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# Height-Growth Gains 40 Months after Fertilization on Young *P. caribaea* var. *hondurensis* in Eastern Colombia[1]

*P.V. Bolstad*, M. Kane*, J. Galindo**

ABSTRACT

Eight fertilizer studies established in five-month-old *Pinus caribaea* var. *houndurensis* Barr. and Golf. in the savannah region of eastern Colombia revealed significant height-growth gains due to K, P, B, and Mg fertilization, and no response to fertilization with N or Zn when measured 17 and 40 months after fertilization. Phosphorus applied as triple superphosphate (TSP) provided larger gains more consistently than equal elemental rates applied as rock phosphate, at least up to a 132 kg/ha rate. Height gains due to K fertilization increased with elemental K rate up to 32 kg/ha. Height growth response to B was highest at 1.8 kg/ha and to Mg at 26 kg/ha. No differences in growth were observed between bare-root and container stock, nor between band and broadcast applications. There were no interactions observed after P, K, and B fertilization. Foliar K levels were significantly higher and B levels were elevated as result of fertilization both five and 40 months after fertilization.

COMPENDIO

Se establecieron ocho ensayos de fertilización de *Pinus caribaea* var. *hondurensis* durante setiembre de 1982 en una joven plantación ubicada en los Llanos Orientales de Colombia. Evaluaciones de la altura de los árboles al transcurrir 17 y 40 meses han demostrado que la aplicación de los nutrimentos, fósforo, potasio, magnesio y boro aumentó la tasa de crecimiento de *P. caribaea* var. *hondurensis*. mientras nitrógeno y zinc no la aumentaron. El orden de ganancia fue potasio, fósforo, magnesio y boro. La aplicación de superfosfato triple en línea a 132 kg/ha produjo la mejor ganancia de fósforo. Ganancias debido a la aplicación de K aumentó hasta 32 kg/ha. Se observaron la máxima ganancia de B a 1.8 kg/ha y de Mg a 26 kg/ha. Las plántulas sembradas a raíz desnuda mostraron ganancias iguales o mayores que las observadas para plántulas producidas en bolsa. No se observaron interacciones entre los elementos P, K, y B. Las concentraciones foliares de K fue significativamente elevada 40 meses después de la aplicación de los fertilizantes.

## INTRODUCTION

*Pinus caribaea* Mor. is a medium to large tree which is widely planted throughout the lowland tropics (9). The species has been the focus of much silvicultural and genetic research because it has the potential to perform suitably on millions of hectares worldwide, and commercial planting programs are established in Australia, East Africa, Fiji, South-East Asia, and Latin America.

The ability to perform well across a wide range of nutrient-poor soils contributes to the success of *P. caribaea* (9). Nonetheless, response to fertilization has

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been observed in *P. caribaea*, particularly on sandy soils with low organic matter contents, and least one operational fertilization program has been established (19).

Afforestation with *P. caribaea* has been suggested as a possible land use for the "llanos" of northern South America, a savannah spanning eastern Colombia and southern Venezuela (6). This region covers more than 20% of both countries and is characterized by flat topography, mean annual temperatures near 25°C, annual rainfall between 1000 and 2500 mm, and well-drained, sandy soils. Afforestation projects using *P. caribaea* are being implemented in the region (15), and marked variation in growth and form is often observed, with severe nutrient deficiencies apparent. This paper reports height growth and foliar nutrient response of *P. caribaea* to phosphorus (P), potassium (K), boron (B), magnesium (Mg), zinc (Zn), and nitrogen (N) fertilization in the llanos of Colombia

## MATERIALS AND METHODS

The research was conducted at 4° 10' N, 72° 10' W near Puerto Gaitan, Meta Department, in the llanos of eastern Colombia. The area is characterized by flat to gently rolling grass-covered plains dissected by occasional streams; woody vegetation occurs naturally only in riparian areas. Principal grass components of the savannah vegetation are *Trachipogon* spp. and *Paspalum* spp. Mean annual temperature is 26°C, and annual rainfall averages 2240 mm, 90% occurring between April and November. Elevation of the study site is 195 m above mean sea level. Soils are generally sandy, well drained, nutrient-poor Ustic Quartzipsamments. The test sites had been used for extensive cattle grazing before 1977, the year forestry activities were initiated by Pizano S.A., a Colombian forest products company. From 1977 to 1982, a series of preliminary fertilization studies were established to identify those elements limiting *P. caribaea* growth; based on these studies, a set of fertilizer trials was established during September and October, 1982, in a five month-old *P. caribaea* var. *hondurensis* Barr. and Golf. (hereafter referred to as *P. caribaea*) planting, the seed provenance being Santa Barbara, Honduras. The study area, originally occupied by native grasses, was double disked in preparation for planting at a spacing of 2.4 by 2.6 meters. Slope was less than 5% over the study area. Soil characteristics at trial establishment (Table 1) were obtained from composite bulk samples taken from the top 20 cm collected from each control plot

Eight different, but complementary trials were designed to determine effects of rate, application method, and interactions between various nutrients (Table 2). Although design varied among trials, certain design characteristics were common to all. All treatment plots were 10 trees by 10 trees, consisting of two border rows on all sides and an interior measurement plot of 36 trees. Treatments were blocked, one replicate per block and four blocks per trial. Slope position was used as the principal criterion for blocking, and areas with an excessive number of leaf-cutter ant nests (*Atta* spp.) were excluded, as these sites often have atypical soil conditions.

Seedlings were produced in containers except where a specific treatment called for bare-root stock. Phosphorus was applied as triple super phosphate (TSP) or rock phosphate (RP), K as potassium chloride, B as borax, Mg as magnesium sulfate, N as ammonium nitrate, and Zn as zinc sulfate. Rock phosphate was 7.1% P, 18.3% Ca, and 48% acid insoluble. Applications were banded 10 to 15 cm to the side of the seedling, in bands 5 cm deep and 1 m long, except where broadcast applications were specified. Broadcast treatments were spread between planting rows and incorporated using a disk plow. All fertilization rates referred to are elemental kilograms per hectare. In an attempt to eliminate confounding nutrient deficiencies of limiting elements not tested in

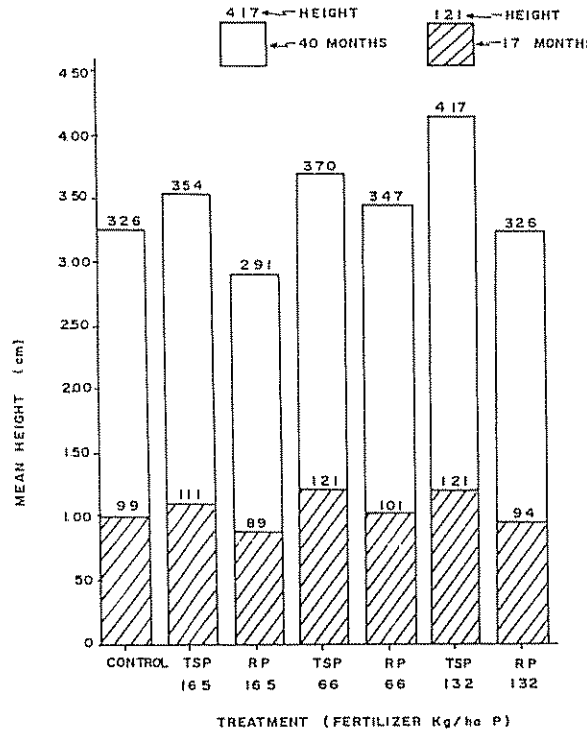


Fig 1. Mean height 17 and 40 months after fertilization with triple super phosphate (TSP) and rock phosphate (RP) at various rates. All treatments were fertilized with K (8 kg/ha), Mg (13 kg/ha) and B (1.8 kg/ha)

the specific trial, missing elements were included with all fertilization treatments. For example, the objective of trial 1 was to evaluate P source and rate. Potassium, B, and Mg were applied at appropriate rates to all plots in addition to the P-rate dictated in the trial, to ensure that these elements would not be limiting (Table 2). This base application was made at the time of trial establishment for P, K, and B, and 16 months later for Mg when the deficiency of this nutrient became evident. Magnesium was inadvertantly applied to the control plots in trial 7 at the rate of 13 kg/ha.

Height and survival of the *P. caribaea* trees were measured at 17 and 40 months after fertilization. Survival averaged over 85% and 80% during the first and second measurement periods, respectively. Analyses of variance were conducted in accordance with the experimental design chosen and statistical significance determined using appropriately calculated orthogonal contrasts at the 5% level (5), except where noted otherwise.

Foliar samples were collected at five and 40 months after fertilization for studies one, four and six. Fully expanded needles from the current year in the upper third of the crown were collected from six trees in each replication of the fertilization treatment sampled. Total N was determined by a Kjeldahl analysis and mineral elements by acid digestion, followed by standard colorimetric, atomic absorption, and flame emission spectra analysis.

Table 1. Pretreatment soil properties, 0-20 cm. Means based on eight composite samples, one from each trial.

| Factor | Mean | Range | S.D. |
|---|---|---|---|
| % Sand[1] | 81.0 | 50–90 | 12.0 |
| % Silt | 8.8 | 0–36 | 10.9 |
| % Clay | 10.5 | 8–14 | 2.2 |
| % O.M.[2] | 1.4 | 1.3–1.5 | 0.01 |
| P. H.[3] | 5.8 | 5.6–6.0 | 0.6 |
| P (ppm)[4] | 2.3 | 2.0–3.0 | 0.11 |
| K (meq/100 g)[5] | 0.04 | 0.3–0.06 | 0.002 |
| Mg (meq/100 g) | 0.096 | 0.06–0.14 | 0.05 |
| Ca (meq/100 g) | 0.39 | 0.2–0.6 | 0.5 |
| Al (meq/100 g)[6] | 0.25 | 0.17–0.46 | 0.04 |
| Zn (ppm)[7] | 0.28 | 0.2–0.5 | 0.01 |
| Fe (ppm) | 15.8 | 11–19 | 1.27 |

1 Sand, silt and clay by the Bouyoucus method
2 Organic carbon, Walkley and Black (1934).
3 EC, pH 1:2 water soil mix.
4 Bray II
5 Leached with 1N $CH_3COONH_4$ (pH 7), cations determined by atomic absorption spectrophotometry.
6 Leached with 1N KCl; acidity of extract titrated with 0.1 N NaOH.
7 Zn, Cu, and Fe determined by atomic absorption spectraphotometry after an acid digest.

## RESULTS AND DISCUSSION

### General

*P. caribaea* exhibited a large, statistically significant height growth response to a number of fertilizer treatments, both 17 and 40 months after fertilization. Since results from the two measurements are similar, emphasis will be on the 40-month data (Table 3). Height growth response at 40 months was greatest to K fertilization, the 32 kg/ha rate providing a 41% increase in height when compared to control plots in the same trials. Height gains computed by averaging the treatment minus control heights over appropriate trials for other nutrients and listed in order of response magnitude are as follows: P band-applied as TSP at 132 kg/ha (38% gain), B at 1.8 kg/ha (20%), Mg at 33 kg/ha (17%), P band-applied as RP at 126 kg/ha (17%), N at 33 kg/ha (8%), and Zn at 1.2 kg/ha (8%). Height gains due to P and K after 17 months are similar to those reported by Copete and Venegas (6) for similar-aged *P. caribaea* in the same zone. Besides increased height growth, trees fertilized with $MgSO_4$ were noticeably greener, and B-fertilized plots had a much lower frequency of stunted, short-needled trees. Analyses of the two trials of P X B interaction (Trial 5) and one trial of P X B X K interaction (Trial 6) revealed no significant interactions for these three elements over the range of rates applied. Potassium foliar concentrations were significantly higher 40 months after fertilization and B foliar levels elevated markedly at five and slightly at 40 months after fertilization. Survival was generally high and unaffected by treatment. Details of both height growth and foliar nutrient response will be discussed for each element.

### Phosphorus

*P. caribaea* responded best to phosphorus when it was banded as TSP. Large, statistically significant gains in height growth were observed at 17 and 40 months in response to most TSP-P fertilization treatments (Fig. 1). Response increased with fertilizer rate up to 132 kg/ha. Phosphorus applied as TSP increased height growth more than equal rates applied as rock phosphate, a difference statistically significant at the 1% level. After P fertilization at 132 kg/ha, the height advantage of TSP over RP was 28% at 17 months and 22% at 40 months, indicating that the slowly soluble RP is less effective than TSP up to 3.5 years after fertilization, and that the RP has not become available during this period.

Table 2. Description of the objectives, design, and treatment in eight forest fertilization trials in eastern Colombia. All doses are in elemental kg/ha; TSP = triple-superphosphate, RP = rock phosphate, RCB = randomized complete block.

| Trial | Objective | Design and Treatments | Base Fertilization (kg/ha) |
|---|---|---|---|
| 1 | Evaluation of P source and rate | Factorial of source (TSP and RP) and rate (0,16, 32, 66, and 132 kg/ha) in a randomized complete block design (RCB) | 8 K + 1.8 B + 13 mg |
| 2 | Evaluate P source, rate, and method | Factorial of application methods (banded vs broadcast), source (TSP vs. RP), and rate (10 and 40 kg/ha) in a split-plot RCB | 8 K + 1.8 B + 13 mg |
| 3 | Evaluation of Zn rate | RCB of zinc rates: 0, 1.2, 5.8, and 11.3 kg/ha | 44 P + 1.8 B + 13 mg + 8 K |
| 4 | Evaluate K rate | RCB design with 5 potassium rates: 0, 4, 8, 16 and 32 kg/ha K | 44 P + 1.8 B + 13 Mg |
| 5 | Test interaction between P, K, and B | RCB complete factorial with P at three rates (0, 14 and 40 kg/ha) and B at three rates (0, 1.8, and 2.6 kg/ha) | 8 K + 13 mg |
| 6 | Test interactions between P, K, and B | RCB complete factorial with P at two rates (0 and 44 kg/ha), K (0 and 8 kg/ha), and B (0 and 1.8 kg/ha) | 13 kg/ha mg |
| 7 | Test interaction among type of plant and N or Mg | RCB split-plot factorial of type of plant (containerized and bare root), and fertilizer N at 0, 33 and 66 kg/ha or Mg at 13 and 26 kg/ha | 44 P + 1.8 B + 10 K |
| 8 | Test interaction among type of plant, fertilization, and application method | Factorial of plant type (containerized and bare-root), fertilization (with and without), and application method (banded or incorporated) in an RCB split-plot | Same as Trial 3 |

Band application of P as TSP at the rate of 66 kg/ha caused a significant 17% greater height growth at 17 months in comparison to broadcast application, but the slight 5% difference between application methods at 40 months was nonsignificant (Fig. 2). This indicates that, although banding provides more rapid early growth by concentration P near the roots, the broadcast and incorporated TSP remains available in the root zone. Response to RP was more variable than to TSP fertilization, and no clear trend between application rate and height growth was discernable for RP (Fig. 1). Trees receiving band-applied RP averaged 17% taller than control trees at 40 months, while incorporated RP treatments provided an 8% gain over controls. The observed differences between bare-root and containerized seedlings, P-source by seedling-type interactions, were insignificant.

The observed response of *P. caribaea* to P fertilization is in agreement with results reported by a number of investigators. The 38% height-growth gain 40 months after fertilization with 132 kg/ha P as TSP is similar to the 24% increase in height reported by Cameron *et al.* (3) after split applications of a total of 292 kg/ha P, and to the 28% gain in height noted by Sundralingam and Ang (16) 38 months after fertilization with 40 kg/ha P. These height gains are considerably less than the 107% increase reported by Lim and Sundralingam (10) in six year-old *P. caribaea* in Malaysia, and the larger gains reported by the Queensland Forestry Commission in annual reports since 1972. In Queensland, the standard fertilization practice is an initial aerial top dressing of 60 kg/ha of P applied as super phosphate, with subsequent foliar analysis used to identify location and timing of refertilization with P (17, 18). Threshold foliar P levels and sampling methodology have not been widely reported, but a successful operational P fertilization system has been established.

In this study, foliar P concentration varied widely for both treatment and control plots, between 0.06 and 0.11% dry weight basis, while treatment and control levels were similar. The general trend and range of foliar P levels are similar to those reported by Cameron *et al.* (4) for young *P. caribaea* in Australia at similar fertilization rates and, given adequate amounts of other nutrients, are in general agreement with their suggested critical levels of 0.06-0.07% using similar sampling methodology. The foliar P levels in all these studies are higher than the 0.053% reported for a 10-year-old productive *P. caribaea*

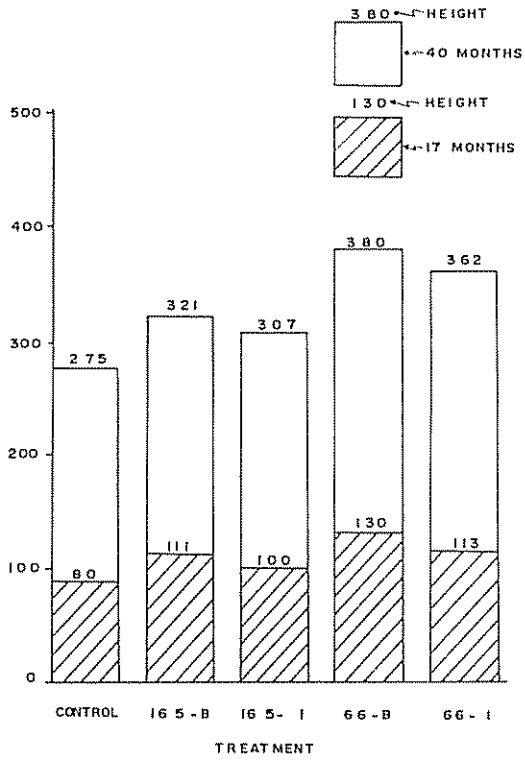


Fig 2. Mean height 17 and 40 months after fertilization at two rates of elemental P applied as triple super phosphate in banded (B) and broadcast-incorporated (I) applications. All treatments were fertilized with K (8 kg/ha), Mg (13 kg/ha) and B (1 8 kg/ha).

stand growing in Nigeria (8). The lower average value may be due differences in sampling methodology, as in the latter study composite samples of all-aged needles were taken from the whole crown, not just of current year's needles from the upper part of the crown. Since foliar P levels in conifers can vary with age of the foliage, position in the crown, time of year, crown class, and genotype (1), care should be taken in comparing results between studies.

The suggested critical values are below the well-established 0.08-0.09% reported for the closely related *P. elliottii* var. *elliotii* Engelm. (13) and *P. taeda* L. (20) in the southern United States, and requires verification in Colombia by further studies.

## Potassium

Potassium fertilization significantly increased *P. caribaea* height growth (Tables 3 and 5). The K-rate trial showed increasing height response with increasing K rate (Fig. 3). Percent height advantage was higher at 40 than at 17 months for most rates, indicating fertilizer K continued to be available or was being effectively cycled. Potassium fertilization also significantly elevated foliar K concentrations. Both mean height and mean foliar K percentage increased with increasing rate of K fertilization (Table 5). However, linear regression using individual plot means indicated a poor relationship (adjusted $r^2 = 0.28$) between plot mean height and plot foliar percent K. Scatter diagrams and a review of the raw data revealed that, above the 0.30% level, foliar K increased with height. Below the foliar K 0.30% level, foliar percent P increased with decreasing height. These high foliar percent P (> 0.10%), low to moderate foliar percent K (< 0.30%), low growth plots were those receiving low rates of K fertilization and a moderate rate of P fertilizer supplied as a "missing" element (Table 2), and were probably K-limited. Phosphorus uptake by trees in these low growth plots was high relative to K uptake. The plots with high foliar percent K (> 0.30%) generally had received higher rates of K fertilization and moderate rates of P fertilization, and thus were probably both P and K limited, at higher rates of growth. Thus, a much better relationship (adjusted $r^2 = 0.66$) was observed between plot mean height and the ratio of foliar percent K over foliar percent P (Fig. 4).

Kadeba and Aduayi (8), working in an apparently unfertilized *P. caribaea* stand growing in Nigeria, reported higher foliar K levels (0.57%) than those observed in the unfertilized plots of the present study (0.24%). The observed foliar K concentrations for both untreated and fertilized plots for the present work are also substantially lower than those reported by Cameron *et al.* (4) from Australia with similar

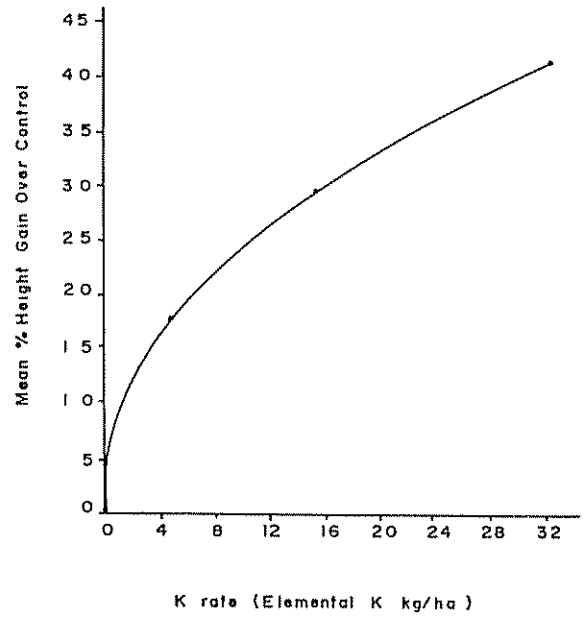


Fig 3. Mean percent height growth gain of K fertilized plots over control plots 40 months after fertilization.

Table 3. Mean height at 40 months, number of trials represented, and statistical significance for treatments implemented (TSP is triple super phosphate, P is rock phosphate).

| Nutrient rate (kg/ha) | Number of trials[1] | Mean Height (cm) | Treatments significant vs control[2] |
|---|---|---|---|
| Unfertilized | 5 | 239 | – |
| Phosphorus (TSP) | | | |
| 0 | 4 | 282 | – |
| 16 | 3 | 327 | 3 of 3 |
| 44 | 5 | 354 | 5 of 5 |
| 66 | 4 | 371 | 4 of 4 |
| 132 | 1 | 417 | 1 of 1 |
| Phosphorus (RP) | | | |
| 15 | 3 | 294 | 0 of 3 |
| 63 | 2 | 334 | 0 of 2 |
| 126 | 1 | 325 | 0 of 1 |
| Potassium | | | |
| 0 | 2 | 270 | – |
| 4 | 1 | 315 | 1 of 1 |
| 8 | 5 | 354 | 3 of 5 |
| 16 | 1 | 347 | 1 of 1 |
| 32 | 1 | 374 | 1 of 1 |
| Boron | | | |
| 0 | 2 | 312 | – |
| 1.8 | 2 | 366 | 2 of 2 |
| 2.6 | 1 | 333 | 1 of 1 |
| Magnesium | | | |
| 13 | 2 | 361 | – |
| 26 | 2 | 422 | 2 of 2 |
| Zinc | | | |
| 0 | 1 | 366 | – |
| 1.2 | 1 | 401 | 0 of 1 |
| 5.8 | 2 | 371 | 0 of 2 |
| 11.3 | 1 | 365 | 0 of 1 |
| Nitrogen | | | |
| 0 | 1 | 361 | – |
| 33 | 1 | 389 | 0 of 1 |
| 66 | 1 | 362 | 0 of 1 |

1 Number of trials in which the given treatment appeared. Other elements applied at the rates (kg/ha) P 44, K 8, B 1.8, Mg 10.

2 Based on orthogonal contrast of treatment vs control in the same study (P = 0.05).

aged *P. caribaea* using similar needle sampling methodology, and are at the low end of the range of 0.23-1.15 foliar percent K reported for the species in Brazil (19). Needles from unfertilized treatments in the Australian study averaged 0.56% K forty-one months after establishment, while needles averaged a significantly larger 0.77% K when fertilized at a rate of 214 kg K/ha, a rate much higher than the highest K rate (32 kg/ha) tested in the present study.

Critical levels have been variously defined, but a common usage is that level associated with 90% of maximum yield (2, 11). Foliar nutrient levels for any one species are often divided into three stages: 1) low levels, associated with poor growth and a high probability of response to fertilizer; 2) marginal levels, associated with marginal growth and only a moderate probability of obtaining a fertilization response; and 3) high levels, associated with good growth and a low

probability of response to fertilizer. The results described do not allow for complete definition of all foliar percent K categories for *P. caribaea* under similar conditions, but they do give some indication of the probable ranges in the llanos region. Based on the present work, *P. caribaea* stands with foliar K levels below 0.30% and with adequate supplies of other nutrients have a high probability of responding to K fertilization. Stands with foliar percent K levels between 0.30 and at least 0.39 have a moderate probability of responding to K fertilization.

### Boron

Positive height growth response to B fertilization was observed (Table 3). The height difference between the best rate, 1.8 kg/ha, and the control was significant 40 months after fertilization. Average height for plots receiving 2.6 kg/ha was lower than those receiving 1.8 kg/ha during both measurement periods, although not significantly. Foliar B concentrations were substantially higher for trees fertilized at 1.8 kg/ha (170 ppm) than for unfertilized trees (29 ppm) five months after fertilization, and were moderately elevated (34 ppm vs. 14 ppm) at 40 months (Table 4), although it was not possible to test significance. The results from B fertilization indicate deficiencies at levels higher than those reported by Van Goor (19), who suggested 10 ppm as a critical B level for *P. caribaea* in Brazil, and by Procter (14), working with Pinus patula in Zambia and Tanzania, and deficiencies at B levels similar to those reported by Pritchett and Llewellyn (12) working with young *Pinus elliottii* in the southeastern United States. In the B fertilized plots, there was a noticeable reduction observed in the frequency of stunted, multiple-leader, resin-exuding trees that exhibited severe B deficiency symptoms. According to Evans (7), the need for B application to plantations in the tropics and sub-tropics is widespread, so managers of tropical forests should be familiar with these symptoms.

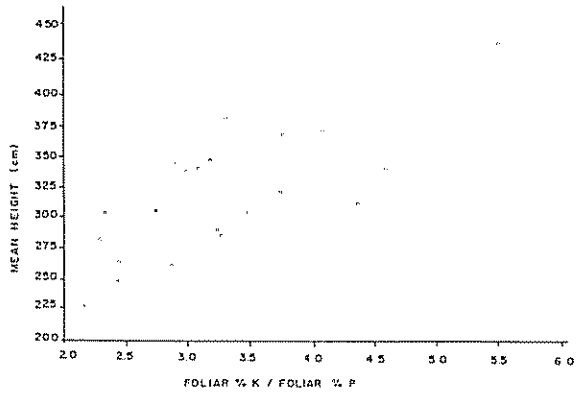


Fig. 4. Scatter diagram of 36-tree plot mean height 40 months after fertilization with various rates of K vs the ratio (foliar % K/foliar % P) Adjusted r-square of associated linear regression is 0.66

### Magnesium

A strong positive and significant growth response due to Mg fertilization at 26 kg/ha was observed in *P. caribaea* (Table 3). Bare-root stock was initially greener and grew faster than did container-produced seedlings in response to Mg application, and there were significant type-of-plant and type-of-plant-by-fertilization interaction effects at 17 months; however, color, growth, and interactions were indistinguishable for the two seedling production methods at 40 months. Apparently, *P. caribaea* bare-root stock is able to obtain or utilize band-applied Mg fertilizer more quickly, but container-produced seedlings attain statistically equivalent heights within 3.5 years after fertilization. Foliar Mg levels were not affected by fertilization (Table 4). Since Mg was applied as $MgSO_4$, the observed growth and color responses might be due to added sulfur.

### Zinc and Nitrogen

Neither Zn nor N significantly affected height growth at the fertilizer rates used. Young *P. caribaea* exhibited a non-significant 8% gain over the control treatment 40 months after fertilization with 33 kg/ha N and a non-significant 7% gain 40 months after fertilization with 1.2 kg/ha Zn.

## CONCLUSIONS

*Pinus caribaea* Mor. var. *hondurensis* can be grown in soils of extremely low native fertility, provided proper fertilization treatments are applied. Height growth gains of up to 95% were observed in the described studies 40 months after fertilization. The results from the present work can assist forest managers and researchers working with *P. caribaea* in sandy, infertile soils found in the llanos of eastern Colombia and southern Venezuela. Conclusions based on these studies are:

1) Significant height growth improvements resulted from the application of the elements P, K, B, and Mg. Largest gains occurred with P and K fertilization, although percentage growth gains from B and Mg were substantial.

2) There were no interactions observed between the elements P, K, and B in fertilization

Table 4. Mean nutrient levels in *P. caribaea* foliage on fertilized and unfertilized plots, trial number 6. Fertilizer treatment was 132 kg/ha elemental P as TSP, 8 kg/ha elemental K, 26 kg/ha elemental mg, and 1.8 kg/ha B. Foliage samples were taken from each replicate and grouped by treatment prior to chemical analysis.

| Treatment | N (%)[1] | P (%)[2] | K (%) | Mg (%) | B (ppm) | Zn (ppm) |
|---|---|---|---|---|---|---|
| Unfertilized, 5 mo. sample | 1.91 | 0.06 | 0.33 | 0.04 | 29 | 20 |
| Fertilized, 5 mo. sample | 1.31 | 0.08 | 0.66 | 0.04 | 204 | 13 |
| Unfertilized, 40 mo. sample | 1.46 | 0.09 | 0.25 | 0.03 | 14 | 18 |
| Fertilized, 40 mo. sample | 1.87 | 0.09 | 0.30 | 0.04 | 34 | 11 |

1 Kjeldahl analysis

2 P, K, Mg, B, and Zn are determined with acid digestion followed by colorimetric or atomic absorption specta measurements. See footnotes in Table 1

Table 5. Mean height and foliar K concentrations from of trial number four 40 months after K fertilization. Observations with a common underline are not statistically different using Duncan's new multiple range test.

| Fertilization rate (kg/ha) | 0 | 4 | 8 | 16 | 32 |
|---|---|---|---|---|---|
| Mean height (cm) | 274 | 309 | 350 | 354 | 369 |
| Foliar % K[1] | 0.24 | 0.24 | 0.29 | 0.31 | 0.39 |

1 Measured with atomic absorption spectraphotometry on acid digestion extract

8) Based upon these results, a biologically optimum fertilizer treatment for *P. caribaea* in the llanos regions of Colombia and Venezuela on soils similar to those of the present study is 132 kg/ha P applied as TSP, 32 kg/ha K, 1.8 kg/ha B hand 26 kg/ha Mg, and would produce a 78% gain in height growth over unfertilized trees after 40 months.

9) Further research is required on *P caribaea* foliar nutrient concentrations so they can be used as an effective tool in diagnosing deficiencies and scheduling fertilization.

3) Nitrogen and zinc apparently are not limiting factors, at least during the first 3.5 years of growth.

4) Triple-super phosphate (TSP) provides significantly greater response as compared to rock phosphate (RP). Height growth response to P fertilization increases with increasing fertilization rate, at least up to 132 kg/ha elemental P. Broadcasting and banding were equally effective application methods. There were no differences in the growth of bare-root or containerized stock, nor interactions between type of seedling and P fertilizer forms.

5) There is a strong growth and foliar nutrient level response to K fertilization, at least up to the rate of 32 kg/ha elemental K. Given an adequate supply of other nutrients, foliar K $\leqslant$ 0.30% and P

concentrations are ≥ 0.09% probably indicative of K deficiency, which can be amended by K fertilization.

6) A large height growth response to B fertilization was observed at 1.8 kg/ha, significantly greater than the response observed in trees fertilized at 2.6 kg/ha. Incidence of forking was lower and stem form was noticeably better after B fertilization.

7) Magnesium sulfate fertilization yielded significant height growth and needle color improvements during the first 40 months after fertilization.

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