Forest Restoration on Degraded Soils in Yap, Federated States of Micronesia

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Abstract

Reforestation of sites with acidic, highly leached soils has been a problem in the tropics worldwide, and results of fertilization have been varied. We applied both fertilizer and lime to a new plantation of *Acacia auriculiformis* A. Cunn. ex Benth. on an Oxisol on the island of Yap in the Federated States of Micronesia. Fertilized trees had 46 percent more height increment than control trees over a 2.4-year period, but there was no effect of lime application. A. auriculiformis is well known for being tolerant of soil acidity. Our results emphasize the value of fertilization during establishment and early growth for trees planted on leached, acidic tropical soils.

Introduction

Restoration of forest cover on deforested sites in the wet tropics can be challenging. Once native forest is cleared, the litter layer and topsoil may be lost due to the exceptionally fast oxidation rates that reduce organic matter at the surface of exposed tropical soils. Frequent fires in abandoned pastures or agricultural lands cause additional reduction of organic matter and can lead to erosion and further soil degradation (figure 1). Highly weathered Oxisols and Ultisols, typically found in tropical areas, are usually acidic and low in nutrients. These soils have high levels of phosphorus (P) fixation and may have high levels of toxic aluminum (Al) or manganese

Figure 1. Badly degraded, acidic soils pose a challenge for reforestation in Yap, Federated States of Micronesia. (Photo by James B. Friday 2015)

(Mn), which is limiting to tree growth (Marcar and Khanna 1997, Scowcroft and Silva 2005). Fertilization of tree plantations is a standard practice in some tropical countries, especially where soils are Oxisols or Ultisols (Gonçalves et al. 1997) or Andisols (Cannon 1983). Unless foresters fertilize trees properly at planting, reforestation projects may never develop well.

We report here on a fertilizer trial for a reforestation project on the island of Yap in the Federated States of Micronesia. Significant areas of Yap have been deforested but are no longer used for agriculture (Falanruw 1992, Mueller-Dombois and Fosberg 1998). These areas burn frequently and harbor invasive plants. Restoration of these deforested areas has long been a priority for Pacific Island foresters (DeBell and Whitesell 1993). Yap Forestry is working to reforest these areas for small-scale wood production, reduce soil erosion, stabilize watersheds, establish fuel breaks, reduce the frequency of grass fires, and shade out invasive grasses, particularly *Imperata cylindrica* (L.) P. Beauv. (figure 2).

Several tree species have been planted in trials in Yap and some of the best performing have been the Australian natives *Acacia auriculiformis* A. Cunn. ex Benth. and *A. mangium* Willd. (DeBell and Whitesell 1993). Foresters have favored these trees because of their ability to survive on poor sites, including on moderately acid soils, and their rapid growth on good sites (figure 3). The thick canopies formed by these species can shade out invasive plants in the understory. These species are not native to the Pacific islands and can be considered invasive in favorable environments. In some locations on Yap, however, growth of these trees has been slow, likely hampered by low pH, Al toxicity, and a lack of nutrients (figure 4). Exceptionally slow tree establishment is risky because their ability to recycle nutrients is impaired and they have low resistance to fungi, insects, and fire. As a consequence of these failings, the benefits associated with established trees are not fully realized.

Growth rate of trees depends greatly on soil fertility. As such, fertilizer experiments are important to determine tree responses to varying types and rates of supplemental nutrients applied to the soil. Cole et al. (1996) studied growth of seedlings of 12 species of Acacia, including *A. auriculiformis*, *A. mangium*, and *A. koa* A. Gray on an acidic Ultisol in Hawaii. They found that 8 of the 12 species responded to post-planting applications of P and potassium (K) but the other species did not. Earnshaw et al. (2016) studied fertilization of plantations of *A. koa* on two acidic Andisols in Hawaii and found that fertilization increased seedling height from 31 percent to 49 percent on one soil, which was on a cooler, rockier site, but not on the other. They also found similar gains in growth with seedlings receiving lower amounts of nutrients applied as slow-release fertilizer as seedlings receiving higher amounts of nutrients applied as soluble fertilizers. Amelioration of soil acidity by application of agricultural lime can increase cation exchange capacity and nutrient supply and decrease Al and Mn soil toxicities (Uchida and Hue 2000). Liming also supplies calcium (Ca) (and magnesium [Mg] if dolomite lime is

Figure 2. A 3-year-old *Acacia auriculiformis* survived one of many brush fires in Yap, Federated States of Micronesia. (Photo by James B. Friday 2014)

Figure 3. Good growth of 14-year-old *Acacia auriculiformis* trees planted on a site with relatively good soil conditions in Yap, Federated States of Micronesia. (Photo by James B. Friday 2014)

Figure 4. Poor growth of 4-year-old *Acacia auriculiformis* trees planted on a site with acidic soils on Yap, Federated States of Micronesia. (Photo by James B. Friday 2014)

used), both of which can be limiting nutrients (Fisher and Binkley 2000). However, liming is seldom used for forestry projects because of the expense of application, which is usually tons per acre, and the difficulty of tilling the lime into the soil.

The objective of our study was to determine whether application of slow-release fertilizer or lime at rates commonly applied during afforestation could help increase *Acacia auriculiformis* seedling growth.

Material and Methods

Site

The study was conducted on a recently planted site with homogeneous topography. The plantation had just one planted species (*Acacia auriculiformis*), planted one month earlier (February 2017) and was located near Graveyard 47 (close to the Yap International Airport, N 9° 29' 38.29 E 138° 5' 2.9). The soil is in the Gagil series, a fine, sesquic, isohyperthermic typic haploperox, typically with a strongly acid pH of 5.2 in the surface 4 in (10 cm) (NRCS 2020). The parent material is a breccia and topography is quite level.

The site had previously been cleared for agriculture but had since been abandoned. Annual precipitation averaged 117 in (2,970 mm) during the experiment (2017 through 2019; NOAA 2020). Yap has a short, but not very distinct dry season from February through April, although rainfall still exceeded evapotranspiration rates for each month during the experiment. The understory of the plantation consists mainly of the sprawling native fern *Dicranopteris linearis* (Burm.) Underw., which is generally regarded as an indicator of poor-quality, acid soils. Understory vegetation was manually controlled at planting and annually ahead of measurements.

Treatments

Trees were fertilized with a fertilizer and quicklime (CaO), both of which were purchased at the local hardware store. The fertilizer was a coated, slow-release formulation (Osmocote® 13-13-13; N:P_2O_5:K_2O). Actual composition of the fertilizer was 13 percent N (nitrogen), 5.7 percent P, and 10.8 percent K. The fertilizer was formulated for a gradual 7-month release, but in the warm, tropical environment of Yap, nutrient release was likely faster.

Four blocks (replications) were designated in the plantation test site, each consisting of 3 rows of 8 *Acacia auriculiformis* seedlings that had been planted 1 month previously. Each row in each block was randomly assigned to receive one of the following treatments:

1) Control (no fertilizer or lime applied)

2) Fertilizer-only (1.8 oz [50 g] per seedling)

3) Fertilizer plus lime (1.8 oz [50 g] of fertilizer and 3.5 oz [100 g] of lime)

Treatments were applied on March 23, 2017. Fertilizer was applied by splitting the dosage between two shallow holes 6 in (15 cm) from each seedling designated for fertilizer. After placement in the hole, the fertilizer was covered with 2 in (5 cm) of soil to prevent N volatilization. Lime was applied by spreading the dose evenly on the soil surface within a 24-in (60-cm) radius of the seedling stem.

Measurements and Statistical Analyses

All seedlings in the experiment were measured for height at the time of planting and again on September 29, 2017; February 1, 2018; August 13, 2018; and August 8, 2019. Any dead or missing seedlings were noted.

Data were subjected to a Shapiro-Wilke normality test and a Levene test for homogeneity of variance—both confirming that the data satisfied necessary assumptions for analysis of variance (ANOVA). ANOVA was then used to analyze differences in height increase among the three treatments over time. Eta-squared statistics were calculated from the ANOVA model to evaluate the size of any treatment effects. A t-test was subsequently used to assess whether the fertilizer and the fertilizer-plus-lime treatments differed non-randomly in their effects. The analyses were conducted using R (R Core Team 2020).

Results

Survival was high, with 95 percent of the trees surviving after 2.4 years. Tree height increased roughly linearly during the experiment for all treatments (figure 5). There was strong evidence of a treatment effect ($p < 0.001$) on height increase, with seedlings that received the fertilizer or fertilizer-plus-lime treatments growing 64 in (153 cm) more on average than unfertilized seedlings, a 46-percent increase (figures 6 and 7). The effect was not especially strong (treatment eta-squared = 0.26), indicating that only about a quarter of the variability in height was due to the treatments. Height increment did not differ significantly between the fertilizer and fertilizer-plus-lime treatments ($p=0.49$).

Discussion

Fertilizer Response

This simple experiment set up on one site in Yap clearly showed a growth response of *Acacia auriculiformis* to fertilizer application. An effect of this magnitude would typically be considered meaningful in forestry, but the plantation purpose and other factors need to be considered to justify the expense and effort of applying fertilizer. For the purposes of just having forest cover, it might not be worth it. If it is important to enable trees to grow faster to avoid the need for weed control, to provide an effective shaded fuel break, or to grow forest products, then this additional growth may be quite important. Other forest plantations on Yap have been burnt by wildfires before canopy closure could shade out understory grasses.

We did not investigate the effect of individual nutrients on tree growth; some future investigation might be useful. Although *Acacia* spp. have the ability to fix atmospheric N, this ability is strongly influenced by the supply of available P (Binkley et al. 2003)—an important factor to account for when considering this species. Leguminous trees growing in acid soils are often observed to nodulate poorly, with growth of the nitrogen-fixing rhizobium severely limited by the acidity (Marcar and Khanna 1997). We suspect that the fertilized trees in our study benefited from both the N and P in the fertilizer. Manubag et al. (1995) found responses to both N and P fertilization with the closely related species *Acacia mangium* in a strongly acid soil in the Philippines. Earnshaw et al. (2016) and Idol et al. (2017) found increases in height growth of *A. koa* with P fertilization on slightly acid to strongly acid soils in Hawaii. Working on similar soils to the Yap site on the neighboring island of Palau, Dendy et al. (2015) found that fertilization with a complete NPK fertilizer increased the rate of expansion of native forest patches into degraded savanna and increased fruit, flower, and leaf production of several native tree species. While N and K are likely leached quickly from the site if not taken up by plants, P fertilizers can have longer term impacts. Meason et al. (2009) found elevated levels of P 3 years after fertilization of an *A. koa* stand on an Andisol in Hawaii. Future tests of fertilizers containing differing combinations of N, P, and K and at varying application rates are warranted.

Lime Response

The lack of response to applying limestone in conjunction with the fertilizer is somewhat puzzling. Typically, lime is incorporated into the soil rather than simply top-dressed as we did in this study. Incorporating lime into

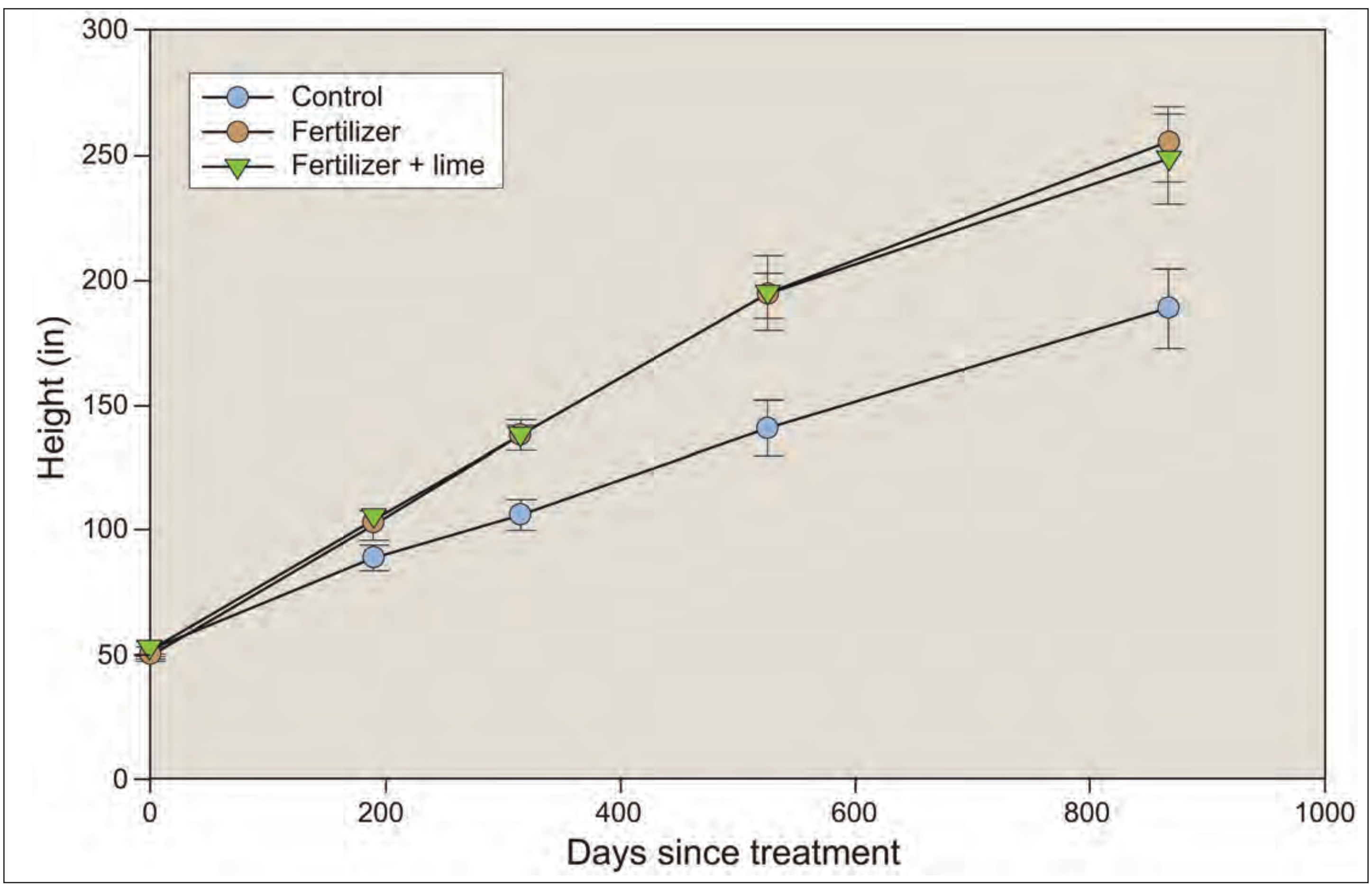

Figure 5. The effect of three fertilizer treatments on height growth of *Acacia auriculiformis* in Yap Federated States of Micronesia. Error bars represent standard errors.

Figure 6. Two-and-a-half-year-old *Acacia auriculiformis* seedling treated with fertilization plus lime 1 month after planting on Yap, Federated States of Micronesia. (Photo by James B. Friday 2019)

Figure 8. Satisfactory growth of an unfertilized 10-month-old *Acacia auriculiformis* seedling on Yap, Federated States of Micronesia. (Photo by James B. Friday 2018)

Figure 7. Growth of fertilized (left row) vs. unfertilized (right row) 19-month-old *Acacia auriculiformis* seedlings on Yap, Federated States of Micronesia. (Photo by James B. Friday 2018)

the soil before the trees were planted might have had a greater effect. *Acacia auriculiformis* is also known for tolerating acid soils (Marcar and Khanna 1997, Powell 1995), as opposed to many other legume trees such as *Leucaena leucocephala* (Lam.) de Wit (National Research Council 1984). In an experiment with *A. koa* on strongly acid soils in Hawaii, Scowcroft and Silva (2005) found differences between seed sources in tolerance to soil acidity. In our study, growth of the unfertilized, unlimed trees was still considerable, averaging 80 in (2 m) per year for the duration of the experiment (figure 8). On an extremely acid soil (pH 4.4) in a somewhat drier location in Hawaii, Cole et al. (1996) found that unfertilized young *A. auriculiformis* grew an average of 83 in (2.1 m)/yr in height but grew 106 in (2.7 m)/yr when limed and fertilized with additional P and K. Diameter growth (and hence volume) increased significantly with liming but not height.

Plants growing in soils with pH less than 5.5 typically show Al toxicity (Cole et al. 1996). The most toxic form of aluminum, Al^{3+}, predominates at pH values below 5.0, whereas the less toxic forms, $AlOH_2+$ and $Al(OH)^{2+}$, predominate at pH values of 5 to 6 (Bojórquez-Quintal et al. 2017). No measurements of soil pH were taken at our study site, but pH values taken on soils of the same series on Yap have ranged from 4.9 to 5.8 (Friday, unpublished data), and so this site may be marginal for showing effects of soil acidity. This experiment should be repeated on a soil type that clearly has Al toxicity issues (as can be evidenced by bauxite nodules lying on the soil surface) and should also include a full factorial such that the effect of lime without fertilizer can also be evaluated. Other research in Yap is currently investigating lime and mulch effects on seedling growth. Another approach to explore is evaluation of native trees with known tolerance to acid soils such as *Rhus taitensis* Guill., C*ommersonia bartramia* (L.) Merr., *Trichospermum ledermannii* Burret, or *Hedyotis* spp.

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