

Predicting Phosphorus Retention in Two Volcanic-Derived Forest Soils of Northern California

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Abstract

Plant available phosphorus (P) occurs in anionic forms which are retained when iron and aluminum oxides form insoluble complexes. P-retention is likely to occur under acid conditions in soils containing short range order (SRO) materials, namely allophane and imogolite. This condition is common in volcanic-derived forest soils in Pacific Northwest timber regions. We investigated P-retention in Powellton (Fine-loamy, parasquic, mesic Andic Haplohumults) and Aiken (Fine, parasquic, mesic Xeric Haplohumults) soil series. Soil materials were used from the Whitmore and Feather Falls "Garden of Eden" experiments. Some soils received applications of N, P and K beginning in 1985; unfertilized soils were compared as a control. Results show that NaF pH and New Zealand P-retention (NZP) decreased with soil depth. The Aiken series showed higher NaF pH and NZP with depth compared to the Powellton series. This result is consistent with other studies showing that Powellton exhibits higher crystallinity, though parent materials are similar. Simple regression of NaF pH versus NZP shows correlation of 0.79. We also present results comparing the NaF field test versus NaF lab test, the former commonly used to identify andic soil properties.

Introduction

"Phosphorus retention" is the chemical sorption of P to mineral soil components, rendering it biologically inaccessible. Degree and permanence of P-retention is affected by pH, soil mineralogy and clay content¹. Results presented here will be used to develop a scalable method to inform timber managers in regions where volcanic soils are prevalent.

Main research questions:

- 1) Do Whitmore and Feather Falls sites differ in their P-status? Why?
- 2) Is the Soil x Treatment interaction significant? Put another way, does fertilization affect both soil types in the same way?
- 3) Is NaF pH an accurate predictor of P-retention?

Methods

This work builds on a larger body of research known as the "Garden of Eden" study². Two mineralogically contrasting, taxonomically similar soils (Table 1) have been well-studied; here, P-retention is explored for the first time (Method 4D8)³. Treatments of heavy fertilization over 25 years (effectively overcoming P-limitation) are compared with natural fertility. Two methods for NaF pH (a field method and a laboratory test, Method 4C1a)³ are investigated as potential parameters for modeling P-retention.

Study Area

	Whitmore Site	Feather Falls Site
Soil Series	Aiken	Powellton
Soil Classification	Fine, parasquic, mesic Xeric Haplohumults	Fine-loamy, parasquic, mesic Andic Haplohumults
Parent Material	Volcanic Mudflow	Tephra over Metadiorite
Elevation (m)	790	1220
Mean Annual Precipitation (mm)	1100	2000
Mean Annual Air Temp (°C)	15	11
Site Index 50 (m)	23	30
Mineralogy	Lower crystallinity More SRO & More Fe Less Felsic	Higher crystallinity Less SRO & More Al More Felsic

Table 1. Site descriptions

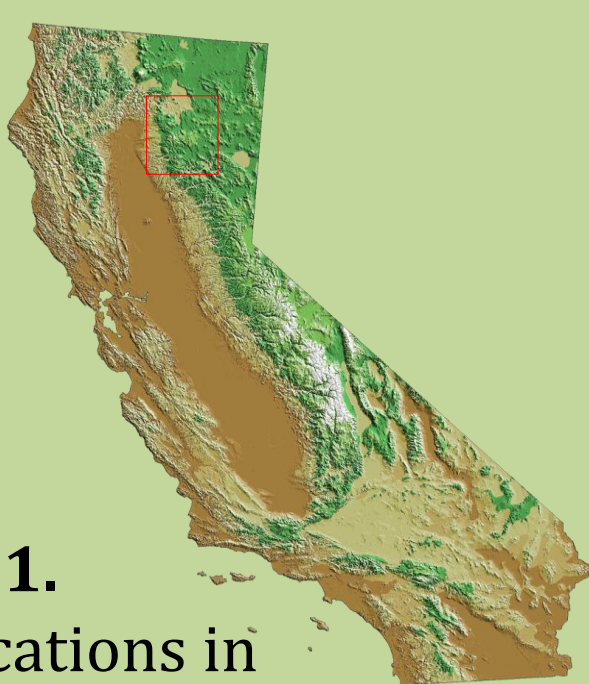


Figure 1. Site Locations in northern California, USA. Image source: ©OpenStreetMap

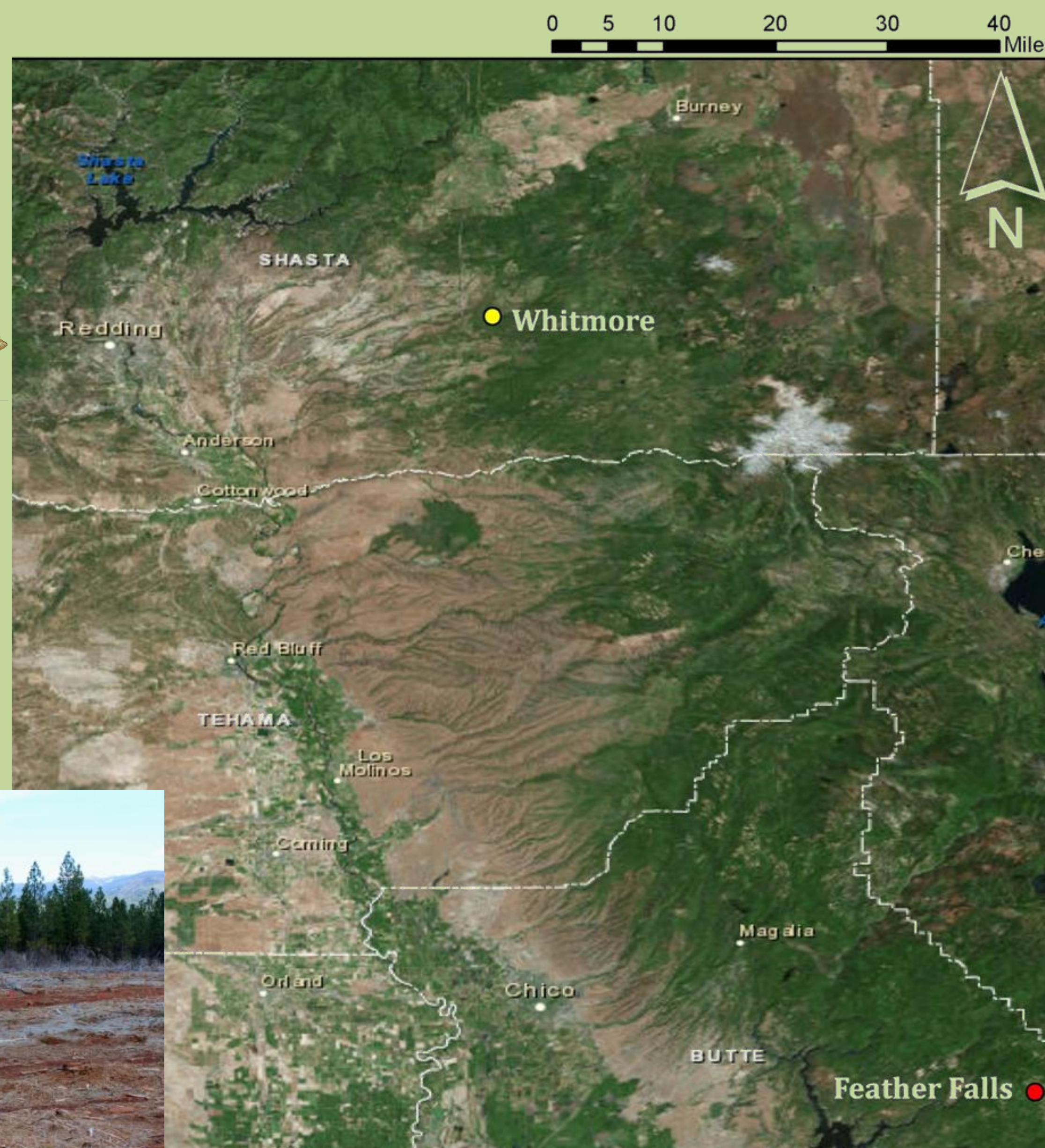


Figure 2. Whitmore Site Spring 2014



Results

P-retention generally decreases with depth in the soil profile (Figure 3).

Soil surface (0-30 cm depth)

- Whitmore: Fertilized has higher P-retention (mean=82) than Control (79) (Fig 4A)
- Feather Falls: Fertilized has lower P-retention (mean=86) than Control (mean=96) (Fig 4B)
- The Fertilized treatment shows highly variable P-retention (Table 2)

Feather Falls shows higher P-retention than Whitmore in control plots; fertilized plots do not differ between sites at the soil surface

Deep in the soil profile (170 cm)

- Neither site shows P-retention which varies with treatment (Fig 4C, Fig 4D)
- Whitmore shows higher P-retention than Feather Falls at depth (Fig 3).

NaF pH is positively correlated with P-retention (Figure 5). The laboratory test is more strongly correlated with P-retention than is the field method. Simple linear regression shows NaF pH (laboratory method) is a significant predictor of P-retention ($p < 0.0001$, adjusted $r^2 = 0.63$).

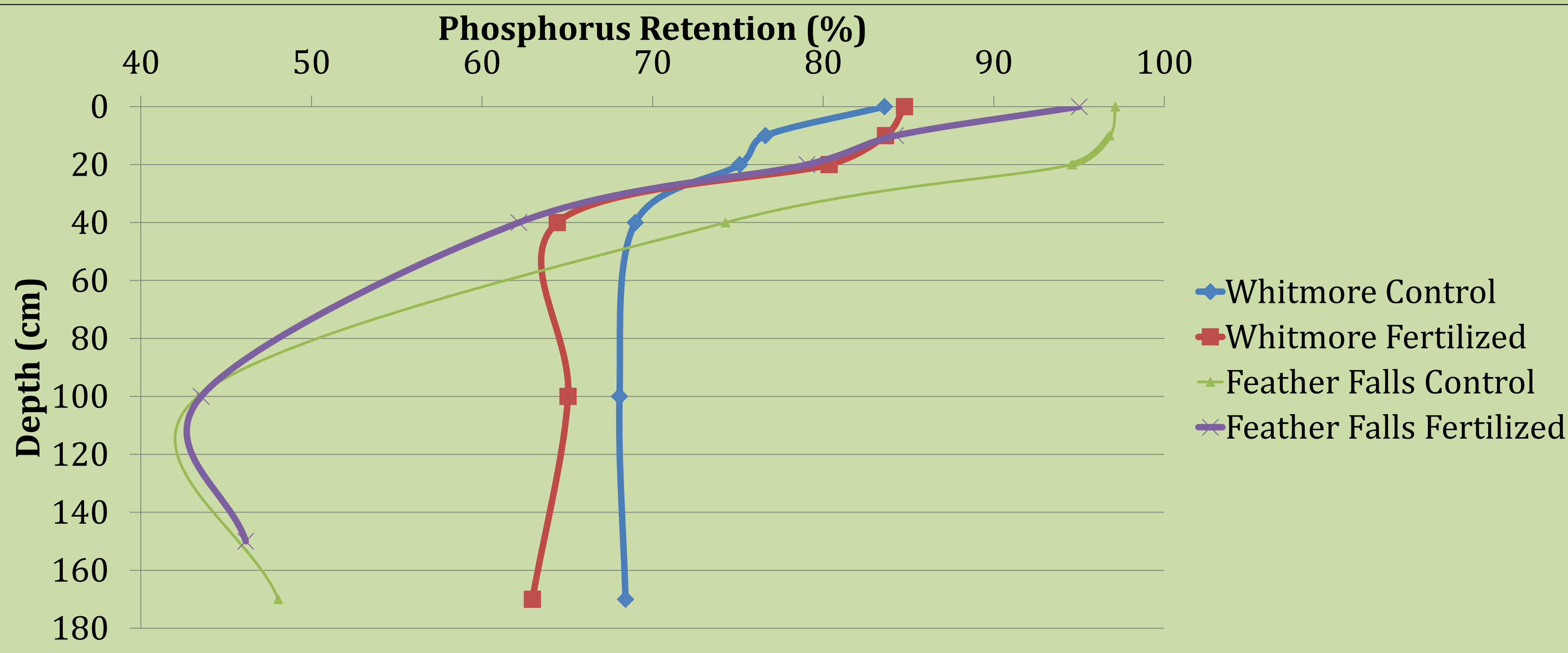


Figure 3. Percent phosphorus retention summarized by site and treatment.

Table 2. Summary of phosphorus retention at soil surface and deep in the profile.

	Mean P-Retention (%)		Standard Deviation	
	Shallow	Deep	Shallow	Deep
Whitmore Control	79.1	64.6	5.08	5.04
Whitmore Fertilized	82.9	63.0	3.08	4.22
Feather Falls Control	96.2	48.1	2.89	4.81
Feather Falls Fertilized	86.0	46.2	12.19	3.59

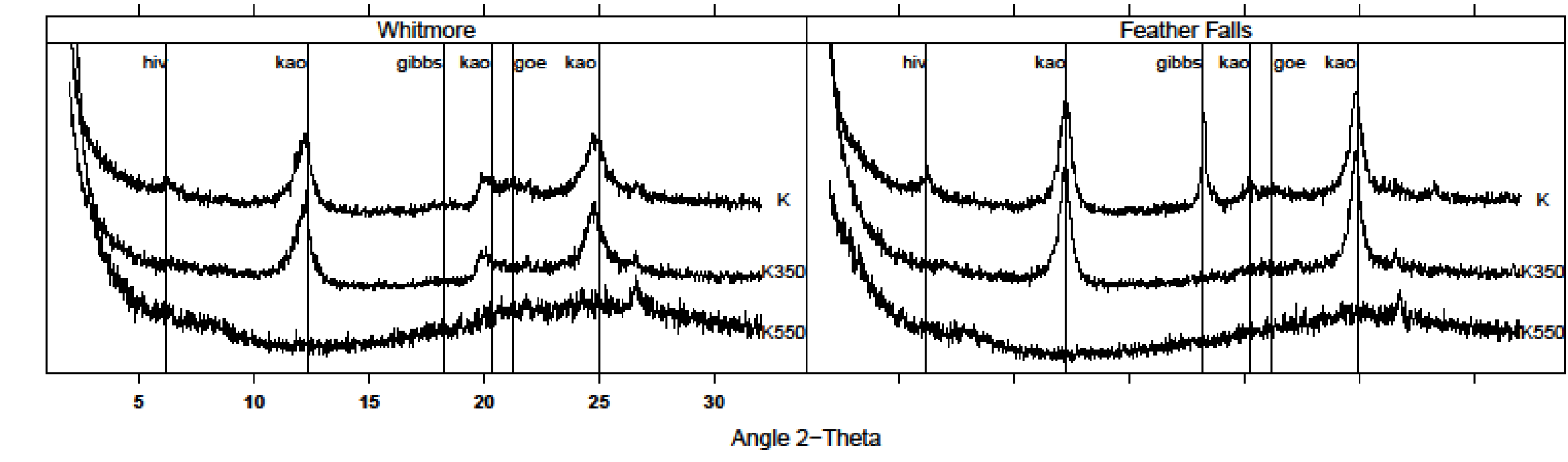


Figure 6. Mineralogy of Whitmore and Feather Falls sites by X-ray Diffraction (near-surface). Sharper peaks at Feather Falls indicates higher degree of crystallinity.

Discussion

Site effects: Our hypothesis about mineralogy and P-retention (more crystalline = less P-retention) is only true deep in the soil profile. At the surface, Feather Falls shows higher P-retention than Whitmore, opposite what we expected. Our hypothesis failed at the surface due to the influence of weathering and organic carbon in near-surface horizons. Weathering has caused the parent materials to effectively "even-out", their crystallinity becoming more similar with time. Additionally, the soil at Feather Falls is enriched with organic matter (Table 3). Since humus consists of high surface area particles with many exchange sites, phosphorus retention does occur - though microbial turnover will return P to the plants, whereas P sorbed to mineral surfaces is more permanently unavailable. In effect, we see that the influence of mineralogy on P-retention is overshadowed by other factors near the soil surface.

Site x Treatment effects: Fertilization does not affect P-retention >40 cm below the soil surface, so only near-surface depths are discussed here. Fertilization was expected to overcome P-limitation (fertilized sites should show lower P-retention). Feather Falls fertilized plots did show 10% less P-retention than control. At Whitmore the trend is reversed: fertilized plots show higher levels of P-retention. Though statistically distinct, the means only differ by 4%, a difference too small to be meaningful to site fertility. Fertilization is related to a drop in P-retention at Feather Falls; at Whitmore fertilized plots showed a barely discernible rise in P-retention.

	Mean % O.C.	Surface	Deep
Whitmore	2.2	0.3	
Feather Falls	3.5	0.2	

Table 3. Percent soil organic carbon in shallow (0-30 cm) and deep (170 cm) parts of the soil profile.

NaF pH and P-retention: The field test does not appear to be an adequate substitute for the laboratory method. The latter is a more accurate predictor of P-retention, though it requires more time and effort to perform.

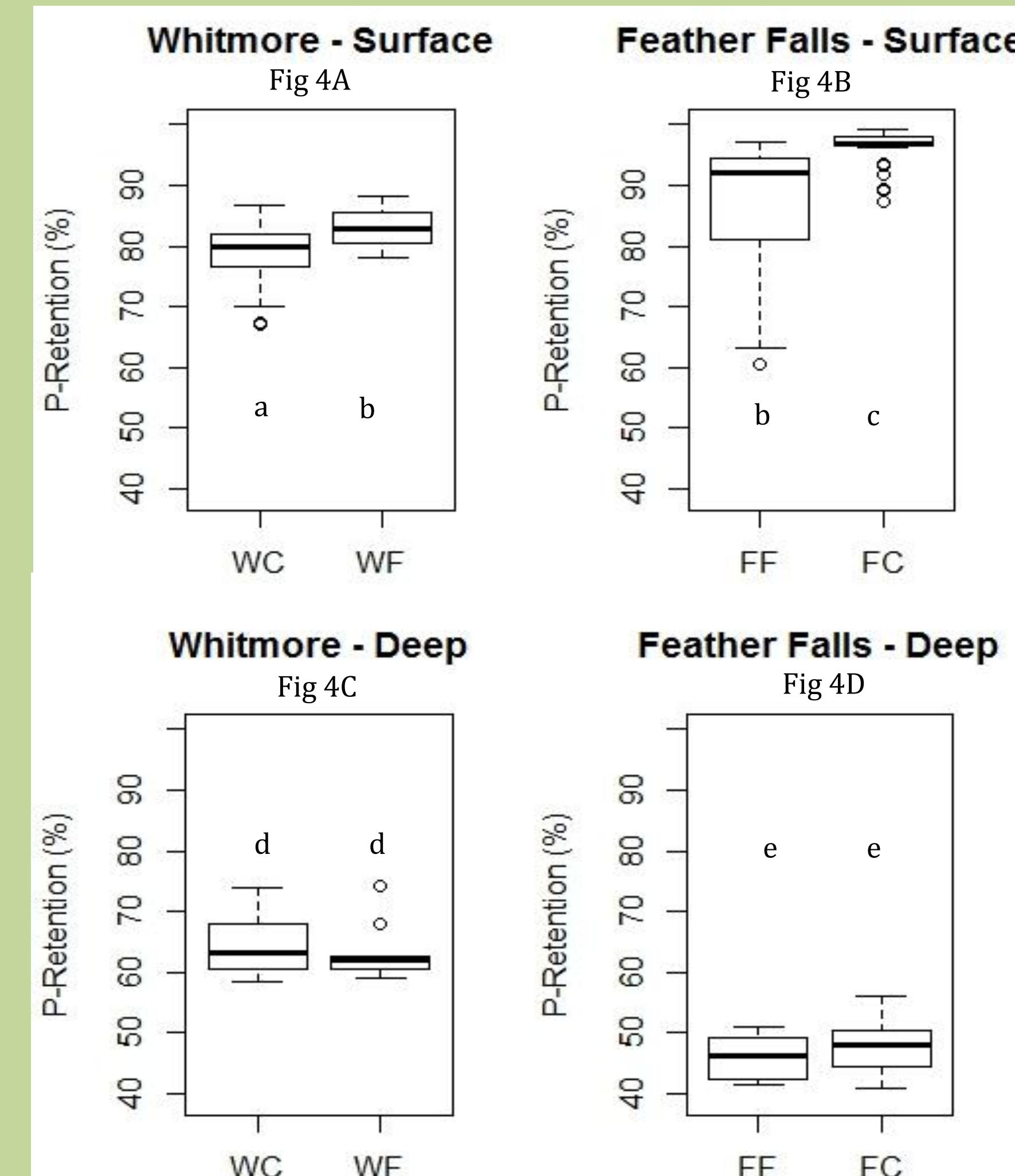


Figure 4. P-retention near the soil surface and deep in the profile. Different letters denote statistically differing means at $p < 0.005$. All Site/Depth/Treatment combinations were tested by pairwise t-test (C = control, F = fertilized).

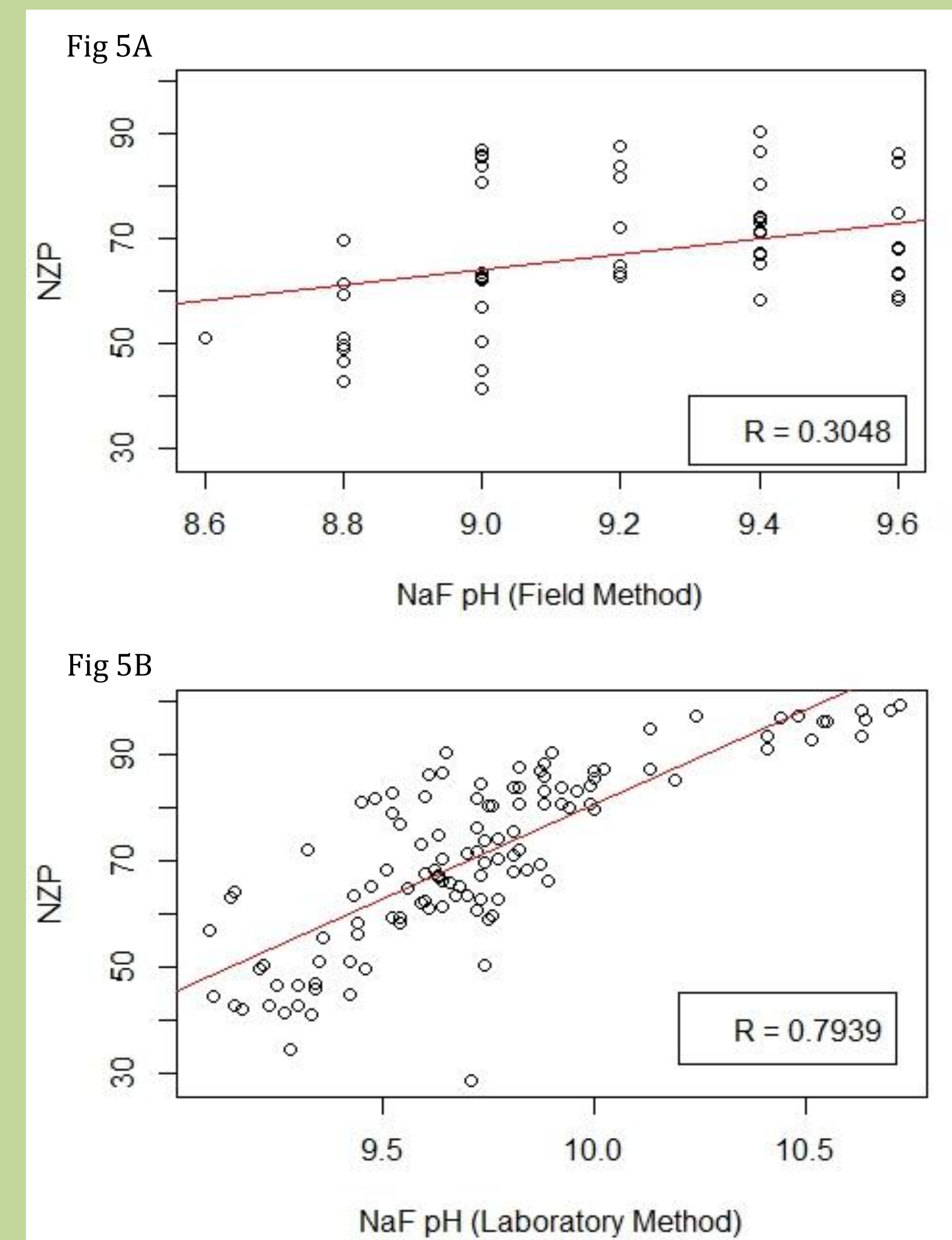


Figure 5. Correlation of NaF pH with P-retention. Fig 5A shows results of a field method using thymol blue pH indicator; Fig 5B shows results of a standard lab method³.

Continuing Analysis

This research provides data which are directly applicable to forest management by increasing an understanding of P-dynamics. We plan to develop a scalable model to inform forest managers on the P-status of their soil using simple assays. These models will include:

- Quantitative soil color
- Organic carbon content
- Mixed effects modeling



Acknowledgements

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