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*Lobelia gloria-montis*

## In This Issue



# Status of *Erythrina sandwicensis* in the NifTAL Experiment Site, Kaho'olawe, Hawai'i: A Reassessment

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**Abstract. In 1989 University of Hawaii NifTAL researchers established a field trial to identify fertility-related constraints to the re-establishment of the native tree species *Erythrina sandwincensis* (*wiliwili*) on highly eroded soils of Kaho'olawe Island, Hawaii. In 1996 we re-surveyed this trial to examine the long-term effects of the fertility treatments on the growth of *wiliwili*. After seven years, survival of the trees in the field trial was 95%. Trees receiving applications of phosphorus (P) and zinc (Zn) at planting were significantly larger and more vigorous than those that did not receive P and Zn. Successful re-establishment of the nitrogen-fixing *wiliwili* on eroded Kaho'olawe soils will likely depend on P and Zn inputs.**

Kaho'olawe Island, Hawai'i once supported diverse native dryland forests. Most of the native ecosystems have been lost through a series of changes in land use. Today about one-third of the island is

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a largely barren plateau, commonly referred to as the "hardpan". Original dry forest vegetation may have initially given way to a grassland in some areas as a result of agricultural practices, particularly burning, by Hawaiians. Severe loss of vegetation and soil began with the introduction of goats in 1793, and the onset of western style ranching in the 1850s. Ranching was discontinued after the U.S. Navy took control of the island for training purposes in 1941; however, feral goats remained, denuding much of the island's summit. The goats continued to thwart restoration efforts until they were finally eradicated in the early 1990s.

Today vegetation on the hardpan consists mainly of introduced species including *kiawe* (*Prosopis pallida*), tamarisk (*Tamarix aphylla*), buffelgrass (*Cenchrus ciliaris*), Natal redtop (*Rhynchelytrum repens*), lantana (*Lantana camara*), *koa haole* (*Leucaena leucocephala*), and pitted beardgrass (*Bothriochloa pertusa*). Native *pili* grass (*Heteropogon contortus*), *'ilima* (*Sida fallax*), and indigenous (status uncertain) *'uhaloa* (*Waltheria indica*) are also present. The first revegetation efforts introduced exotic species such as *kiawe* and Australian saltbush (*Atriplex semibaccata*). More recent efforts have been concerned with reestablishing native species like *wiliwili* (*Erythrina sandwicensis*), a dominant dryland forest species. Restoration of native species on Kaho'olawe is difficult because of (i) severe soil erosion that has reduced available nutrients, organic matter, and microbial activity; and (ii) harsh climate, which includes low seasonal rainfall, high solar radiation, high potential evaporation, and strong, persistent trade winds. A history of environmental degradation and prior revegetation projects are provided in other works (Kaho'olawe Island Conveyance Commission, 1993; Giambelluca et al., 1997).

In November 1989, University of Hawaii NifTAL (Nitrogen Fixation by Tropical Agricultural Legumes) researchers, with the support of the US Navy, installed a split-plot field trial on the hardpan to identify microbial and mineral constraints to re-establishing the *wiliwili* tree, an endemic nitrogen-fixing leguminous species (Nakao et al., 1993). Analysis in 1990 by NifTAL researchers confirmed the experimental hypothesis that phosphorus + zinc inputs, combined with the reintroduction of the *wiliwili* microbial symbiont for nitrogen fixation, would enhance the success of reestablishing *wiliwili* on the hardpan (Nakao et al., 1993). In 1996 we re-surveyed the NifTAL experiment site to determine the survival of the experimental trees and the long-term effects of the various treatments.

## Study Area

The NifTAL experiment site is located on the hardpan between tamarisk (*Tamarix aphylla*) windbreak rows on gently sloping land near the northern rim of Lua Makika, the shallow caldera at the summit of Kaho'olawe. The soil of this area is largely the Bw horizon of an exhumed paleosol, dominated by the *Kaneloa* soil series—which resembles the Molokai Oxisol of Hawai'i (Soil Conservation Service, 1976; Nakamura & Smith, 1995). Soil hydrological, chemical, and physical properties associated with the *Kaneloa* Oxisol are listed in **Table 1**. In general tropical Oxisols are deficient in nitrogen, phosphorus, potassium, sulfur, zinc, and molybdenum (Manrique, 1993). Warren et al.,(1988) determined the low levels of phosphorus and zinc to be limiting nutrients for revegetation in Kaho'olawe soils. Additionally they found levels of potassium to be very high; sodium, iron, copper, sulfur, and boron to be high; and calcium and magnesium to be adequate. Estimated mean annual rainfall on Kaho'olawe is 371 mm, with nearly 70% coming between November and March (Ziegler & Giambelluca, 1997).

## The Original NifTAL Experiment on Kaho'olawe

In November 1989, a split-plot experimental design was implemented at the NifTAL site (Nakao et al., 1993). The main plots were designed to measure long-term effects of P and Zn fertilization; the subplots tested short-term N-source effects within the two main plots (Fig. 1). There were four replications of six treatment combinations (Table 2). Each subplot consisted of 20 seedlings, planted in five rows of four trees, with a spacing of 1.5 m, for a total of 480 seedlings. Details of seedling germination and inoculation are described by (Nakao et al.,1993). At six months, the seedlings were planted with fertilizer treatments in 15 cm diameter holes created in the hardpan with explosives. The trees were watered immediately following planting, but long-term irrigation was not used.

Basal diameter (*BD*), height (*h*), and stem volume (*SV*) of the inner six plants in each

**Table 1.** Chemical, Physical & Hydrological Characteristics of the Kaneloa Soil Series on Kaho'olawe Island.

| Soil Characteristics | Units | Value† |
|---|---|---|
| From Warren et al.,(1988) | | |
| Phosphorus (Bray P1)* | kg $ha^{-1}$ | 2.0 ± 0.0 |
| Phosphorus (Bray P2) | kg $ha^{-1}$ | 3.8 ± 0.6 |
| Potassium | kg $ha^{-1}$ | 629.2 ± 166.4 |
| Calcium | kg $ha^{-1}$ | 2004.3 ± 487.9 |
| Magnesium | kg $ha^{-1}$ | 739.4 ± 164.4 |
| Sodium | kg $ha^{-1}$ | 1869.2 ± 878.2 |
| Zinc | mg $kg^{-1}$ | 950 ± 450 |
| Synthesized from data of Nakamura and Smith (1995) | | |
| Nitrogen | — | *low* |
| Exchangeable $Ca^{2+}$ | cmol (+) $kg^{-1}$ | 3.61 |
| Exchangeable $Mg^{2+}$ | cmol (+) $kg^{-1}$ | 2.88 |
| Exchangeable $K^{+}$ | cmol (+) $kg^{-1}$ | 1.27 |
| Kaolinite / Halloysite | — | moderate |
| Gibbsite | — | moderate to large |
| Soil texture | — | Silty clay loam |
| Available water capacity | m/m | 0.10 - 0.14 |
| Drainage class | — | well-drained |
| Depth to bedrock‡ | m | > 1.5 |
| Determined in this study§ | | |
| pH in water (1:1) | — | 6.4 ± 0.3 |
| Organic carbon | g $kg^{-1}$ | 0.85 ± 0.15 |
| Sat. hydraulic conductivity | mm $h^{-1}$ | 72.3 ± 33.1 |
| Field bulk density | g $cm^{-3}$ | 1.10 ± 0.06 |
| Soil moisture at saturation | — | 0.46 ± 0.04 |
| Soil strength | bars | 4.51 ± 2.65 |
| silt/clay fraction | — | 0.09 ± 0.01 |
| Typical surface material | — | duracrust/durapan |

*Phosphorus was extracted with Bray P1 (1:10 soil: solution of 0.03 ammonium fluoride and 0.025N HCl) and P2 (1:10 soil: solution of 0.03 ammonium fluoride and 0.1 HCl).

† Values are ± one standard deviation about the mean.

‡ Parent material is strongly weathered volcanic ash over strongly weathered basic igneous rock.

§ Data are for 5 soil samples taken near the NifTAL site except for Zn data, which was collected at 4 locations within the CERL experimental watershed (Warren and Aschmann, 1993).

subplot were determined by NifTAL researchers four months after planting (Nakao et al.,1993). Inoculated seedlings at both high and low P/Zn fertility levels had the greatest relative increase in *SV*; however, direct comparisons of *SV* among the various subplots showed few significant differences. At that time, block effects were significant, with plants at the bottom of the slope with the largest *SV*. This effect indicated water availability was likely affecting the experimental results.

## Methods

For the reassessment reported herein, height and basal diameter of the inner six trees within each sub-plot were measured in 1996. Stem volumes were not calculated, as was done in the 1990 assessment, because the trees no longer had conical stems. Two-factor ANOVA was used to assess interaction between the two application rates of P + Zn and the three N-source treatments. If during ANOVA testing, significant differences were detected within factors, post-hoc multiple comparison testing using Fisher's Protected Least Significant Difference test (FPLSD) was used to identify statistically indistinguishable groups. Because the untransformed data were positively skewed (all skewness values > 1.0 for n ≥ 24), *h* and

**Table 2.** Characteristics of the NifTAL split block design. The main block was designed to test two application rates of phosphorous and zinc fertilizer; the sub-block, three nitrogen-source treatments, including rhyzobial inoculation. TI=Treatment Identifier.

| TI | (kg ha$^{-1}$) | (kg ha$^{-1}$) | (kg ha$^{-1}$) | (yes/no) |
|---|---|---|---|---|
| LI‡ | 0 | 0 | 0 | y |
| LN | 0 | 0 | 200 | n |
| L | 0 | 0 | 0 | n |
| HI | 800 | 5 | 0 | y |
| HN | 800 | 5 | 200 | n |
| H | 800 | 5 | 0 | n |

† Fertilization rates for phosphorus (P), zinc (Zn), and nitrogen (N).

‡ L = no P/Zn applied; H = high P/Zn application rate; I = inoculated; N = nitrogen applied.

*BD* values were log-transformed to stabilize variances and approach normality as suggested by Zar (1996).

## Results

Of the 480 trees planted in 1989, 458 had survived in 1996 (95%). The survival rate was higher until early 1996 when removal of military ordinance in the area caused several trees to be lost (Dan Holmes, Protect Kaho'olawe 'Ohanna, pers. comm., 1997). Many of the trees showed insect damage and did not appear healthy. The field site was barren hardpan when the experiment was planted, and now supports various, mostly alien, grass species between the trees—total cover is < 10% in most areas.

Two-factor ANOVA testing of the P + Zn application rates and the inoculation treatments indicated (i) significant differences in *h* and *BD* between the high and low application rates of P/Zn; (ii) no significant differences in *h* and *BD* among the N-source treatments; and (iii) no interaction between the P/Zn treatments and the N-source treatments. All treatments that received P + Zn had greater biomass than the treatments that did not receive P and Zn (one-factor AVOVA). Mean values of *h* and *BD* are shown in Table 3.

## Discussion

As there were originally no indigenous rhizobia detected in the hardpan soil prior to the planting, the original NifTAL investigators determined that the introduction of the microsymbionts through inoculation was

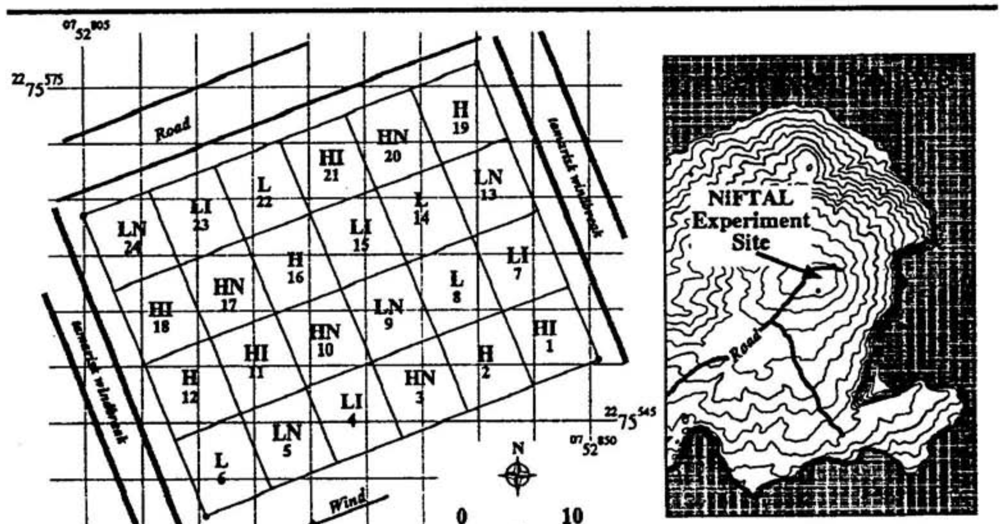


**Fig. 1.** The NiFTAL study area on eastern Kaho'olawe Island, Hawai'i. The six different treatments tested in each of the 24 planting blocks are described in Table 2. The site is sheltered on the windward side by a tamarisk (*Tamarix aphylla*) windbreak row.

**Table 3.** Mean values for height and basal diameter for *wiliwili* receiving one of two application rates of P and Zn, and various N-source treatments. Determined in 1996, seven growing seasons after planting. Treatments are described in Table 2. All data were log-transformed prior to statistical testing.

| Treatment | LN | L | LI | HN | H | HI |
|---|---|---|---|---|---|---|
| Sample number* | 24 | 22 | 24 | 23 | 21 | 24 |
| Height (cm)† | 38.8 ± 10.3[a] | 39.5 ± 16.4[a] | 34.4 ± 12.8[a] | 74.5 ± 32.5[b] | 64.2 ± 27.2[b] | 78.1± 36.9[b] |
| Basal diameter (mm) | 25.1 ± 12.7[a] | 23.8 ± 7.4[a] | 21.9 ± 8.2[a] | 42.1 ± 15.4[b] | 37.1 ± 15.8[b] | 44.9 ± 19.4[b] |

* Sample size refers to the number of living *wiliwili* out of a possible of 24 (6 inner planting locations x 4 plots).
[a,b] Mean values in a given row with the same letter are NOT significantly different (ANOVA, a= 0.01).
† Means are ± one standard deviation

necessary to establish a nitrogen fixing symbiosis for *wiliwili* at the site. Further, their initial analyses of the experiment in 1990 indicated that native soil nitrogen (treatment with neither rhizobia nor mineral N added) was insufficient to support maximal growth of the *wiliwili*. *Wiliwili* is a deciduous species with a high requirement for N; therefore, seven seasons of growth (1989 to 1996) would have exacerbated limitations due to inadequate soil N. Since differences can no longer be detected among the three N-source treatments (i.e., Table 2), we speculate the introduced rhizobia have spread throughout the experimental site through movement of water during rainstorms, and all of the trees are benefiting from symbiotically fixed N. In support, pre-planting inoculation trials by NifTAL researchers indicated loss of "uninoculated" control treatments to cross contamination is generally inevitable after four months, even in carefully managed environments (Nakao et al., unpublished data).

Because P and Zn applications were combined in the NifTAL field experiment, it is not possible to determine the individual contributions of each nutrient in producing the increased biomass. Soil tests indicate that both nutrients occur in low concentrations on the island (Warren et al.,1988). The application rate of P was high at 800 kg $ha^{-1}$ (per hole basis)—a rate that may not be practical in large scale revegetation efforts. In a pot test, *wiliwili* grown in the hardpan soil, amended with seven levels of P, required 800 kg P $ha^{-1}$ to maximize growth potential after four months; however, when *wiliwili* was inoculated with vesicular arbuscular mycorrhiza (VAM), the level of P required to maximize growth potential was reduced to 200 kg $ha^{-1}$ (Nakao et al.,1993). Further research in the field is needed to determine optimal rates for P inputs, and to increase the efficiency of the inputs through VAM.

In 1990, NifTAL investigators found that seedlings planted at the same time as the experimental trees but at another site (CERL Phase II, see Giambelluca et al.,1997 for review) were developing more biomass than the NifTAL experimental trees. The trees at the CERL II site were inoculated and fertilized similarly to those in the HI treatment, but were planted in loose soil along 1-m high soil berms. Vegetative ground cover is higher at the CERL II site (73% compared to the nearly barren experimental site). Our survey of 40 trees at the CERL II site again indicated these trees were considerably larger than those at the experimental site. The CERL II trees had *h* and *BD* of 162.3 cm and 68.0 mm, respectively. Several factors may contribute to the increased growth of *wiliwili* at the CERL II site: (1) the trees may benefit from increased soil moisture resulting from higher water infiltration and capture from the berms in which they were planted, e.g., mean saturated hydraulic conductivity at the NifTAL site is approximately 73 mm $h^{-1}$, compared to 180 mm $h^{-1}$ in the CERL II site (estimated from data in Ziegler & Giambelluca, 1997); (2) increased vegetation at CERL II may have accelerated VAM infection of the *wiliwili* root systems; and (3) the berms may have provided greater wind protection to the seedlings than is available at the experimental site.

The survival rate of the *wiliwili* trees at the NifTAL and CERL II sites is high compared to other sites on the island. At the CERL Phase I site (Warren & Aschmann, 1993; Ziegler et al.,unpublished), only 14 of 103 *wiliwili* trees planted in 1991 have survived. At two other sites

(U.S. Forest planting exclosures 4 and 5), only six of 88 *wiliwili* planted in 1971 and 1973 now survive. These low survival rates at the CERL Phase I and U.S. Forest Service sites can be attributed at least in part to the much greater wind exposure at these locations compared with the CERL II and NifTAL plantings (Giambelluca et al., 1997).

## CONCLUSIONS

1. There are significant long-term benefits to P and Zn inputs in the re-establishment of *wiliwili* on the Kaho'olawe hardpan area.
2. Assuming nitrogen fixation is occurring within the site, *wiliwili* can probably meet N requirements without mineral N inputs. Additional work is needed to verify nitrogen fixation within the site.
3. The comparatively better growth at the CERL II site indicates that the growth of *wiliwili* at the NifTAL site may be constrained by other factors, such as poor infiltration of water into the soil.
4. In regard to island restoration, 95% of the seedlings planted in 1990 survived on the hardpan without irrigation, demonstrating the resilience of this species, and thus, suitability as a revegetation species. However, low survival rates at other experiment sites on Kaho'olawe suggest that protection of *wiliwili* from the high winds is a necessary strategy for establishing the trees.

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## REFERENCES

Giambelluca, T.W., Egan, J.R., Garcia, K., Louis, R., Perry, J.L., Richardson, F., Chun-Smith, A.A., Ziegler., A.D. (1997) Lessons Learned: Kaho'olawe Restoration Efforts Prior To 1996. Final Report. Kaho'olawe Island Reserve Commission, Honolulu, HI.

Kaho'olawe Island Conveyance Commission. (1993) Kaho'olawe Island: Restoring a cultural treasure. Final report to the Congress of the United States. xiv + 158 pp.

Manrique, L.A. 1993. Tropical Soils. In L.A. Manrique, Soil Management and Conservation in the Tropics. Manrique International Agrotech, Box 61145, Honolulu, HI, 96839. 215 pp.

Nakamura, S. & Smith, C.W. (1995) Soil Survey of Island of Kahoolawe, Hawaii. U.S. Department of Agriculture, Natural Resources Conservation Service, in cooperation with the United States Department of Navy, Pacific Division, Naval Facilities Engineering Command. Washington, D.C.

Nakao, P.L., Keyser, H.H., Bohlool, B.B., & Singleton, P.W. (1993) Soil constraints to the reestablishment of *Erythrina sandwicensis* in an eroded soil in Hawai'i. *Erythrina* in the New and Old Worlds (eds., S. Westely & M. Powell), pp. 322-329. NFTA-CATIE, Turrialba, Costa Rica.

Soil Conservation Service. (1976) Soil Survey, Laboratory Data, and Descriptions for Some Soils of Hawaii. Soil Survey Investigations. Report No. 29. U.S. Gov. Printing Office, Wash. D.C., 208 pp.

Warren S.D., Vachta, E.G., and Banwart, W.L. (1988) Rehabilitation proposal for Kahoolawe Island, Hawaii. U.S. Army Corp of Engineers Construction Engineering Research Laboratory, Champaign, Illinois.

Warren, S.D., & Aschmann, S.G. (1993) Revegetation strategies for Kaho'olawe Island, Hawaii. J. Range Manage. 46, 462 - 466.

Whitesell, C.D. & Wong Jr., H.C. (1974) Sixth progress report on vegetation trials for rehabilitating Kahoolawe Island, Hawaii. Pacific Southwest Forest and Range Experiment Station, Honolulu, HI.

Zar, J.H. (1996) Biostatistical analysis. 3rd ed. Prentice-Hall, Inc., Upper Saddle River, NJ. 662 pp.

Ziegler, A.D. & Giambelluca, T.W. (1997) The influence of revegetation efforts on hydrologic response and erosion, Kaho'olawe Island, Hawai'i. J. Land Degrad. Develop. (in press).

Ziegler, A.D., Perry, J.L., Giambelluca, T.W. & Warren, S.D. (unpublished) Reassessment of revegetation strategies for Kaho'olawe Island, Hawai'i. J. Range Manage. (in review).