformly coated filters.

Day 1: Ferric Chloride Soaking

Vertically drop 100 Whatman no. 50 filters into a 1 L beaker of 0.65 M $FeCl_3$, one at a time. Cover to block all sunlight and soak for 16 hours to allow optimal deposition of ferric ions onto the filter matrix.

Day 2: Drying

Uncover the beaker, use a glass stir rod to hold the filters aside, and dispose of the $FeCl_3$ solution in a properly labeled waste container. Line two trays with paper towels and a fitted screen. Using clean plastic forceps, place 50 filters on each tray to dry overnight. Be sure that none of the filters are touching and that there is no excess $FeCl_3$ pooling on the top of the strips.

Day 3: Ammonium Hydroxide Treatment and Rinsing

Fill two 2 L beakers with DDI for rinsing. Line two trays with paper towels and a fitted screen. Using plastic forceps, dip each filter vertically into the earlier prepared 2.7 M NH_4OH solution, submerge briefly, remove, and tap off excess solution. Rinse each filter in both DDI beakers for 5 seconds, agitating back and forth, and tap off excess DDI. Place 50 filters on each tray to dry overnight, then store them in a paper bag at room temperature in a dark spot.

These subsequent drying and rinsing steps remove excess salts and promote the formation of amorphous FeO. On the third day, treatment with NH_4OH induces hydrolysis of ferric ions, producing iron oxyhydroxide coatings that give the strips their strong sorption capacity.

Step 3: Extraction of P from Soil (Two Days)

The soil extraction phase involves incubating an FeO-coated filter strip while in contact with a suspension of soil and 0.01 M $CaCl_2$. A 16-hour shaking period ensures sufficient equilibration between the soil solution and the FeO surface, allowing labile P species to diffuse and adsorb onto the strip.

Day 1: Soil Incubation

a. Weigh 1 ± 0.002 g of air-dried, 2 mm sieved soil into a 100 mL glass jar.
b. Clip one dry FeO-coated filter between two fitted fiberglass mesh squares using four plastic clips.
c. Add the clipped filter to the jar with soil.
d. Add 80 mL 0.01 M $CaCl_2$, cap the jar, and shake on an orbital shaker at 265 RPM for 16 hours.
e. Set up trays with labeled paper towels and screens for Day 2.
f. Quality Control: For each set (20 samples), include one duplicate sample, one reference soil, and one blank.

Day 2: Desorption and Analyses

a. Remove jars from the shaker, maintaining their original sample order.
b. Remove the filter/mesh, detach the mesh from the filter, and rinse the filter under a slow stream of DDI using plastic tongs.
c. Dry filters on labeled trays for three to four hours.
d. Place each filter in a labeled 125 mL Erlenmeyer flask with 50 mL 0.1 M H_2SO_4, cover with parafilm, and shake at 265 RPM for one hour (start at 150 RPM to prevent sticking and progressively increase the RPM to 265). This acid treatment releases the bound P into solution, where it can be quantified.
e. Pour 20 mL of the solution into a labeled scintillation vial; dispose of excess in a labeled waste container.
f. Use a small, hooked spatula to retrieve and dispose of the filter.
g. To quantify P desorbed (removed) from the FeO strips, use the Murphy and Riley (1962) colorimetric method with minor modifications to optimize sensitivity (replacing half of the 5 M H_2SO_4 in the mixed reagent with DDI) and analyze after 10 minutes.

The FeO-extractable P is expressed as mg P kg^{-1} soil and can be calculated as follows:

$$FeO - P = \frac{C * V}{W}$$

Equation 1.

where:

C = P concentration in the extract (mg L^{-1})

V = volume of the extract (L)

W = weight of soil used (kg)

Appendix 2.

Table 2. Descriptive statistics (including sample numbers [n], mean, minimum, maximum, and standard error [SE]) of FeO-P concentrations (mg kg^{-1}) measured from 11 sampling locations across the following Florida regions: central Florida (CFL1=78, CFL2=32, CFL3=7, CFL4=16); north Florida (NFL1=238, NFL2=125, NFL3=212); south Florida (SFL=39); and southwest Florida (SWFL1=65, SWFL2=40, SWFL3=144).

Location	n	Mean FeO-P	Min	Max	SE
CFL1	78	41.0	20.1	118.3	1.8
CFL2	32	45.0	16.3	85.6	3.1
CFL3	7	36.7	2.7	91.6	13.7
CFL4	16	7.7	3.9	17.5	0.9
NFL1	238	34.5	11.3	102.6	0.9
NFL2	125	24.8	13.8	57.3	0.5
NFL3	212	64.0	21.9	128.7	1.6
SFL1	39	31.6	10.5	58.4	2.0
SWFL1	65	44.0	7.2	119.6	2.8
SWFL2	40	21.5	2.4	64.3	2.0
SWFL3	144	49.9	8.0	129.2	2.4

Table 3. Descriptive statistics (including sample numbers [n], mean, minimum, maximum, and standard error [SE]) of M1-P concentrations (mg kg^{-1}) measured from 11 sampling locations across the following Florida regions: central Florida (CFL1=78, CFL2=32, CFL3=7, CFL4=16); north Florida (NFL1=238, NFL2=125, NFL3=212); south Florida (SFL=39); and southwest Florida (SWFL1=65, SWFL2=40, SWFL3=144).

Location	n	Mean M1-P	Min	Max	SE
CFL1	78	88.6	33.4	235.5	5.3
CFL2	32	70.9	33.8	132.5	4.2
CFL3	7	61.4	1.3	147.4	22.8
CFL4	16	6.9	2.8	18.1	1.1
NFL1	238	55.9	28.8	162.8	1.2
NFL2	125	40.1	28.9	75.0	0.7
NFL3	212	110.2	30.3	237.1	3.4
SFL1	39	49.4	13.7	85.1	3.1
SWFL1	65	94.0	12.1	242.2	6.7
SWFL2	40	34.3	4.6	87.4	3.2
SWFL3	144	105.8	5.8	247.1	4.6

Table 4. Descriptive statistics (including sample numbers [n], mean, minimum, maximum, and standard error [SE]) of M3-P concentrations (mg kg^{-1}) measured from 11 sampling locations across the following Florida regions: central Florida (CFL1=78, CFL2=32, CFL3=7, CFL4=16); north Florida (NFL1=238, NFL2=125, NFL3=212); south Florida (SFL=39); and southwest Florida (SWFL1=65, SWFL2=40, SWFL3=144).

Locations	n	Mean M3-P	Min	Max	SE
CFL1	78	100.7	41.0	257.3	5.7
CFL2	32	215.8	109.3	355.0	10.3
CFL3	7	83.7	3.3	214.8	31.6
CFL4	16	20.0	6.5	32.2	1.9
NFL1	238	179.5	94.5	326.1	3.1
NFL2	125	79.7	56.8	133.4	1.2
NFL3	212	177.0	73.7	308.6	4.0
SFL1	39	59.8	32.2	89.4	2.4
SWFL1	65	118.1	18.1	375.3	10.8
SWFL2	40	37.6	10.5	95.6	2.8
SWFL3	144	110.7	33.6	242.4	4.1

Table 5. Descriptive statistics (including sample numbers [n], mean, minimum, maximum, and standard error [SE]) of SPSC (mg kg^{-1}) measured from 11 sampling locations across the following Florida regions: central Florida (CFL1=78, CFL2=32, CFL3=7, CFL4=16); north Florida (NFL1=238, NFL2=125, NFL3=212); south Florida (SFL=39); and southwest Florida (SWFL1=65, SWFL2=40, SWFL3=144).

Locations	n	Mean SPSC	Min	Max	SE
CFL1	78	−70.0	−208.7	−12.4	5.4
CFL2	32	−97.4	−233.0	21.0	10.0
CFL3	7	−60.3	−172.7	19.3	28.7
CFL4	16	35.6	−16.1	114.6	11.3
NFL1	238	−71.0	−219.3	18.9	3.1
NFL2	125	−25.2	−75.3	−9.9	0.9
NFL3	212	−117.0	−247.3	18.4	4.4
SFL1	39	−46.3	−78.9	−18.8	2.5
SWFL1	65	−98.6	−291.5	−10.6	8.7
SWFL2	40	−27.6	−80.8	−1.1	2.5
SWFL3	144	−64.7	−194.3	88.8	4.9

[1] This document is SL545, one of a series of the Department of Horticultural Sciences, UF/IFAS Extension. Original publication date July 2026. Visit the Ask IFAS website at https://ask.ifas.ufl.edu/ for the currently supported version of this publication.

[2] Lilit Vardanyan, biological scientist III, UF/IFAS Department of Soil, Water, and Ecosystem Sciences, Gainesville, FL; Vimala D. Nair, research professor, environmental soil chemistry, UF/IFAS Department of Soil, Water, and Ecosystem Sciences, Gainesville, FL; UF/IFAS Extension, Gainesville, FL 32611.