COOPERATIVE EXTENSION
UNIVERSITY OF HAWAI'I AT MĀNOA
COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES

In Transition Towards Organic Farming: Effects of Rock Phosphate, Coral Lime, and Green Manure on Soil Fertility of an Acid Oxisol and the Growth of Soybean (*Glycine max*) Seedlings

X. (Robert) Huang and N.V. Hue

Agricultural Diagnostic Services Center and Department of Tropical Plant & Soil Sciences

College of Tropical Agriculture and Human Resources

University of Hawaii at Manoa

Abstract

Maintaining soil fertility and obtaining good crop yields in highly weathered tropical soils through organic practices – without chemical/synthetic inputs—requires a scientific approach and skillful managements. A controlled (greenhouse) experiment was conducted to quantify soil properties, and soybean (*Glycine max* cv. Kahala) growth when rock phosphate, coral lime, and cowpea (*Vigna unguiculata*) green manure were applied as organic amendments to an acid, nutrient poor Oxisol of Hawaii. The treatments were a factorial combination of 3 application rates (0, 1, 2 g/kg) of coral lime (86% $CaCO_3$ equivalent) from Western Samoa, 3 rates (0, 75, 150 mg/kg total P) of rock phosphate (10.6% total P, and 3.7% citrate extractable P) from central Florida, and 3 rates (0, 5, 10 g/kg) of a local cowpea green manure (2.7% N, 2.8% K). Each treatment was replicated 3 times, yielding a total of 81 pots of 2 kg soil each. Soybean seedlings were grown as a test crop. Our results showed that a combination of 1 g/kg (2 tons/ha) of lime and 75 mg/kg (150 kg P/ha) of rock P provided enough P for soybean growth and simultaneously alleviated soil acidity problems (the green manure was to supply adequate N and K to the crop). Corresponding soil parameters were: soil pH = 5.2, exchangeable (KCl-extractable) Al = 3.6 mg/kg, and Olsen ($NaHCO_3$- extractable) P = 11 mg/kg.

Organic soil inputs challenges

Organic farming, with an emphasis on a holistic approach to agriculture, avoids the use of synthetic fertilizers and pesticides (USDA National Organic Program, 2022). With no chemical inputs organic farming must be managed skillfully. In fact, soil nutrient management poses a serious challenge to organic practices, especially if the farmed soil is acidic and phosphorus (P) deficient as is often the case of Oxisols (Sanchez, 2019).

Along with nitrogen (N) and potassium (K), P is a major (needed in large amounts) and essential nutrient to all crops (Havlin et al., 2017). More specifically, P is a component of genetic molecules (DNA, RNA) as well as Adenosine Triphosphate (ATP), which transfers energy during photosynthesis and respiration (Barker, 2010; Sanchez, 2019). Phosphorus-deficient plants grow slowly, appear dark green or blue-green as a result of stunted growth with concentrated green pigment in leaves. In advanced stage of P deficiency, leaves often turn purple (Hue and Silva, 2000).

One of the main sources of P in organic farming is rock phosphate having a chemical formula of $Ca_{10}(OH)_2(PO_4)_6$ with some minor substitutions of OH^- by fluoride (F^-) or carbonate (CO_3^{2-}). In the US, rock phosphate is often mined from sedimentary rocks in Florida and North Carolina (Sanchez, 2019). Unlike chemical P fertilizers, such as ammonium phosphate ($NH_4H_2PO_4$) or treble superphosphate ($Ca(H_2PO_4)_2.H_2O$), rock phosphate is sparingly soluble in water (Lindsay, 1979). Thus its availability to crops is very low, unless the conditions are strongly acidic (pH <5.0) as predicted by the following reaction.

$$Ca_{10}(OH)_2(PO_4)_6 + 14\ H^+ \longrightarrow 10\ Ca^{2+} + 6\ H_2PO_4^- + 2H_2O$$ *Reaction 1* (or **R1**)

However, in acid soils the concentrations of aluminum (Al) and/or manganese (Mn) are so high that any P that is dissolved from the rock is precipitated (as shown below) before it can move far enough in the soil for plant roots to absorb it. Adsorption of P on solid Al and iron (Fe) oxides, which are abundant in Oxisols further reduces P availability.

$$Al^{3+} + H_2PO_4^- + 2H_2O \longrightarrow Al(OH)_2H_2PO_4\ (solid) + 2H^+$$ **R2**

Moreover, Al^{3+} and H^+ in acid soils can damage the root systems such that no uptake of water and nutrients, including P, would be feasible (Hue, 2022).

Given such an apparently paradoxical situation, our objective was to find/characterize an acceptable condition in which the soil pH is low enough so that rock P would be adequately soluble, yet is high enough so that soil Al (and perhaps Mn or H) does not adversely affect our crops.

The experiment

Soil and Organic Amendments

A strongly acidic, Al toxic soil from a former sugarcane plantation in Oahu was used in this experiment. The organic inputs consisted of rock phosphate from central Florida, and coral lime from Western Samoa, and ground cowpea leaf to provide N and K and other micronutrients. Their nutrient composition is listed in Table 1. The organic amendments were mixed thoroughly with the finely ground (< 5 mm diameter) soil, which was stored in plastic pots containing 2 kg of air-dried soil each.

The experiment design

A factorial setup consisted of 3 levels of coral lime (0, 1, and 2 g/kg equivalent to 0, 2, and 4 tons/ha if 1 ha is assumed to weigh 2×10^6 kg), 3 levels of rock P (0, 75, and 150 mg P/kg) and 3 levels of cowpea green manure (0, 5, and 10 g/kg). The pots were arranged in a randomized complete block (RCB) design with 3 replications. The treated soil was incubated moist for two weeks, then one 2-weekd old soybean seedling cv. Kahala was transplanted to each pot and grew for one month. Soil analysis was performed at transplanting time. Plant dry weight and nutrient composition were performed at harvest.

Table 1. Chemical composition of the organic inputs used in the experiment.

Input Source	N	P	K	Ca	Mg	Na
	←---	------	---% --	----	----	----→
Cowpea GM	2.70	0.14	2.76	1.6	0.45	0.03
Florida rock P†	---	10.64	0.09	31.7	0.19	0.43
Samoa coral lime¶	---	0.02	0.02	34.5	1.47	0.31

† Labile P, as extracted with neutral 2% ammonium citrate, was 3.7%.

¶ Calcium carbonate ($CaCO_3$) equivalent was 86%.

Results and Discussion

Soil Properties as affected by organic amendments

Predictably, applications of coral lime raised soil pH from 4.46 (no lime) to 4.96 at 1 ton/ha and to 5.41 at 2 tons/ha of lime, respectively. More interestingly is the moderate rise in soil pH by the additions of rock P (Fig. 1A) and cowpea green manure (Fig. 1B). Such pH increases can be explained as follows.

$$Ca_{10}(OH)_2(PO_4)_6 + 12\ H_2O \longrightarrow 10\ Ca^{2+} + 6\ H_2PO_4^- + 12\ OH^- \qquad \textbf{R3}$$

(**R3** is another form of **R1**)

Thus, the dissolution of rock P, although very limited, would consume H^+ (see **R1**) or release OH^- (see **R3**). Similarly, the addition and subsequent mineralization of cowpea green manure would yield first NH_3, which raised soil pH.

The precipitation of $Al(OH)_3$ as a results of Al^{3+} reacting with OH^- caused a decrease in exchangeable Al (Fig. 2). For example, Figure 2 shows that the coral lime lowered exchangeable Al from 56 mg/kg in the control (0 lime-0 RP-all 3 GM combined) to 5.3 and 2.4 mg/kg in the 1 g/kg and 2 g/kg lime treatments, respectively. The alleviating effects of rock P on exchangeable Al was also significant: rock P decreased exchangeable Al from 56 mg/kg (zero rock P) to 27.5 and 18.6 mg/kg at 75 and 150 mg/kg P additions, respectively (Fig. 2).

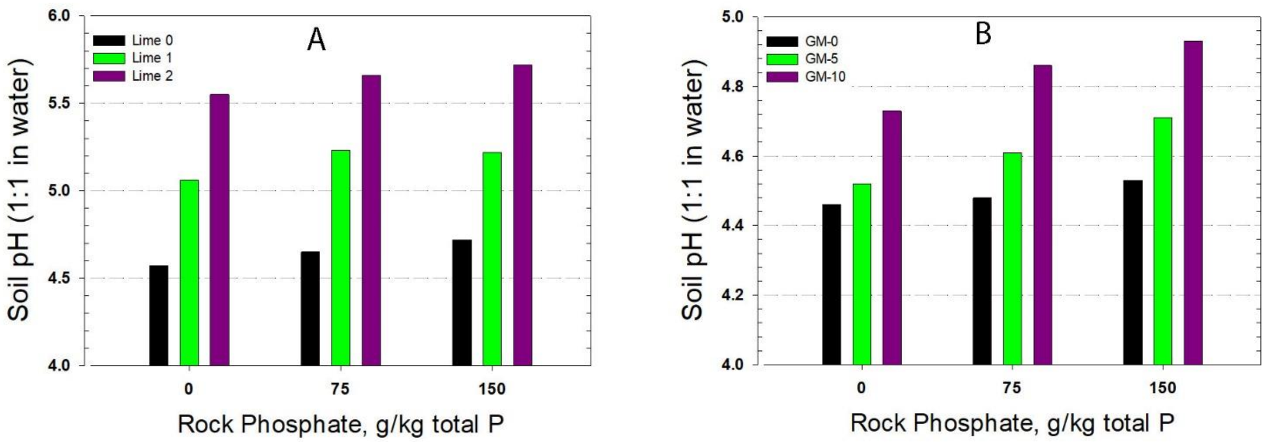
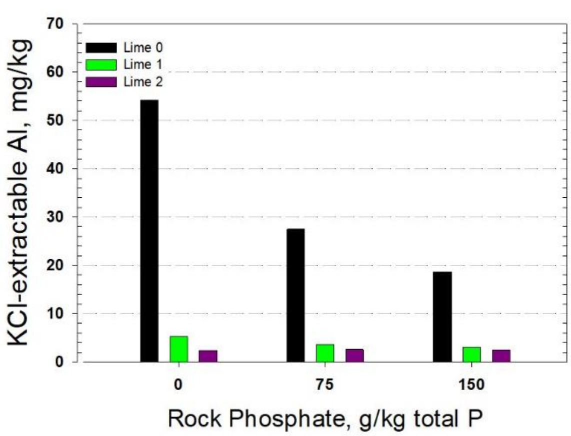


Figure 1. Soil pH as affected by lime and rock P (A), and by green manure and rock P (B).



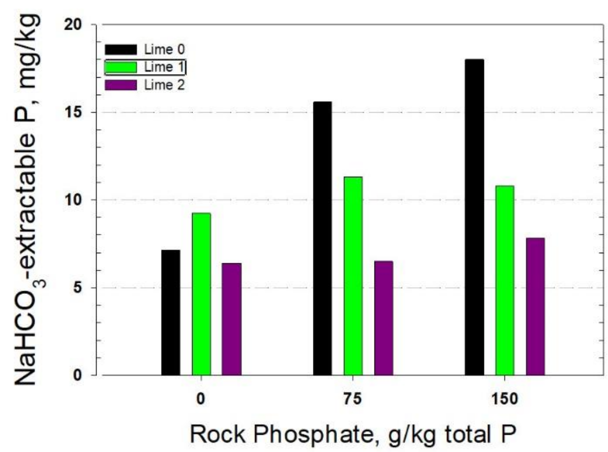


Figure 2. Soil Al as affected by lime and rock P.

Figure 3. Soil P as affected by lime and rock P.

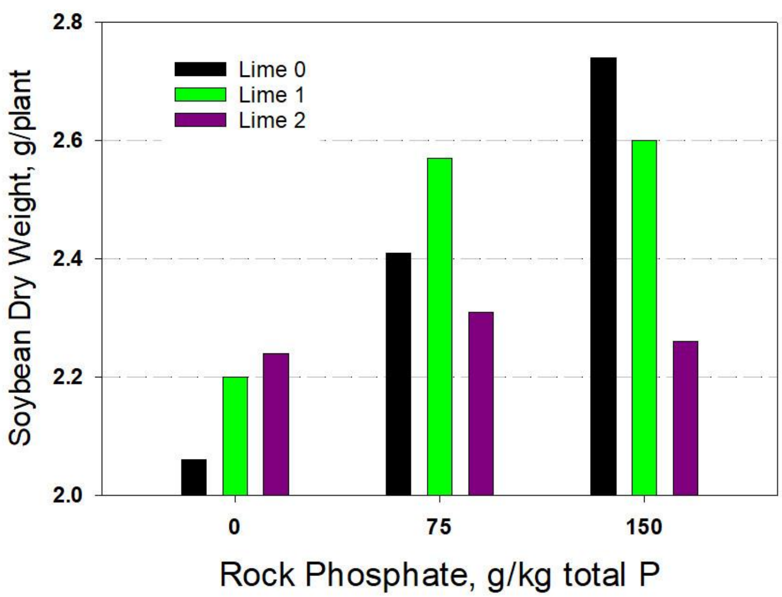
Changes in Olsen-P as affected by lime and rock P were more complex. The low rate of lime (1 g/kg) slightly increased soil Olsen-P, but the high rate (2 g/kg did not (Fig. 3) in the zero rock P treatments. When rock P were added, lime reduced Olsen P (Fig. 3). Perhaps, high Ca in the lime would react with HCO_3^- of the $NaHCO_3$ solution, thereby diminishing its P extracting power. A suggested reaction is:

$$Ca^{2+} + 2\,HCO_3 \longrightarrow CaCO_3\ (solid) + H_2O + CO_2 \qquad \textbf{R4}$$

Predictably, rock P increased Olsen P significantly in treatments with no lime: Olsen P concentrations were 7.13 mg/kg (in the control: no lime, no P, all 3 GM treatments), 15.69 and 18.0 mg/kg in the 75 and 150 mg P/kg, respectively (Fig. 3). However, the higher rock P rate (150 mg P/kg) only increased Olsen P moderately over the lower P rate. That suggests that the P releasing capacity of rock P might have approached a plateau not far beyond the 150 mg P/kg rate.

Soybean responses to organic amendments

Since the cowpea green manure was used to provide N and K to soybean, and was not a focus of this experiment, all three green manure treatments were combined in examining the effects of lime and rock P on soybean growth. When such combined data were statistically analyzed (Fig. 4), it reveals that the best growths were obtained from treatments (A) no lime + 150 RP, (B) lime 1 + 150 RP, and (C) lime 1 + 75 RP (Fig. 4 and its associated Table). Over time, treatment (A) may have some potential problems with marginal Al and relatively high Mn in leaves (average: 31.7 mg Al/kg and 250 mg Mn/kg) compared to those in treatment (B) and particularly treatment (C), which averaged 21.6 mg Al/kg and 135 mg Mn/kg. Furthermore, treatment (C) used only ½ rock P as much as treatment (B). Based on such material and economic considerations, treatment (C), containing lime 1+ 75 mg P/kg rock P, seems to be the most appropriate input. Soil parameters corresponding to treatment (C) were: soil pH (1:1 in water) = 5.2 (Fig. 1A), exchangeable Al = 3.6 mg/kg (Fig. 2), and Olsen P = 11 mg/kg (Fig. 3).



	Soybean shoot Dry weight, g/plant		
Rock P	Coral Lime, g/kg		
mg/kg	0	1	2
0	2.06 c	2.20 bc	2.24 bc
75	2.41 b	2.57 a	2.31 b
150	2.74 a	2.60 a	2.26 bc
Dry weight numbers followed by a different letter differ at 95% level.			

Figure 4. Shoot dry weight of soybean seedlings as affected by lime and rock P amendments.

Conclusion

Our 'organic growing' experiment on an acid, nutrient poor Oxisol of Hawaii showed that rock phosphate (10.6% total P and 3.7% citrate extractable P) applied at 75 mg/kg total P (equivalent to approximately 150 kg/ha) in combination with 1 g/kg (2 tons/ha) of a coral lime (86% $CaCO_3$ equivalent) would alleviate acidity problems and provide adequate P to the growth of soybean seedlings, which were used as a test crop.

References

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