Deficiency of Inorganic Nutrients as a Contributing Factor to Ohia Decline

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ABSTRACT

Stands of native ohia trees in Hawaii are in serious decline and many trees have died. Declining trees treated with a complete fertilizer (NPK plus micronutrients) responded by producing numerous new leaf buds on branches and trunks. The trees also responded to a mixture of NPK without micronutrients. Application of N, P, and K individually or a mixture of micronutrients were not effective. Declining trees responded to a combination of NP, but not to combinations of NK and PK. Results indicated that ohia trees are declining because of nutrient deficiency.

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Thousands of acres of native ohia [*Metrosideros collina* (Forst.) Gray subsp. *polymorpha* (Gaug.) Rock] forests on the Island of Hawaii are declining (2). It is seen as a gradual thinning and unthrifty appearance of the crowns of trees followed by defoliation and death (Fig. 2-A); or, less commonly, the entire crown wilts suddenly (5). The decline is of great concern because recent surveys have indicated an intensification of the deterioration of ohia forests. The ohia tree is important because it is a pioneer species on new lava flows and provides valuable watershed protection. Loss of ohia would mean the loss of forest cover. Rootlet mortality was consistently associated with declining ohia trees (Kliejunas and Ko, *unpublished*). Although *Phytophthora cinnamomi* causes root rot of ohia trees (4), its involvement in ohia decline is still unknown. This paper reports the relationship between nutrient deficiency and ohia decline.

MATERIALS AND METHODS.–*General descriptions.*–The elevation of decline areas used for this study ranged from 53 to 1,769 m above sea level. Average annual rainfall varied from 190 to 630 cm. Differences in age and type of lava flows contributed greatly to topographic and edaphic differences. Sites at higher elevations contained mostly aa lava (small porous lava with rough surface), and at lower elevations mostly pahoehoe lava (massive lava with relatively smooth surface) partially overlaid with a thin layer of largely undecomposed organic matter.

Declining ohia trees selected for experiments were 1.2 to 2.4 m in height and 2.5 to 7.6 cm in diam 30 cm above ground. Individual trees used in each experiment were selected for uniformity of variety within the species, size, and stage of decline. Trees were arbitrarily assigned to two stages of decline: intermediate, with twig and branch dieback affecting one-quarter to one-half of the tree; and severe, with twig and branch dieback affecting three-quarters or more of the tree. Most individually treated ohia were in the intermediate stage of decline, although in earlier experiments severely declining trees were treated as well. Ohia trees in all stages of decline were treated when large plots were fertilized.

Fertilizer application.–Fertilizers for ground application included a complete fertilizer (Keaau 19, composed of 12.14%N, 27.33% P, 7.27% K, 0.23% CaO, 0.24% Mn, 0.22% Zn, 0.023% B, 3.69% Mg, 7.09% S, 0.23% Cu, 0.23% Fe and 0.0199% Mo) and a mixture containing only N, P, and K (Ortho Unipel, 16-16-16). N, P, and K also were applied individually as calcium nitrate, superphosphate, and potassium sulfate. Other elements applied as a mixture of micronutrients included Ca (calcium nitrate), Mg (magnesium sulfate), Mn (manganese sulfate), Mo (sodium molybdate), B (soluble borate), Cu (copper sulfate), Zn (sequestrene zinc chelate), and Fe (sequestrene iron chelate). Although Ca and Mg are usually considered to be macronutrients, they were included in micronutrients in this study.

Complete fertilizer or NPK were applied to individual ohia trees by broadcasting approximately 150 g to a 0.91 m radius circle around each tree cleared of vegetation. When it was apparent that the major portion of a root system followed a crack or cracks in pahoehoe lava, fertilizers were also applied there rather than only around the tree. When N, P, and K were applied individually, the salts were applied in a concn equal to that in NPK (16%). The combination of micronutrients were applied in concns equal to those in the complete fertilizer.

A solution of mixed nutrients (Greenzall, composed of 2.2% N, 2.2% P_2O_5, 2.2% K_2O, 2.6% Mn-chelate, 1.3% Cu-chelate, 2.6% Fe-chelate, and 2.6% Zn-chelate) with Triton B-1956 as a spreader-sticker was applied to leaves and stems of individual ohia with a Solo mist blower until run-off occurred. The solution was diluted with water to give a concn of 46.7 ml/liter. For the initial application, 1.03 g of calcium nitrate, 1.03 g of magnesium sulfate, 0.24 g of soluble borate, and 0.08 g of

TABLE 1. Response of ohia trees with intermediate and severe decline symptoms to foliar and ground application of inorganic nutrients 3 mo after treatment

Treatment	New lateral buds produced (No./tree)[x]	
	Intermediate	Severe
Ground application[y]	575 a	119 a
Foliar application[z]	53 b	31 b
Control	3 c	8 c

[x]Average of five trees per treatment. Means followed by the same letter in the same column are not significantly different, $P = 0.05$.

[y]One application of 150 g of complete fertilizer per tree.

[z]Three biweekly applications of NPK plus Mn-, Cu-, Fe-, and Zn-chelates, Mg, B, and Mo.

sodium molybdate were added to each liter of Greenzall mixture.

Analysis of variance was applied to appropriate data, and differences between means were determined using Duncan's multiple range test.

RESULTS.–*Effect of mineral nutrients on declining ohia trees.*–Foliar application was used initially because it was considered possible that roots of declining ohia trees were not functional. Ohia trees in intermediate decline were selected at elevations of 580 m, 1,220 m, and 1,769 m above sea level, and five trees at each elevation were sprayed biweekly for 6 wk. During the same period, an experiment was set up at the 1,220 m elevation to compare response to foliar application with response to ground application. Each treatment consisted of five intermediately-declining and five severely-declining ohia trees. Trees were either sprayed biweekly for 6 wk or fertilized once with 150 g of complete fertilizer per tree.

Declining trees which received ground application of nutrients at the three locations responded after 6 wk by producing numerous new leaf buds on defoliated branches and main trunks (Table 1). After 3 mo, the buds had opened and produced vigorous healthy new leaves (Fig. 1-A, B). Ground application gave a better response than foliar application, indicating that roots were still functional in the uptake of the inorganic nutrients. Both intermediately and severely-declining trees responded to application of inorganic nutrients. However, the former were more responsive than the latter. The new growth produced in response to the treatments, remained vigorous after 1 yr (Fig. 1-C).

In another experiment at the 1,128 m elevation, trees were treated with foliar application or ground application, or with both. Ten trees were used for each treatment. Again, ground application was more effective than foliar application. Combined foliar and ground application was not better than ground application alone.

To determine the minimum amount of fertilizer needed for response, ohia trees in intermediate stages of decline were treated with one application of 75, 150, 300, 400, 500, or 600 g of complete fertilizer per tree. New buds produced on branches and trunks were counted 8 wk later. Three trees were used for each treatment and the experiment was repeated once. Results indicated that the minimum amount of fertilizer needed for a significant response was about 150 g per tree.

Seven additional decline areas throughout the island were located and treated to assure that the response to inorganic nutrients was not limited to a specific area. Sites included a diversity of environmental conditions under which ohia grow. Five intermediately-declining ohia trees at each location were treated with one application of 150 g of complete fertilizer per tree. All treated ohia trees responded at all locations. Response included production of new buds and greening of healthy leaves. Leaves that were chlorotic before treatment remained chlorotic after treatment, even though new buds which subsequently produced healthy leaves often developed on the same branch. Response of terminal leaf buds to fertilization was also striking (Fig. 1-D). Tight leaf buds became swollen and opened 6 wk after treatment. The number of terminal leaf buds that opened was so great that it was difficult to count them. An increase in shoot length was also evident compared to control trees.

Nutrients required for the response of declining ohia trees.–Ohia trees in intermediate decline were treated with different combinations of nutrients to determine which element (or combination of elements) was required for the response. Treatments included complete fertilizer, NPK, micronutrients only (Ca, Mg, B, Mn, Zn, Cu, and Fe), and N, P, and K individually. Three trees were used for each treatment, and the experiment was repeated once at another location. Declining ohia trees responded to both complete fertilizer and to NPK without micronutrients (Table 2). The difference between these two treatments was not statistically significant. Micronutrients alone or N, P, and K individually were not effective.

Different combinations of NPK were tested to determine which elements were required for the response. Three trees were used for each treatment and the experiment was repeated once. Declining ohia trees responded to the combinations of NPK and NP, but not to NK and PK (Table 3). The combination of NPK was significantly better than that of NP.

Fertilization of large plots.–A 15.3 × 30.5 m plot

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Fig. 1-(A to D). Response of declining ohia trees to a single ground application of complete fertilizer. **A)** Lateral buds produced from a naturally defoliated twig 8 wk after treatment. **B)** New shoots developing on the stem 12 wk after treatment. **C)** Same ohia stem as in A) one year after treatment. Note the vigorous shoot growth. **D)** Development of new growth from terminal leaf buds 10 mo after treatment.

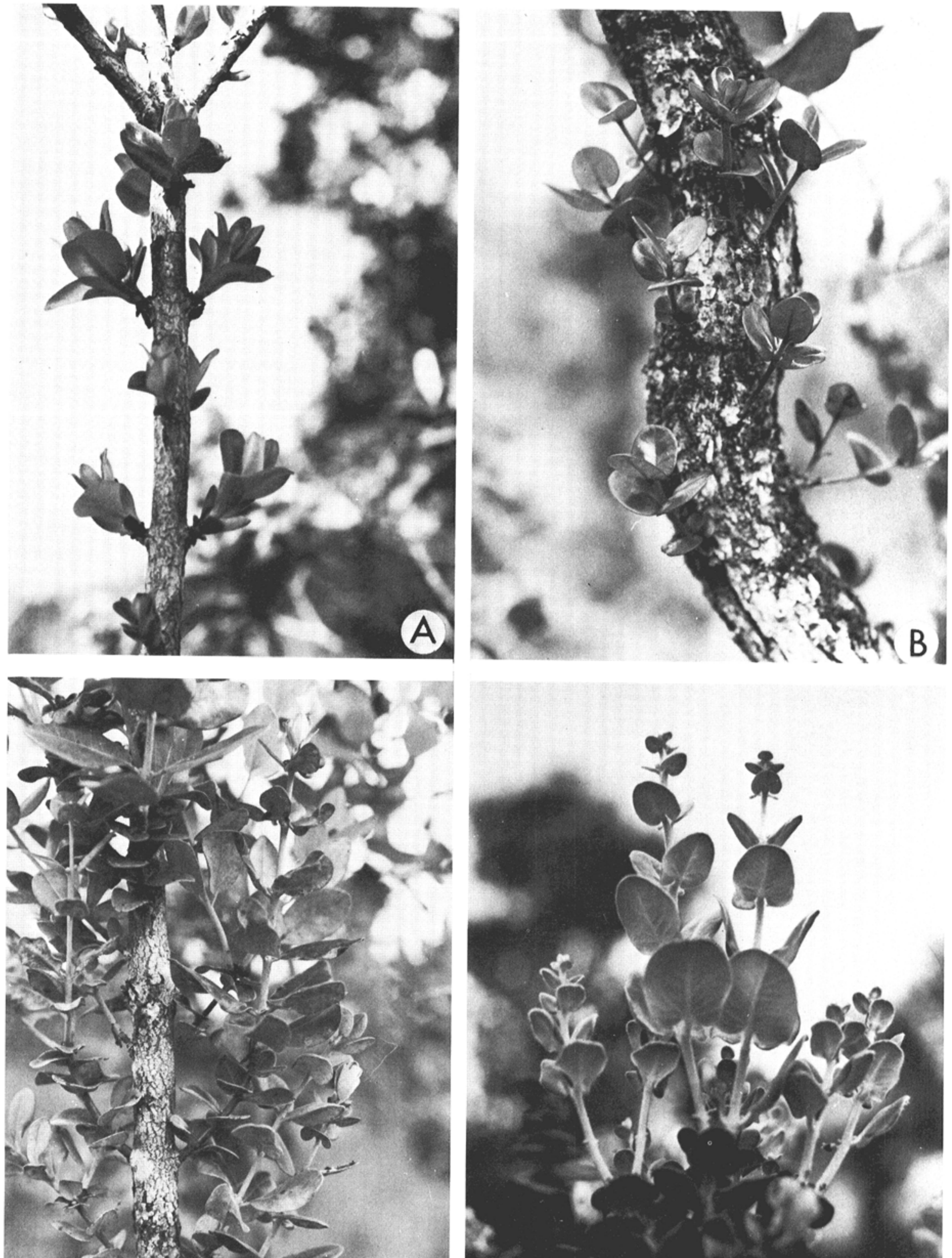
A
B
C
D

TABLE 2. Response of ohia trees to different nutrients

Treatment	New lateral buds produced 8 wk after treatment[y] (No./tree)
NPK + micronutrients[z]	83 a
NPK	102 a
Micronutrients only	8 b
N	6 b
P	6 b
K	6 b
Control	7 b

[y]Average of six trees per treatment. Means followed by the same letter are not significantly different, $P = 0.05$.
[z]Micronutrients included Ca and Mg.

TABLE 3. Response of ohia trees to different combinations of N, P, and K fertilization

Treatment	New lateral buds produced 8 wk after treatment[z] (No./tree)
N + P + K	149 a
N + P	104 b
N + K	39 c
P + K	20 c
Control	20 c

[z]Average of six trees per treatment. Means followed by the same letter are not significantly different, $P = 0.05$.

in a decline area (1,220 m elevation) was cleared of ground vegetation and treated with a broadcast application of complete fertilizer at a rate of 784 kg/hectare (ha) (equivalent to 38.6 kg N/ha; 86.7 kg P/ha; and 23.1 kg K/ha). The plot contained ohia trees of various ages and in all stages of decline. A control plot, treated similarly except that no fertilizer was applied, was established 61 m from the fertilized plot.

Eight weeks after treatment a striking response was evident in the fertilized plot. Numerous new buds developed on all trees including the severely-declining ohia. The average number of new buds produced per tree on 10 randomly selected intermediately-declining ohia trees was 231 in the fertilized plot and 10 in the control plot.

Foliar analysis 6 mo after treatment indicated an increase in uptake of inorganic nutrients by ohia trees in the fertilized plot (Table 4). The levels of N, P, and K were higher in foliage from the fertilized than from the control plot, as were levels of Mg, Cu, Fe, Zn, and Mn. Ca and B were lower in foliage from the fertilized plot, but Al levels were not different.

After 3 mo the vigor and color of ohia leaves in the fertilized plot were strikingly improved compared to leaves in the control plot or even on ohia trees immediately outside the fertilized plot. Fertilized trees were still producing new leaf buds 11 mo later (Fig. 2-B). All trees in intermediate decline could now be classified as healthy on the basis of crown appearance.

Three other plots (6.1 × 9.2 m) at 1,738 m elevation were treated with a broadcast application of the complete fertilizer at a rate of 784 kg/ha. Three control plots were also established. None of the plots was cleared of other vegetation. Ohia trees in these plots were larger and more organic matter was present on the pahoehoe lava surface than in the 15.3 × 30.5 m plot. Three months after treatment only a few new buds on branches and trunks were visible. The plots received a second application of complete fertilizer. Four months later, a definite response was evident. The response of large declining ohia trees to fertilization was somewhat different from that of smaller trees in the previous tests; terminal bud development was stimulated, giving the trees a healthy appearance.

DISCUSSION.—Results of the fertilization trials on declining ohia trees indicate that the trees are declining because of nutrient deficiency. All trees that received complete fertilizer responded by producing numerous new buds on branches and trunks and by subsequent growth of shoots from these buds. Many intermediate-decline trees in plots which were treated with a broadcast application of complete fertilizer a year ago could now be classified as healthy, and show no signs of regression. The question still to be answered is for how long the single broadcast application of inorganic nutrients will continue to alleviate the declining condition.

TABLE 4. The mineral content of leaves from ohia trees in fertilized and nonfertilized plots 6 mo after broadcast application of complete fertilizer

	% dry wt					μg/g					
Treatment	N	P	K	Ca	Mg	Cu	Fe	Zn	B	Mn	Al
Fertilized	0.97	0.08	0.47	0.52	0.17	9.64	25.88	7.68	9.96	340.55	40
Control	0.63	0.04	0.38	0.85	0.15	7.97	21.73	4.69	12.54	336.14	40

Fig. 2-(A, B). Response of declining ohia trees in a 15.3 × 30.5 m plot treated with a single broadcast application of complete fertilizer at a rate of 784 kg/hectare. **A)** Plot at time of treatment. **B)** Same plot as in A), 11 months after treatment. Note the new growth in response to fertilization, which is especially evident in the crowns of the larger ohia trees.

Declining ohia trees responded better when fertilizer was broadcast to large areas than when it was applied directly around an individual tree. A striking response was obtained when complete fertilizer was broadcast at a rate of 784 kg/ha, but application of 75 g to individual trees, equivalent to 897 kg/ha, did not result in a significant response. This probably was because more roots were exposed to nutrients with broadcast application.

Inability of roots to obtain sufficient nutrients to maintain the crown could result from various factors, including infection of roots by a pathogen(s), low soil fertility, or a combination of both. If root destruction by a pathogen was resulting in nutrient deficiency, one would expect to find a consistent association of the pathogen with declining trees. Although *Phytophthora cinnamomi* causes root rot of ohia trees (4), the pathogen was not consistently isolated from roots of declining trees. *Armillaria mellea* had been reported on some ohia trees (6), and we were able to isolate this fungus from ohia trees with mycelial fans and rhizomorphs. However the number of declining trees with signs of *A. mellea* was extremely low.

The rapid response of declining ohia trees to the application of inorganic nutrients, suggests that the root systems are functional but unable to obtain sufficient nutrients from the natural substrate. Most soils on the Island of Hawaii are known to be deficient in certain elements required for plant growth (Y. N. Tamimi, *personal communication*). It is not known if low soil fertility aggravated by environmental conditions could result in such widespread occurrence of ohia decline.

Littleleaf disease of both *Pinus echinata* in the southeastern United States and *Pinus radiata* in New Zealand has been associated with unfavorable soil conditions and root mortality caused by *P. cinnamomi* (1, 3). Application of nitrogen in the case of *P. echinata* (7) and superphosphate in the case of *P. radiata* (8) resulted in control of that disease.

Our preliminary tests showed that addition of fungicides to declining trees increased their response to fertilization. Fungicides alone gave no significant response compared to untreated trees, but treatment with a mixture of Dexon, benomyl, and Difolatan in combination with complete fertilizer was significantly better than fertilizer treatment only (Kliejunas and Ko, *unpublished*). This indicates that at least in certain areas, root pathogens may be involved in ohia decline. The involvement of *P. cinnamomi* and other possible root pathogens in the decline is currently under investigation.

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