

Effects of early fertilization on the performance of *Nothofagus dombeyi* planted in the Coastal Range of south-central Chile

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Abstract

P.J. Donoso, D.P. Soto, J.E. Schlatter, and C.A. Büchner. 2009. Effects of early fertilization on the performance of *Nothofagus dombeyi* planted in the Coastal Range of south-central Chile. Cien. Inv. Agr. 36(3):475-486. Native *Nothofagus dombeyi* growth rates excel in secondary forests and in some plantations, and the species has good timber quality. However, few have reported on the effects of fertilization on *N. dombeyi* plantations. This is a key matter since fertilization has environmental and financial costs, and therefore its use to increase growth and survival for production or restoration must be carefully evaluated. Here we evaluated the early effects of fertilization (control and three levels) using several performance variables (leaf properties, growth, plant quality, and survival) in a *N. dombeyi* plantation at a low elevation in the Coastal Range of south-central Chile, which has a rainy temperate climate and medium fertility soils. Four years after plantation and fertilization, there were no differences in growth among all treatments despite initial gains in the fertilized plants. Trees with a single leader represented 58% for the lower fertilization treatment and between 42-49% for the other treatments, although this difference was not significant. Survival was only significantly lower (75%) with the highest fertilizer doses. Although the results are not conclusive, they provide a good platform for discussion regarding the feasibility of fertilizing *N. dombeyi* plantations and using other early silviculture prescriptions for this species. The reported early growth rates are similar to *P. radiata* plantations and fast-growing hardwood species in other temperate and subtropical regions, suggesting that *N. dombeyi* plantations are a true alternative for timber and fiber production, which would decrease pressure on natural forests in Chile.

Key words: Fast-growing tree species, hardwood plantations, mineral nutrition, plant quality, survival.

Introduction

Plantations that produce high-quality timber are an attractive option for timber production, especially for small and medium landowners (Grant *et al.*, 2006) and for conservation of native forest species. *Nothofagus dombeyi* (Nothofagaceae) is a high-quality native tim-

ber species (Hall and Witte, 1998; Díaz-Vaz *et al.*, 2002) and one of the most productive in secondary growth forests (Donoso *et al.*, 1999a) and plantations in Chile (Donoso *et al.*, 1999b, 2005, 2007; Cubbage *et al.*, 2007). Currently, *N. dombeyi* plantations without soil preparation, fertilization, or weed control have yielded average annual volume growth rates as high as 18 m³ha⁻¹ (Donoso *et al.*, 1999b), which indicates the promising economic potential of complete rotations (Cubbage *et al.*, 2007). Intensive silviculture aimed to increase the productivity of

these plantations (Allen *et al.*, 1990; Albaugh *et al.* 2003, 2004; Nilsson and Allen, 2003; Nilsson and Örlander, 2003) could make them more attractive to landowners, but to date there are no reports on the effects of intensive silviculture on the growth and yields of these plantations.

Nothofagus dombeyi is a shade-intolerant species, which suggests that it could exhibit high growth rates with increasing nutrient availability (Grime, 1979). This has been observed for nursery seedlings (Bustos *et al.*, 2008), but fertilization trials are necessary to determine whether *N. dombeyi* would respond to soil fertilization at the diverse sites where it grows naturally (Donoso *et al.*, 2006) or could be established through plantations, from sea level to about 1,000 m above sea level (a.s.l.) and from 34 to 47°S.

Fertilization during the initial stages of plantation aims to increase survival and short-term productivity (Duryea and Dougherty, 1991; Binkley, 1993; Fox *et al.*, 2006), reduce competition for light, water, and nutrients, and increase growth rates (Allen *et al.*, 1990; Nambiar and Sands, 1993; Nilsson and Allen, 2003; Nilsson and Örlander, 2003). The use of fertilization should be determined according to the potential soil nutrient supply and species' requirements, in addition to considering economical and environmental factors (Rodríguez, 1993; Alvarez *et al.*, 1999). This is a common way to proceed in hardwood plantations (Pritchett and Fisher, 1987), although fertilization of hardwood plantations has been poorly studied (Brown, 1999).

The objectives of this study were (i) to evaluate the one-year effect of fertilization on the leaf morphology and nutrient content of planted seedlings and (ii) to evaluate the effects of fertilization on growth, plant quality, and survival during the four initial years of plantation.

Material and methods

Study area

The *N. dombeyi* plantation was established on the eastern side of the Coastal Range (39°58'S and 73°20'S) in the province of Valdivia, between 50 and 80 m above sea level (a.s.l.) on a hill with a convex 10-20% slope facing North. The region has a rainy temperate climate with a slight Mediterranean influence and narrow thermal oscillation (Di Castri and Hayek, 1976). The mean temperatures are 12°C annually, 18°C for the warmest months (January and February), and 7.5°C for the coldest months (July and August). Annual rainfall varies between 2,500 and 3,000 mm and is highly concentrated between May and August (Di Castri and Hayek, 1976).

Soil characterization

The plantation is on red clay soil from the Los Ulmos series (Acruoxic Hydric Hapludand; CIREN, 1999). These soils are deep to very deep, well structured, and have high contents of organic matter. The high aluminum and iron levels cause phosphorus fixation (IREN *et al.*, 1978). Using three samples of the upper 20 cm of soil collected from the center of each of the three control plots, we followed standard laboratory procedures to measure pH, total carbon, total nitrogen, available phosphorus, sodium, potassium, calcium, magnesium, extractable aluminum, iron, manganese, copper, extractable zinc, sulfur, exchangeable aluminum, and boron. Results (Table 1) show that according to reference values, the soil is strongly acidic and rich in organic matter and total nitrogen, and has an adequate C/N ratio, a very low base saturation, and very low levels of available phosphorus. It has high available sulfur and iron contents, high

levels of extractable and exchangeable aluminum, and a high aluminum saturation. Overall, it is a nutritionally poor soil in cation bases and phosphorus, but has adequate temperature and water regimes, so it has medium fertility.

Table 1. Means and standard deviations of the chemical characteristics of the soil in the plantation area, the Los Ulmos series, east coastal mountain range, province of Valdivia.

Variable	Mean (SD)	Variable	Mean (SD)
pH - H ₂ O	5.48 (0.15)	SB (cmol+100 g ⁻¹) ¹	1.7 (0.3)
C total, %	9.54 (2.06)	Al - KCl, mg kg ⁻¹	41 (21.8)
N total, %	0.61 (0.12)	Al Saturation, %	20.2 (9.6)
P, mg kg ⁻¹	1.6 (0.6)	Fe, mg kg ⁻¹	145 (6)
K, mg kg ⁻¹	79 (17)	Mn, mg kg ⁻¹	8.3 (2.1)
Ca, mg kg ⁻¹	181 (27)	Cu, mg kg ⁻¹	5.1 (0.6)
Mg, mg kg ⁻¹	54 (14)	Zn, mg kg ⁻¹	1.0 (0.4)
Na, mg kg ⁻¹	36 (5)	B, mg kg ⁻¹	0.5 (0.2)
Al, mg kg ⁻¹	1,803 (310)	S, mg kg ⁻¹	20 (5.3)

¹Sum of bases.

Site preparation and plantation specifications

The planted area was cleared of its previous native forest about 80 years ago to allow for extensive cattle grazing in a small land holding. The *N. dombeyi* seedlings used were produced in the nursery of the Department of Silviculture, Universidad Austral de Chile. Seeds were collected in the Coastal Range in the area known as Raulintal (40°10'52''S, 73°24'42''W at 530 m a.s.l.), in the province of Valdivia. We used one-year-old bare root seedlings that were sown in 24-cm³ containers and transplanted near the middle of the first growing season in nursery beds at a spacing of 10 x 15 cm (860 seedlings per m²) following production protocols recommended

by Duryea and Landis (1984). Final seedlings used for plantation had a mean root collar diameter of 0.38 ± SD 0.06 cm and a mean height of 41.5 ± SD 9.70 cm, and there were no significant differences in either of these variables among seedlings used in the different treatments tested in this study (ANOVA; $p > 0.05$).

The soil in the experimentation area was plowed (and blocks were crashed) in 40-cm-deep rows along level contours to reduce superficial compaction, improve the water regime, and reduce weed competition during the first year. The plantation was established in regular 3 x 2 m spacings at the end of the dormant season during August 2004. Fertilization treatments were then applied during the first week of September of the same year, and weeds were mechanically controlled every year for the first three seasons.

Fertilizers

We used N-P-K fertilizer (10 N, 30 P₂O₅, 10 K₂O for every 100 g) composed of urea (46% N), triple superphosphate (20% P), and potassium muriate (50% K). Three doses of N-P-K were applied: one determined through the rational method of fertilization (*sensu* Rodríguez, 1993; Álvarez *et al.*, 1999), and double and triple that amount. The rational method of fertilization estimates the demand of the trees according to a conservative expected growth rate, the nutrient availability from the soil (after nutrient analysis), and the efficiency of nutrient uptake by seedlings. The resulting fertilizer treatments (in addition to the untreated control) were ~ 50 g plant⁻¹ (T50; 5 N, 15 P₂O₅, 5 K₂O), 100 g plant⁻¹ (T100; 10 N, 30 P₂O₅, 10 K₂O), and 150 g plant⁻¹ (T150; 15 N, 45 P₂O₅, 15 K₂O). T100 and T150 should allow for an evaluation of how seedlings respond to additional nutrient supplies. Fertilizers were applied in lateral

bands at a distance of 15 cm from the seedlings and at a depth of 5 cm to avoid volatilization and superficial runoff.

Design and statistical analysis

Fertilization treatments were distributed according to a complete randomized design with three replicates of 20 trees each. The root-collar diameter (RCD), total height (TH), and quality were determined annually (May) after establishment (August 2004) until the fourth growing season. Quality was estimated, with three classes for the shape of the crown and three classes for the angle (straightness) of the tree (Figure 1; *sensu* Rock *et al.*, 2004). We also recorded dead trees to determine mortality rates. With RCD and TH, we estimated the volume (V) of each plant as follows (*sensu* Rose and Ketchum, 2003):

$$V(\text{cm}^3\text{pl}^{-1}) = \frac{\pi \cdot (\text{RCD}^2) \cdot \text{TH}}{12} \quad (1)$$

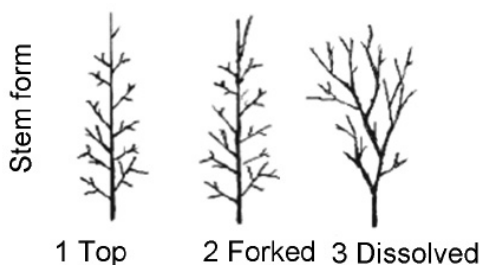


Figure 1. Form criteria used for trees sampled in this study (modified from Rock *et al.*, 2004).

To evaluate fertilization efficiency, we collected 100 g mixed foliar samples in May after the first growing season from all replications and the upper 50% of the crown (*sensu* Schlatter *et al.*, 2001). Leaves were oven-dried at 75°C and later crushed and analyzed for essential nutrients (*sensu* Mengel and Kirkby, 1978; Will, 1985; Schlatter *et al.*, 2003). Simultaneously, a straight complete branch was collected at the base of the upper third of the crown from five of the largest trees in each treatment. In the middle part of the branch, the number of leaves within a region of 10 cm was counted and then scanned to

determine the foliar area with the ImageTool® program. The remaining leaves were separated from the branch and each component (branch and leaves) was weighed (0.01-g precision). All material was oven dried at 75°C to obtain the total dry weight.

We used one-factor ANOVA with four levels for the fertilization variable (three fertilized treatments and one control) to evaluate the one-year foliar parameters (area, weight, and leaf numbers), branch weight, and annual growth parameters (RCD, TH, and V). We also tested cumulative RCD, H, V, and DBH at the fourth season for all trees and for the best 20% of trees (five per replication). When ANOVA was significant, mean separation for the analyses was evaluated with the LSD test (Sokal and Rohlf, 1995). We were not able to statistically compare results of the foliar analyses since we mixed foliar samples from each treatment, as mentioned earlier. To evaluate cumulative effects of fertilization on crown form and tree straightness by treatment, as well as the survival differences following each growing period, we used a non-parametric Kruskal-Wallis (H-test) ANOVA and the Mann-Whitney (U-test) for treatment separation when the H-test was significant. For every analysis, we considered $\alpha = 0.05$ (Zar, 1999).

Results

Effect of fertilization on chemical and morphological parameters after the first year of growth

Following the first growing season, the foliar percentage of nitrogen (N) was higher in TT than in the three fertilized treatments (Table 2). Among the fertilized treatments, only T150 had an N level above marginal (1.36%) (*sensu* Will 1985). For the remaining nutrients, levels were similar among treatments, although phosphorus (P) and potassium (K) were slightly greater in the treatments with more fertilization. These P and K contents are considered marginal to good according to the laboratory of Forest Nutrition and Soils of the Universi-

dad Austral de Chile, who considers >0.08% and >0.5% to be good concentrations for P and K, respectively, based on literature and its own

studies of *N. dombeyi*.

The foliar area was significantly different among treatments ($p < 0.001$), with significantly

Table 2. Foliar analysis of *Nothofagus dombeyi* after the first growing season.

Macroelements %	Treatments				Microelements mg·kg ⁻¹	Treatments			
	TT	T50	T100	T150		TT	T50	T100	T150
N	1.56	1.14	1.19	1.36	Fe	199	127	172	92
P	0.06	0.06	0.07	0.09	Mn	239	224	259	223
K	0.44	0.44	0.51	0.53	Cu	4.3	3.6	3.7	4.1
N/P	26	19	17	15.4	Zn	15	13	11	13
Ca	0.28	0.32	0.30	0.30	B	18	16	16	31
Mg	0.11	0.13	0.13	0.12					

greater areas for T150 and T100 compared to TT and T50 (Table 3). Similarly, the dry foliar weight was also significantly different among treatments ($p = 0.035$), with significantly greater dry foliar weights of T150 and T100 compared to T50 and TT. Dry foliar weights per leaf and per branch were only marginally significant among treatments ($p = 0.052$ and $p = 0.054$), but they were evidently higher in T150 and T100. Finally, the number of leaves per branch was

significantly different among treatments ($p = 0.002$), with a significantly higher abundance of leaves in T150 with respect to TT and intermediate values for T100 and T50 (Table 3), which illustrates that this variable was stimulated the most by fertilization. Overall, T100 and T150 considerably stimulated biomass development during the first growing season.

Effects of fertilization on annual growth

Table 3. Means and standard deviations (in parenthesis) for some foliar variables of *Nothofagus dombeyi* seedlings in response to fertilization treatments after the first growing season.

Variable	Fertilization treatments			
	TT	T 50	T 100	T 150
Foliar area, cm ²	3.67b (0.97)	3.72b (0.96)	4.73a (1.07)	4.66a (0.92)
Dry foliar weight, gcm ⁻²	0.22b (0.03)	0.21b (0.03)	0.28a (0.03)	0.27a (0.02)
Dry foliar weight per leaf, g	3.23 (1.68)	3.32 (1.47)	4.51 (1.11)	6.55 (0.95)
Dry foliar weight of branches, g	1.58 (0.85)	1.30 (0.54)	2.13 (0.47)	3.47 (1.25)
Leaves, n°	19b (13)	37ab (23)	36ab (24)	49a (16)

Different letters in a row denote significant differences between treatments from the LSD test for means separation following significant ANOVA tests.

Following the first growing season, the fertilization treatments induced highly significant differences in the annual growth parameters RCD and TH with respect to the unfertilized treatment (Table 4). There were no significant differences in annual RCD growth after the second, third, and fourth growing seasons among treatments ($p = 0.153$, 0.157 , and 0.130 , respectively), although T150 had greater growth rates during

these seasons (Table 4). Annual TH growth rates showed a complete shift during the second year, since the treatment with the best first-year growth (T100) had a significantly lower growth rate than TT during the second year. Annual TH growth rates were not significantly different among treatments following the third growing season ($p = 0.168$), but during the fourth growing season TT had the greatest growth rate,

which was significantly different from T50 and T150 in this case (Table 4). Annual V growth rates were significantly greater in the fertilized treatments with respect to the control for years

one, two, and three, but not significantly greater for year four (Table 4). Cumulative growth after four growing seasons was not significantly different among treatments

Table 4. Mean annual growths (and standard deviations) for root collar diameter, height, and volume variables.

Treatments	Root collar diameter, cm					Height, cm					Volume, cm ³ pl ⁻¹				
	2005	2006	2007	2008	Total	2005	2006	2007	2008	Total	2005	2006	2007	2008	Total
TT	0.43b ¹ (0.17)	1.31 (0.59)	1.61 (0.62)	2.20 (0.89)	6.00 (0.92)	44.8b ¹ (20.5)	84.6a (41.8)	81.9 (35.7)	141.5a ¹ (46.5)	398.5 (46.5)	14.8b ¹ (10.4)	241.3b ¹ (221.8)	840.9b ¹ (625.7)	3088.2 (1972.8)	4190.2 (1497.3)
T50	0.77a (0.27)	1.25 (0.55)	1.70 (0.82)	2.14 (0.74)	6.29 (0.59)	69.6a (22.4)	67.0b (39.9)	96.5 (54.1)	121.3b (46.5)	399.5 (34.9)	40.1a (27.2)	272.0b (214.2)	1034.4ab (726.8)	3109.3 (2041.8)	4463.2 (1080.5)
T100	0.83a (0.24)	1.30 (0.47)	1.51 (0.52)	1.94 (0.68)	5.90 (0.81)	76.8a (21.1)	66.3b (39.6)	93.1 (37.3)	125.4ab (43.1)	400.7 (50.1)	45.3a (26.0)	296.7ab (226.2)	962.9b (613.4)	2802.4 (1692.3)	4115.4 (1329.3)
T150	0.82a (0.27)	1.40 (0.69)	1.76 (0.57)	2.25 (0.71)	6.52 (0.88)	73.3a (25.0)	82.7ab (40.8)	101.2 (36.3)	116.5b (33.4)	414.6 (52.2)	42.9a (27.1)	385.8a (363.2)	1332.2a (1039.6)	3537.9 (2224.7)	5304.6 (1827.5)

¹Different letters in a column denote significant differences between treatments from the LSD test for means separation following significant.

for any of the variables evaluated (RCD, TH, V, and DBH) when all trees per plots were considered or when only the best 20% of trees per plot (five trees) were considered. The best trees had on average 20% higher growth than the average for RCD, TH, and DBH and between 30% and 50% more for V.

Effect of fertilization on quality of trees

The quality of trees did not differ significantly among treatments after the first growing season or after the fourth growing season ($p > 0.05$ for Top, Forked and Dissolved trees in both cases). Quality deteriorated from more than two-thirds of top trees (Top 70%, Forked 25%, and Dissolved 5%) to only one-half of the trees classified as top after the fourth growing season (Top 50%, Forked 36%, and Dissolved 15%; Figure 2). However, after four growing seasons, T50 had 58% top trees while all other treatments had between 40% and 50% top trees, with the lowest amount (42%) for T150 (Figure 2).

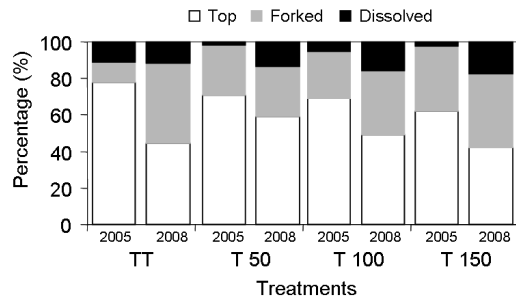


Figure 2. Forms of *Nothofagus dombeyi* trees after the first (2005) and fourth (2008) growing seasons.

Effect of fertilization on tree survival

Survival was significantly different among treatments after the first growing season ($H = 7.94$, $p = 0.047$), with a survival rate (97%) for T100 that was significantly higher than T150 (73%), but not significantly higher than T50 (86.6%) and TT (81.6%). Following the first year, there was nominally extra mortality (TT had an additional 1.87% mortality and T50 2.07%), but after the fourth growing season there were no significant differences in survival rates among treatments ($H = 7.22$, $p = 0.065$).

Discussion

The most important effect of fertilization on plantations in Chile is the increased foliar level of N. In this study, after the first growing season, fertilization (especially T100 and T150) increased the number, area, and dry weight of leaves, as well as the weight of branches (Table 3). This result was also illustrated in the greater RCD, TH, and V growth rates during the first growing season of the plantation for the fertilized treatments (especially T100), which is similar to a report by Donoso *et al.* (2007) for a one-year-old *N. dombeyi* plantation in the Chilean Andes on soils of recent volcanic ash, where intermediate doses of fertilizer (110 g pl⁻¹) caused the best growth rates. The addition of N through fertilizers is associated with the production of proteins that stimulate photosynthesis and therefore growth (Lea *et al.*, 1980; Hinckley *et al.*, 1992). However, during the second year, the effect of the fertilization treatments was surprising since the best growth rates were achieved by treatments that had the lowest rates after the first year (TT and T150). Initial gains were gradually lost over time to a point where differences were only marginal with respect to the unfertilized treatment at year four (Table 4). The significant effect of fertilization on growth occurred only during the first year (2005), which has been reported elsewhere (Duryea and Dougerthy, 1991; Binkley, 1993; Rodriguez *et al.*, 2001; Albaugh *et al.*, 2003; Amishev and Fox, 2006). This effect manifests especially in soils of low to medium nutritional supply like the soil in this study since plants stimulated by the fertilizer during the first growing season later need to physiologically adjust to the true nutrient supply of the local site and therefore lose their initial gains (Table 4).

We suggest that N (in a low doses) and P stimulated the growth of the fertilized plants and this caused a dilution of the N in the new biomass. The dilution of N is illustrated in the foliar N levels following the first growing season in T50

and T100, which were marginal and about 25% lower than in TT (Table 2). The N dilution was caused by insufficient N supply that was unable to sustain the level of leaves produced during the first year (*sensu* Lea *et al.*, 1979, 1980; Bellote and Ferreira, 1995; Fife and Nambiar, 1997). A fertilized plant usually has a greater foliar volume than root volume (Binkley, 1993). Although root growth was not analyzed, the control trees probably had to put more energy in this tissue, and eventually a more balanced shoot/root ratio allowed the control trees to have better growth the next year compared to the fertilized trees, which did not get the nitrogen supply from the soil that they needed to maintain their greater biomass. If the soil cannot supply the plant's nutrient demands during the second year, the plants must dramatically adapt to this condition. This is what likely happened in our study with the seedlings fertilized during the first year. Plants with the higher fertilization doses were partially able to maintain a more adequate supply during the second year since they had a better nutrient level in their foliage than in the other treatments, and plants without fertilization also had a nutritionally better status, in addition to likely having a more balanced shoot/root ratio probably compared to the fertilized plants. After four growing seasons, plants had similar growth behaviors (except for some insignificantly lower values for T100), illustrating that early fertilization did not eventually affect growth of *N. dombeyi*.

One possible way to prevent the observed decline in volume that occurred in the T100 treatment, which had the best performance during the first year, i.e., to diminish the effect of nutritional dilution, would be to apply a second fertilization treatment, with a different nutritional composition that favors N, at the end of winter and before the onset of the second growing season. This may require a strong weed control program since fertilization can stimulate weed growth (*sensu* Albaugh *et al.*, 2003, 2004; Nilsson and Allen, 2003; Nilsson and Örlander, 2003; Amishev and Fox, 2006). This strategy would be op-

timal since it would favor the treatment with the lowest mortality and would decrease the time to crown closure, therefore increasing competition and the probability of obtaining straight trees, an important consideration in *N. dombeyi*, a species with a great tendency to lose its epinastic control (Donoso *et al.*, 1999b). Through this type of fertilization program, we would probably expect that the initial volume gains would remain at least until crown closure, which has been widely reported (Binkley and Reid, 1985; Nilsson and Allen, 2003; Prescott and Blevins, 2005).

The plantations had good survival rates (three out of four trees survived in the worst treatment, T150) that were similar to rates observed for *Pinus radiata* plantations subjected to different silvicultural treatments in the Coastal Range (Albaugh *et al.*, 2004; Rubilar *et al.*, 2008). T150 had lower survival rates that were only marginally and not significantly different than those for T100, clearly suggesting that this high dose can be toxic to the plants (Duryea and Dougherty, 1991). In terms of quality, a major problem with *N. dombeyi* is its high rate of forking (Donoso *et al.*, 1999b), which is a common issue in some hardwood plantations (e.g., Erskine *et al.*, 2005). However, 42-58% of the trees had single leaders (that were not forked), which represents approximately between 500 and 700 trees per ha (considering the 75-85% survival range over an initial density of 1,600 trees per ha), so we can expect that a plantation would reach a final rotation age with sufficient high-quality trees. Most of the forked trees could be gradually harvested through intermediate cuttings such as thinning or improvement cuttings. This suggests there may be no need to establish dense plantations or conduct early pruning of forked trees to maintain a leader branch, as suggested by Donoso *et al.* (1999b), thus reducing plantation costs while still yielding a high-quality and fast-growing plantation.

In general, the cumulative height growth rates observed for unfertilized *N. dombeyi* trees in this study were noticeably greater than those registered in open fields in the Andes [0.45 m during the first year at 700 m (Donoso *et al.*, 2007); 0.65 m per year at age 7 at 550 m (P. Donoso's unpublished data)] or in strips between 5-m tall *Chusquea coleou* [0.6 m per year

at age 4 at 650 m (Alvarez and Lara, 2008)] and slightly greater than those reported for open field plantations in the central depression (Donoso *et al.*, 2005) and in low-elevation foothills of the Andes (Wienstroer *et al.*, 2003). Height growth of *N. dombeyi* without fertilization in this study was also greater than many planted hardwood species in other temperate regions and in some subtropical regions (Belanger and Pepper 1978; von Alten 1988; Cogliastro *et al.*, 1997; De Bell and Harrington 2002; Jacobs *et al.*, 2005; Grant *et al.* 2006; Renou *et al.*, 2007; 2008) and comparable to those of *Pinus radiata* in red clay soils (Albaugh *et al.*, 2004) and derived from metamorphic rocks (Rubilar *et al.*, 2008) in south-central Chile.

The growth rates reported in this study illustrate the potential use of *N. dombeyi* plantations established with adequate initial soil management and good-quality seedlings. Although further fertilization experiments must be conducted, it would be advantageous to reduce establishment costs through a modest and low-intensity silviculture prescription. This would also have the added benefit of reducing the potential negative effects on the environment associated with application of significant amounts of chemicals under intensive silviculture treatments (Kimmins, 1997). Yet, greater growth could be achieved with more research to develop early silviculture prescriptions for this species.

The value (Cubbage *et al.*, 2007) and great variety of uses (Díaz-Vaz *et al.*, 2002) of *N. dombeyi* will continue to pose harvesting pressure on second-growth or old-growth forest stands that comprise this species, unless timber of *N. dombeyi* is supplied from plantations. The argument that plantations could decrease pressure on the harvest of natural forests (Sedjo, 1983; Binkley, 1997; Sedjo and Botkin, 1997) seems stronger if fast-growing plantations include native species, as with *N. dombeyi*. In addition, plantations of *N. dombeyi* in open fields or severely high graded forest stands facilitate the entrance of other tree species once it has grown enough to provide shade to the understory, a feature that is rarely observed in plantations of exotic species (P. Donoso, personal observation), illustrating that *N. dombeyi* plantations may have potential for timber produc-

tion and forest restoration. This study provides additional evidence for the great potential of *N. dombeyi* plantations in Chile and reports greater growth rates than in all previous studies with plantations of this species. Although it is not conclusive that the use of fertilization is a feasible method to achieve greater growth rates, survival, and quality, these variables

performed better either with the lower or intermediate fertilization doses.

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Resumen

P.J. Donoso, D.P. Soto, J.E. Schlatter y C.A. Büchner. 2009. Efectos de la fertilización temprana en el comportamiento de una plantación de *Nothofagus dombeyi* en la Cordillera de la Costa del centro sur de Chile. Cien. Inv. Agr. 36(3): XXX-XXX. Las tasas de crecimiento de *Nothofagus dombeyi* son superiores a las de otras especies nativas en bosques secundarios y plantaciones, y la especie tiene buena calidad de madera. Sin embargo, pocas experiencias han sido reportadas acerca de los efectos de la fertilización en plantaciones de *N. dombeyi*. Esto es fundamental, ya que la fertilización tiene costos ambientales y financieros, y la necesidad para incrementar el crecimiento y la sobrevivencia debe ser cuidadosamente evaluada. En este estudio evaluamos el efecto de la fertilización (control y tres niveles) en una serie de variables (propiedades de las hojas, crecimiento, calidad de plantas y sobrevivencia) en una plantación de *N. dombeyi* a baja altitud en la Cordillera de la Costa del centro sur de Chile, con un clima templado lluvioso y suelos de mediana fertilidad. Cuatro años después de establecida y fertilizada la plantación no hubo diferencias entre tratamientos en crecimiento, a pesar de las ganancias iniciales en plantas fertilizadas. Los árboles con un solo ápice dominante fueron un 58% en el tratamiento con menor fertilización, y entre 42-49% para el resto, diferencia no significativa. La sobrevivencia fue sólo significativamente menor (75%) con la mayor dosis de fertilización. A pesar de que los resultados no son concluyentes, ellos proveen una buena base para discutir acerca de la conveniencia de fertilizar plantaciones de *N. dombeyi* y de efectuar otras prescripciones de silvicultura inicial. Los resultados de crecimiento temprano reportados son similares a los de plantaciones de *P. radiata* y de latifoliadas de rápido crecimiento en otras regiones templadas y subtropicales, lo que sugiere que estas plantaciones son una verdadera alternativa para la producción de madera y fibra, y para reducir la presión sobre bosques naturales en Chile.

Palabras clave: Calidad de plantas, especies arbóreas de rápido crecimiento, nutrición mineral, plantaciones de latifoliadas, sobrevivencia.

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