AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

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1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture

B. SECONDARY: Soils

2. TITLE AND SUBTITLE

pH dependent charge in soil clays

3. AUTHOR(S)

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4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1973	8 p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

University of Hawaii, Department of Agronomy and Soil Science, College of Tropical Agriculture, Honolulu, Hawaii 98622

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(In Proceedings, Sixth Hawaii Fertilizer Conference, Honolulu, 1973, p. 13-19)
(In Hawaii Cooperative Extension Service Miscellaneous Publication 104)

9. ABSTRACT

In many soils in Hawaii, particularly those in the wet uplands, the charge on soil particles develops from adsorption of hydrogen ions or hydroxyl ions on the surface of the soil particle. For example, a particle of hydrated iron oxide may have a net surface charge of zero. At some pH, an equal quantity of hydrogen and hydroxyl ions will be adsorbed on the particle surface. As the pH is increased, the charge on the particle will become increasingly more negative. When a farmer adds lime to such a soil, he does so to raise the soil pH and increase the calcium level. In experiments conducted on the Island of Hawaii, soil samples were treated with several levels of phosphorus fertilizer and calcium silicate. The pH of all treatments was held constant. The results clearly suggest that phosphate fertilizer and calcium silicate not only serve as sources of nutrients (P, Ca, Si), but also improve the fertility of these soils by increasing their capacity to hold nutrients against leaching losses. Figures included illustrate the pH-dependent cation exchange capacity, pH-dependent charge, and amounts of calcium, magnesium, and potassium leached vs. leachate volume.

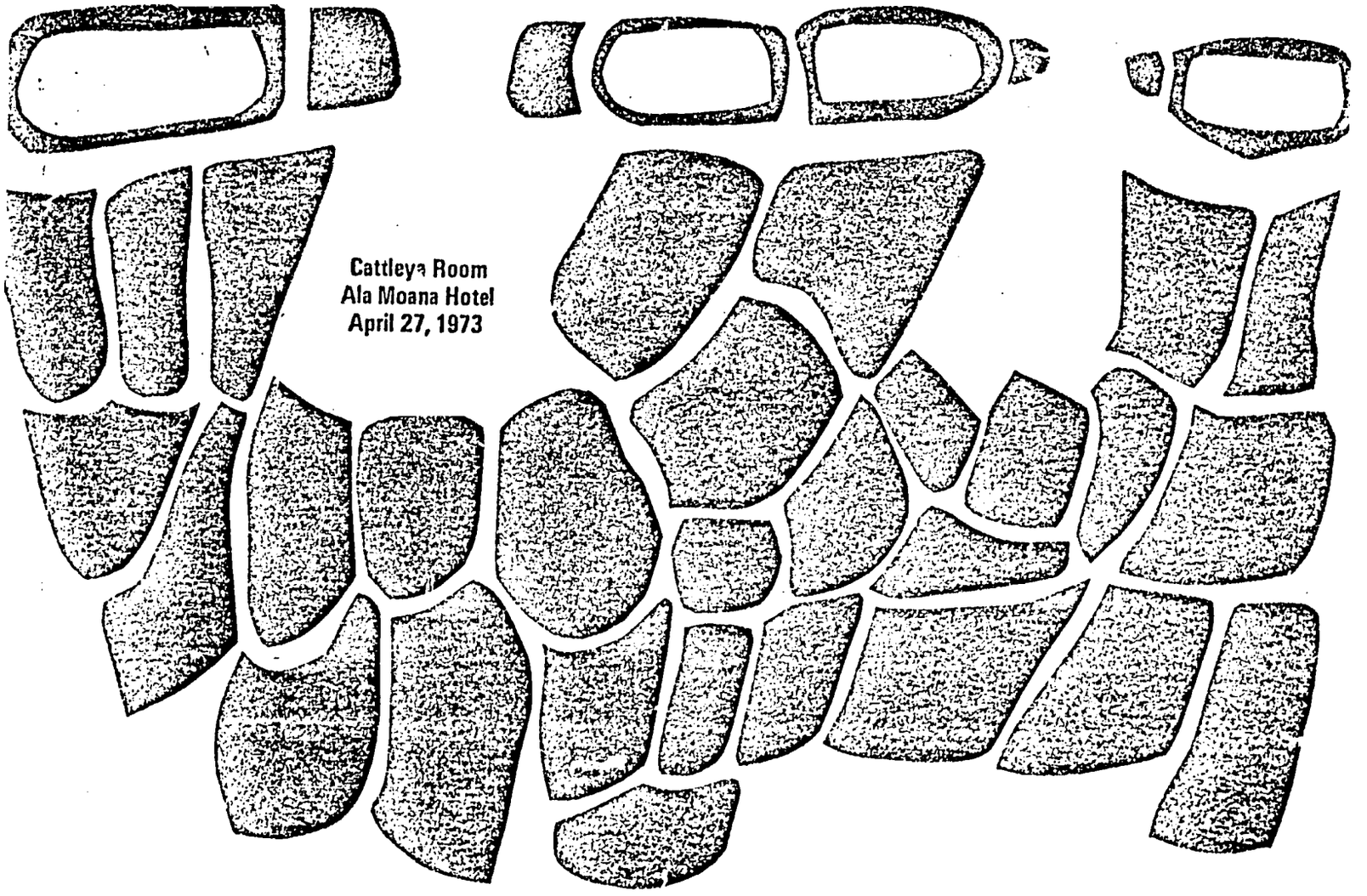
10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAC-375	
12. DESCRIPTORS	**13. PROJECT NUMBER**
Clay soils pH	**14. CONTRACT NUMBER** CSD-2833 211(d)
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

Cooperative Extension Service
University of Hawaii
Miscellaneous Publication 104

CSW-2873 2/[illegible]
PN-AAC-375

PROCEEDINGS:
Sixth Hawaii Fertilizer Conference



Cattleya Room
Ala Moana Hotel
April 27, 1973

pH DEPENDENT CHARGE IN SOIL CLAYS

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A soil serves as a reservoir for plant nutrients. The capacity of this reservoir increases as the number of electrical charges in a given weight of soil increases. The sign of the charge may be negative or positive, but it is more generally negative.

These negative charges are balanced by positively charged ions (cations) such as potassium, calcium, magnesium, and hydrogen ions. The maximum quantity of cations which a soil can adsorb, expressed in milli-equivalent meq per 100 grams of soil, is termed cation exchange capacity. The cation exchange capacity of Hawaii soils ranges from 5 to 80 meq per 100 grams. Most soils have cation exchange capacity values near 20 meq per 100 grams.

For example, a soil with 5 meq of calcium per 100 grams of soil can retain 4000 pounds of calcium in an acre-foot of soil, or the amount of calcium which is contained in 10 tons of limestone. Similarly, 1 meq of potassium would be equivalent to 1564 pounds of potassium or 1877 pounds of K_2O in an acre-foot of soil.

In most soils of the world (but not in Hawaii) the electrical charge on soil particles arises from defects in the interior structure of the clay particles. These defects often involve the occurrence of a metal ion of lower charge in a position normally occupied by an ion of higher charge. For example, if magnesium ion (Mg^{++}) fills a position normally occupied by aluminum (Al^{+++}), the clay particle acquires a net negative charge, and this charge is balanced by an ion such as potassium (K^{+}) which resides in the soil solution. The ions in solution which balance the charge of the clay particle are called counter-ions or exchangeable ions.

When the charge on the clay particle arises from defects in the interior of the clay particles, the cation exchange capacity of a soil cannot be changed by soil management.

In many of the soils in Hawaii, particularly those which occur in be wet uplands, the charge on soil particles develops from adsorption of hydrogen ions (H^{+}) or hydroxyls ions (OH^{-}) on the surface of the soil particle.

For example, a particle of hydrated iron oxide may have a net surface charge of zero. If this same particle is immersed in an acid solution, the hydrogen ions in solution will be adsorbed on the surface of the particle and render the particle positively charged. Similarly, if the same particle is immersed in a strongly alkaline solution, the particle will acquire a net negative charge through adsorption of negatively charged hydroxyl ions.

At some pH, an equal quantity of hydrogen and hydroxyl ions will be adsorbed on the particle surface. At this pH, the soil particle will carry a net surface charge of zero. Cations and anions can still be adsorbed on the particle because there still exist positive and negative charges on the particle, but the quantity adsorbed is generally very small. As the pH is increased (more OH^{-} is added to the soil), the charge on the particle will become increasingly more negative.

Soils which contain minerals whose surface charges vary with pH are referred to as soils with pH-dependent charges.

When a farmer adds lime to such a soil, he does so to raise the soil pH and increase the calcium level of the soil. It follows that, as he raises pH, he also increases the cation exchange capacity of his soil and thus increases the soil's capacity to adsorb calcium. In addition, since the hydroxyl ions are adsorbed on the surface, the pH of the soil solution does not rise as rapidly as one would expect.

In liming experiments conducted on the Island of Hawaii (Rixon, 1966), addition of 34,000 pounds (17 Tons/acre) of lime raised the soil pH from an initial value of 5.0 to a final value of 6.4. In most other soils, the final pH would have been much higher.

The curves in Figures 1 and 2 illustrate how the charge on soil particles varies with pH.

Adsorption of ions other than H^+ or OH^- can also alter the cation exchange capacity of a soil. The cation exchange capacity of a soil can be increased by heavy applications of phosphate fertilizers. For example, Ayers and Hagihara (1953) demonstrated that loss of potassium through leaching could be markedly reduced by applying phosphate fertilizers to a soil. We now know (Mekaru and Uehara, 1972) that adsorption of phosphate ions by soils causes an increase in their cation exchange capacities.

Figures 3 to 5 show the effect of silicate and phosphate application on leaching losses of calcium, magnesium, and potassium. Soil samples from the Kauai Branch Station of the Hawaii Agricultural Experimental Station were treated with several levels of phosphorus fertilizer and calcium silicate. The pH of all treatments was held constant to eliminate the effect of soil pH on the end result.

The soils were placed in 1-quart containers and seeded with sorghum. Excess water was added during irrigation to allow collection of leachate. The data in Figures 3 to 5 show that, as more phosphate fertilizer and calcium silicate were added to the soil, loss of calcium, magnesium, and potassium decreased.

The results clearly suggest that phosphate fertilizer and calcium silicate not only serve as sources of nutrients (P, Ca, Si) but also improve the fertility of these soils by increasing their capacity to hold nutrients against leaching losses.

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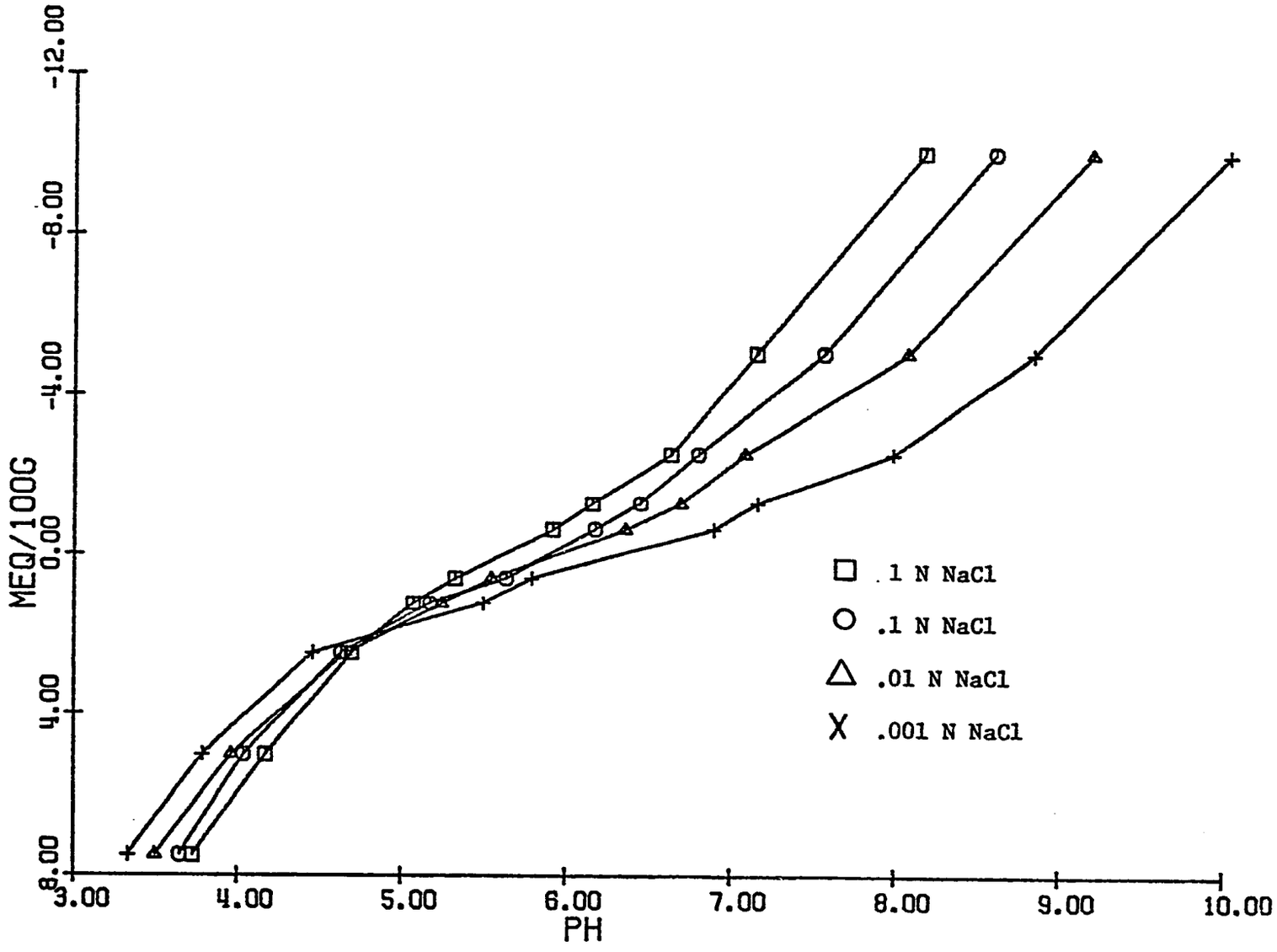

Figure 1. pH dependent cation exchange capacity of Molokai soil. Note that the shape of the curve also depend on the concentration of the neutral salt in which the measurement was made.

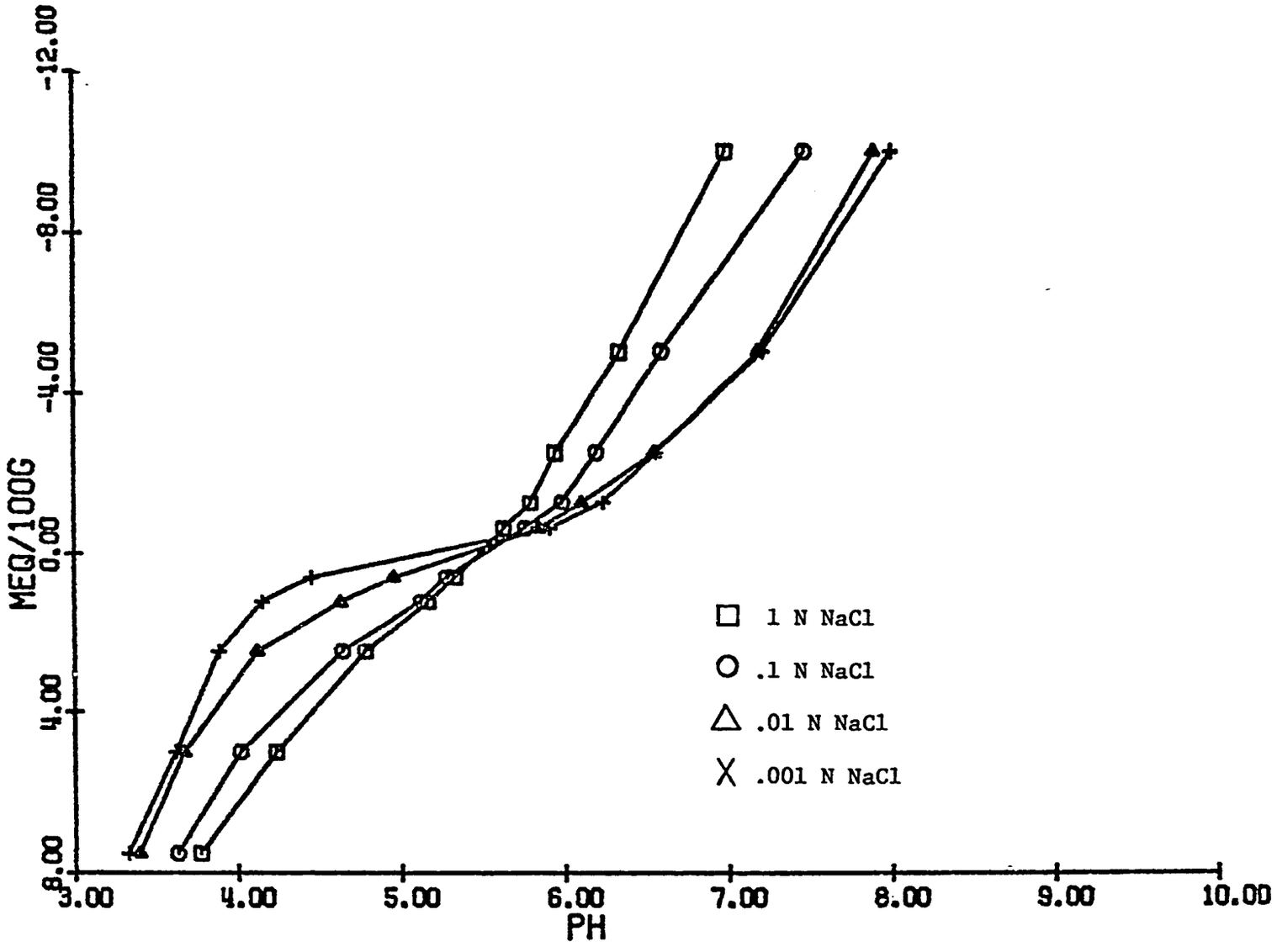

Figure 2. pH dependent charge of Halii soil.

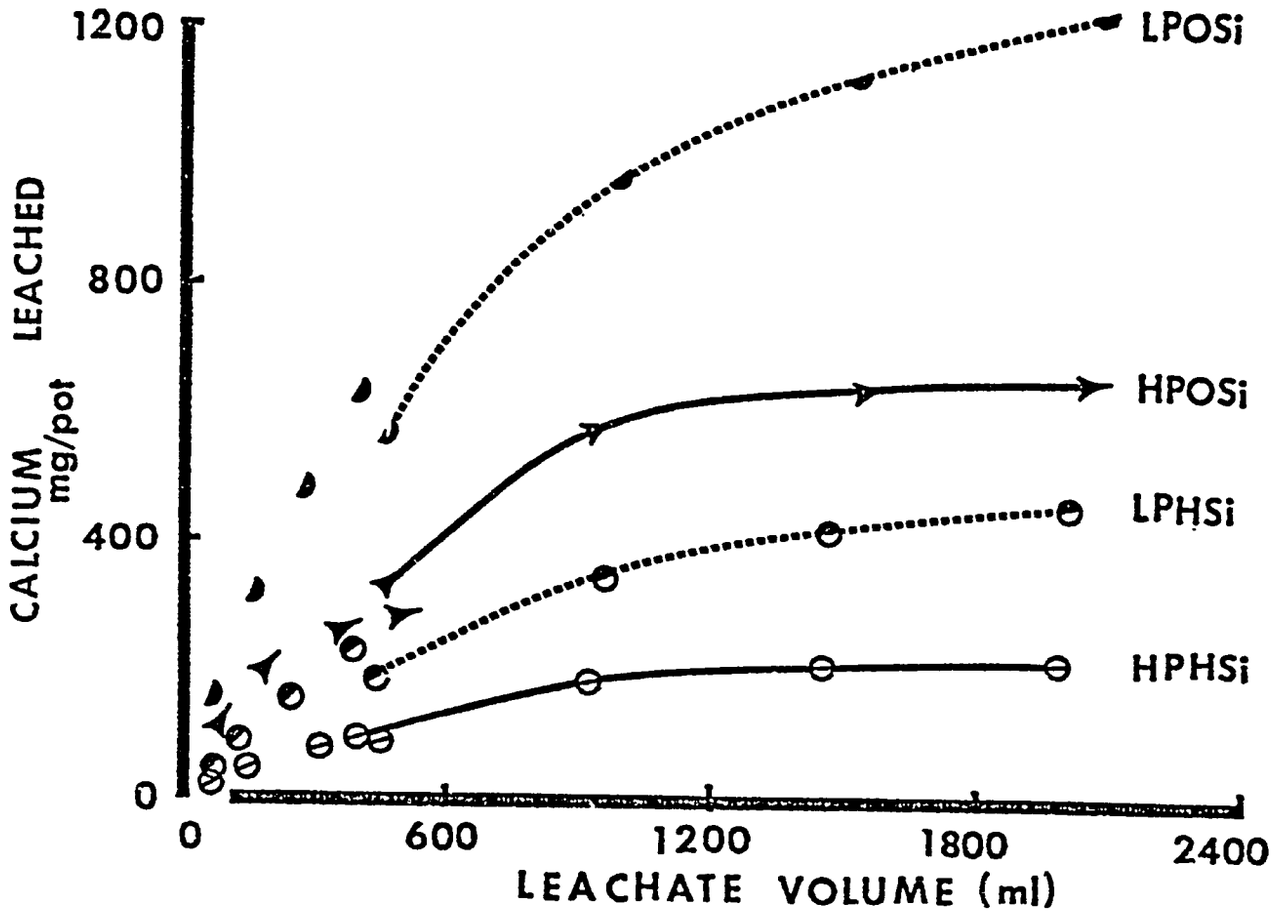

Figure 3. Cumulative Ca leached in Halii soil as a function of leachate volume. Data points joined by dashed or solid line represent leachate from high water application rate; unlined region represents low water application rate (LP = 100 ppm P, HP = 750 ppm P, OSi = zero Si, and HSi = 968 ppm Si). (Syed-Fadzil, S. B., 1972)

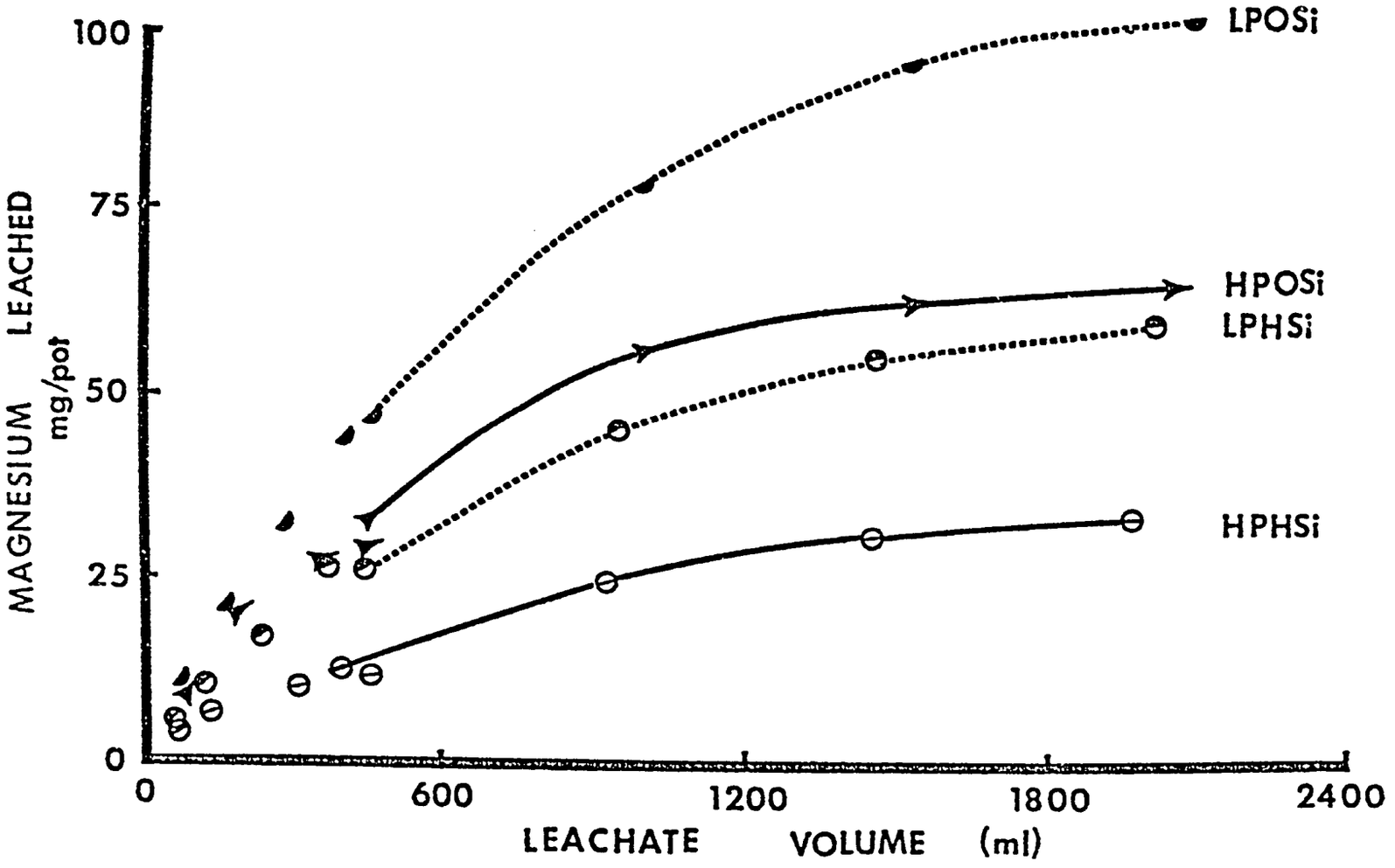

Figure 4. Cumulative Mg leached in Halii soil as a function of leachate volume. Data points joined by dashed or solid line represent leachate from high water application rate; unlined region represents low water application rate (LP = 100 ppm P, HP = 750 ppm P, OSi = zero Si and HSi = High Si). (Syed-Fadzil, S. B., 1972)

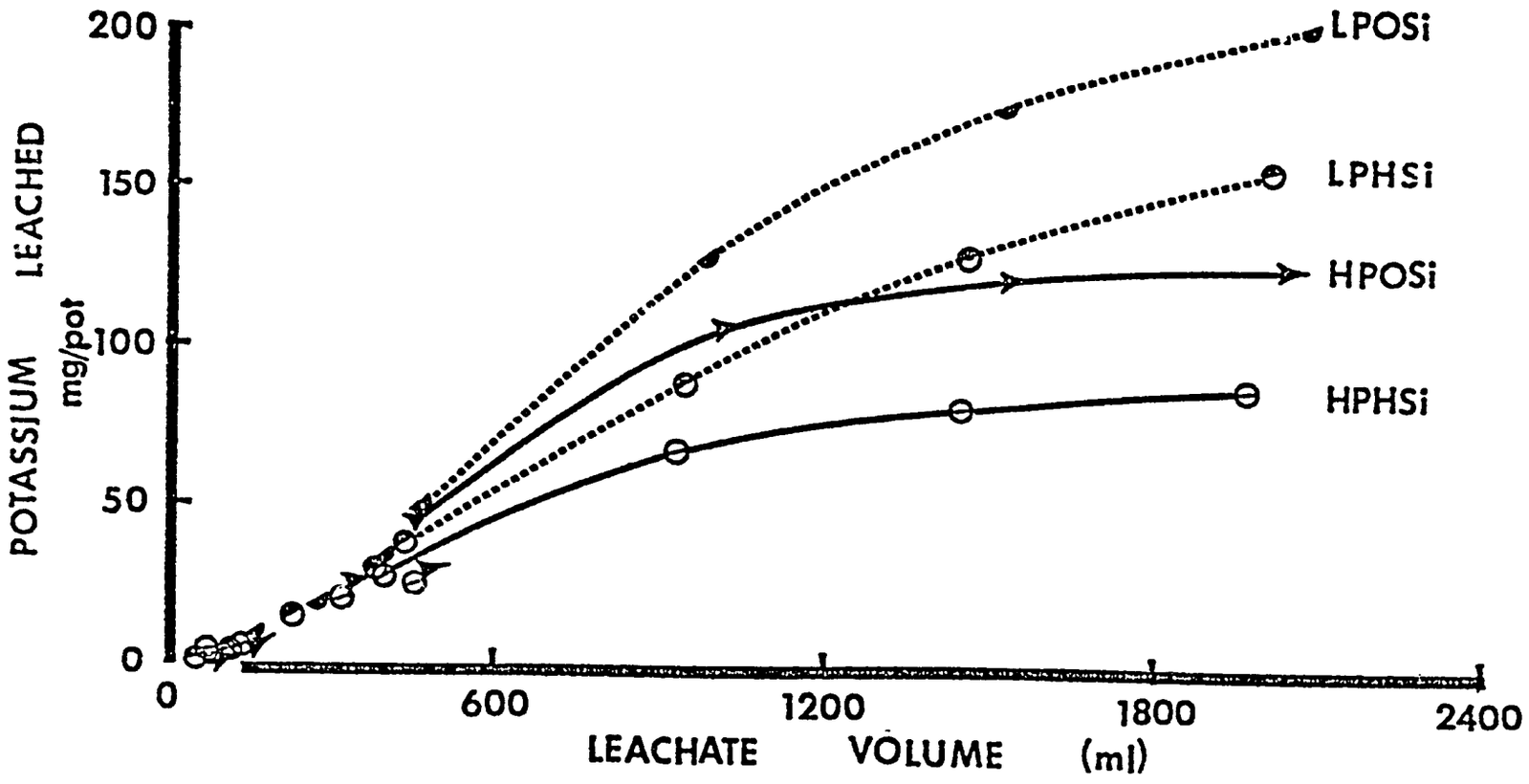

Figure 5. Cumulative K leached in Halii soil as a function of leachate volume. Data points joined by dashed or solid line represent leachate from high water application rate; unlined region represents low water application rate (LP = 100 ppm P, HP = 750 ppm P, OSi = zero Si, and HSi = 968 ppm Si). (Syed-Fadzil, S. B., 1972)