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Wild cherry tree (*Prunus avium* L.) growth in pure and mixed plantations in South America

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ABSTRACT

Seven-year-old pure and mixed-species plantations containing cherry tree (*Prunus avium* L.) were analyzed at six sites in the central and southern area of Chile. The study examines the growth, pests, diseases, and stem form of cherry trees in mixtures and monocultures. Compared to pure plantations, mixed plantations had higher cherry height (up to 28%) in 5 out of 6 sites and higher cherry DBH (up to 34.5%) in 4 out of 6 sites, which could be attributed to a combination of effects, including the presence of nitrogen fixing species.

Companion species can play an important role in cherry cultivation. With the exception of piche (*Fabiana imbricata* Ruiz & Pav.), cherry tree growth was faster and had better sanitary conditions in mixtures than in monocultures. Treatment (species associations) and environment interaction was significant, indicating the presence of different mechanisms underlying plantation effects at different sites, and the convenience of carefully identifying the characteristics of main and companion species, as well as site conditions, to propose suitable site-specific designs for mixed plantations. The growth characteristics of companion and primary species, as well as site conditions, should be selected and matched to improve plantation performance.

1. Introduction

A more sustainable and profitable forestry that allows a more efficient use of the soil as well as increasing biodiversity and stability of systems can be based on the use of forest species associations (mixed plantations) oriented to high-value timber production. Mixed plantations are models associating main species that generate high-value products at the end of the rotation (saw logs and veneer logs) and companion species that favor main species growth and improve their form, leading to better products quality, which can also generate products (posts, rolls, fruits, others) during the rotation.

Mixed plantations, if properly established and maintained, diversify the production, reduce phytosanitary risks, facilitate cultural interventions (especially pruning and weed control), improve timber quality, increases landscape aesthetic values and productivity (Buresti, 1995; Binkley, 2003; Forrester et al., 2004; Gabriel et al., 2005; Kelty, 2006; Piotto, 2008; Pretzsch and Schütze, 2009 and Hung et al., 2011). Certain main species associated with other N-fixing species account for high increments in diameter and height when compared with pure plantations of the main species (Forrester et al., 2006; Richards et al., 2010 and Forrester et al., 2011). Many of the research initiatives implemented around the world have studied acacias and eucalypts (Hung et al., 2011 and Manson et al., 2013). In South America, literature on mixed species plantations is scarce. Some productive experiences and research initiatives show interesting results, such as those reported by Loewe and González (2006) for Chile.

Cherry is an interesting commercial forest species because it can produce high-quality timber used for veneer and sawn wood, valued for its aesthetic quality and color (Fioravanti et al., 2009). Cherry produces cabinet-making wood, which is sought after by furniture manufacturers; other uses include carvings, lamps, musical instruments, parquet floors and indoor panels. Its sales price has remained at a very high level for several decades (INRA, 2008), being one of the most appreciated noble timbers, with prices reaching up to € 1000/m^3 (Loewe and González, 2004). Intensive management is usually necessary to produce such valuable logs; the lower trunk must be 5–6 m, branch-free, with a minimum diameter of 45 cm.

Timber quality and growth rate are the key characteristics for a high economic return in cherry plantations (Hajnala et al., 2007). Several authors recommend that pure plantations should not be

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larger than two hectares to minimize the chance of disease, or preferably that mixed plantations should be established (Buresti, 1995; Loewe et al., 2001 and Anonymous, 2008). The bacterial canker disease (*Pseudomonas siringae pv. Mors-prunorum* Van Hall.) and the cherry slugworm (*Caliroa cerasi* L.) cause losses in fruit yield and tree death; the first corresponds to one of the major limitations in the use of cherry for timber production due to the difficult control of that disease even using chemicals; in fact, the Forestry Commission imposes a 15% limit on cherry trees in farm woodlands, but still growers are keen to plant higher proportions due to the high economic value of timber (Roberts, 2001).

Mixed plantations would also have other benefits, such as greater scenic value. Pure species plantations are profitable, but mixed plantations seem to be a better option in the country (Donoso et al., 2009). Furthermore, forest owners may find a highly practical option in mixed plantations due to their additional resilience to disturbances (Knoke et al., 2008) and climatic change (Laurent, 2003). They may provide insurance, and its diversity may provide a range of products for alternative markets, along with a resource capable of withstanding climate change (Mohni et al., 2009). The specific objectives of this paper were to compare pure and mixed-species plantation of cherry trees in Chile regarding: (1) height and diameter growth, (2) pest and diseases, and (3) survival and stem form.

2. Materials and method

2.1. Experimental plantations

This study examines the growth, sanitary conditions and stem form of cherry trees in mixtures and monocultures involving several arboreal species across six sites in the central and southern area of Chile for seven years after planting. The study involves 24 plantations; site characterization is shown in Table 1, and pure and mixed arboreal associations used for cherry tree are presented in Table 2. All plantations were established during winter 2001. Morphometric and growth curves were studied over a period of seven years.

Plantations were established and managed under arboriculture techniques for high-quality timber production (Buresti et al., 2001), whose goal is to maximize timber quantity and technological timber quality (individual trunks, straightness, small tapering, regular diameter growth and absence of defects) (Berti et al., 2003). Mixed plantations appear to be an effective mode of reducing branching and forking, which can markedly affect both the quality and quantity of timber produced from a particular stem (Hung et al., 2011). This is particularly important given that the main high-value markets for this species require high-quality timber. This is achieved through soil preparation, weed control, initial fertilization, formative pruning and in some cases irrigation. We also included companion species interesting for their effect on cherry tree, and for their positive role in farming sustainability. Some companion species were exotic (*Elaeagnus angustifolia* L., *Corylus avellana* L., *Alnus glutinosa* (L.) Gaertn.) and others were native (*Quillaja saponaria* Mol., *Gevuina avellana* Mol., *Embothrium coccineum* J.R.Forst. & G.Forst). Field trials were established under a complete randomized block design with three replications at each site, with treatment number varying across sites. The area of each experimental plot (unit) ranged from 196 to 630 m^2, the design of the plots involved several species proportions, the proportion of cherry trees ranging between 2 and 88, depending on the association complexity. The species were mixed tree-by-tree, involving a buffer between treatments greater than two rows. Within a site, all treatments were subjected to the same planting pattern, spacing, and tending.

2.2. Data

Height and DBH measurements on cherry trees were taken yearly for seven years (2001–2007), with the exception of Linares site (2001–2006) since each live tree was cut at the beginning of 2007, always in winter time; in Los Lagos DBH was measured from 2005, when average cherry tree height was higher than 1.3 m.

Stem form variables observed at the end of the study period were straightness (0: straight tree; 1: curved less than average; 2: curve more than average; 3: strongly curved tree) and tree forking (0: presence; 1: absence). Phytosanitary variables were measured at the end of the study period, considering any disease or plague present in cherry trees, including damage agent, attack intensity (low, medium and high), and damaged section of trees, following Arriagada (2010). The identified diseases or conditions were cherry slugworm, Bacterial canker, and lichens adhered to the trunk.

2.3. Statistical analyses

First, a test of treatment (mixed and pure plantations) by environment interaction was run using the growth data. The interaction was significant, indicating the presence of different mechanisms underlying plantation effects at different sites then Mixed and pure plantations were compared at each site. Growth data for cherry trees under various treatments were modeled using polynomial regressions for each site. To represent the structure of (co)variances associated with growth data, linear mixed models were used (Diggle et al., 2002). Taking repeated measures on the same tree introduces correlations among observations and, therefore, the assumption of independence is not fulfilled. In addition, growth models in forests are usually characterized by an increase of variances through tree age (heterocedasticity) (Balzarini et al., 2005). Mixed models also allow us to account for correlation between observations of trees located in the same stand (Calegario et al., 2005). Modeling the structure of (co)variances of observations allows us to make more precise inferences to compare treatments (Carrero et al., 2008). Fitted mixed models in-

Table 1
Characteristics of the sites.

Trial name	Nearest city	Site location		Altitude (masl)	Soil Type/Productivity level	Rainfall (mm)	Average Tempera- ture (°C)	Spacing (m)
		Latitude	Longitude					
Alupenhue	Molina	35°13′58.02″S	71°5′14.33″W	568	Silty-sandy, Regular	701.9	13	3.5 × 3.5
Curanilahue	Cabrero	37°11′55.29″S	72°19′53.63″W	156	Silty- sandy, Regular	1107.0	13	3.5 × 3.5
Linares	Linares	35°53′6.42″S	71°36′13.73″W	157	Silty- sandy, Regular	1000.0	14	3.5 × 3.5
Los Lagos	Los Lagos	39°50′48.55″S	72°46′7.52″W	87	Trumao[a], Very productive	1331.8	11	4 × 8
Saval	Valdivia	39°50′1.50″S	73°15′31.36″W	20	Trumao, Productive	1871.0	11	3 × 3
Yacal	Molina	35°12′3.60″S	71°7′28.13″W	536	Silty- sandy, Low	701.9	13	3 × 3

[a] Trumao: volcanic soil, light, deep, fertile and with good drainage.

Table 2
Species associations (treatments and codes) used in pure and mixed plantations at six sites of Chile, South America.

Curanilahue	Yacal	Alupenhue	Los Lagos	Saval	Linares
T1: Pure Cherry (*Prunus avium*)	T1: Pure Cherry	T1: Pure Cherry	T1: Pure Cherry	T1: Pure Cherry	T1: Pure Cherry
T2: Mixed Walnut (*Juglans regia*), Cherry	T6: Mixed Walnut, Cherry, Pear (*Pyrus communis*), Apple (*Malus communis*)	T9: Mixed Cherry, American Red Oak	T14: Mixed Cherry, American Red Oak, Chestnut, European Oak	T2: Mixed Walnut and Cherry	T23: Mixed Cherry, Black Locust at low density
T3: Mixed Walnut, Cherry, Black Alder (*Alnus glutinosa*)	T7: Mixed Walnut, Cherry, Pear, Apple, Black Alder	T10 Mixed Cherry, American Red Oak, Black Alder	T15: Mixed Cherry, American Red Oak, Chestnut, European Oak, Black Alder	T3: Mixed Walnut, Cherry, Black Alder	T24: Mixed Cherry, Black Locust at high density
T4: Mixed Walnut, Cherry, Quillay (*Quillaja saponaria*)	T8: Mixed Walnut, Cherry, Pear, Apple, Russian olive (*Elaeagnus angustifolia*)	T11: Mixed Cherry, American Red Oak, Russian olive	T16: Mixed Cherry, American Red Oak, Chestnut, European Oak, Chilean Hazelnut (*Gevuina avellana*)	T22: Mixed Walnut, Cherry, Russian olive	
T5: Mixed Walnut, Cherry, Black Alder, Quillay		T12: Mixed Cherry, American Red Oak, Black Alder, Hazelnut (*Corylus avellana*)	T17: Mixed Cherry, American Red Oak, Chestnut, European Oak, Notro (*Embothrium coccineum*)		
		T13: Mixed Cherry, American Red Oak, Russian olive, Hazelnut	T18: Mixed Cherry, American Red Oak, Chestnut, European Oak, Piche (*Fabiana imbricata*)		
			T19: Mixed Cherry, American Red Oak, Chestnut, European Oak, Black Alder, Piche		
			T20: Mixed Cherry, American Red Oak, Chestnut, European Oak, Chilean Hazelnut, Piche		
			T21: Mixed Cherry, American Red Oak, Chestnut, European Oak, Notro, Piche		

cluded species associations, time and interaction effects on the mean structure (fixed effects). Several structures for the residual (co)variance matrix were tested at each site, including: (1) unstructured (UN), (2) compound symmetry (CS), (3) first-order autoregressive (AR1), (4) heterocedastic compound symmetry (HCS), and (5) heterocedastic first-order autoregressive (ARH1) (Littell et al., 2006). Parameters were estimated by restricted maximum likelihood (REML). Co-variance models were selected using Akaike information criterion (AIC; smaller is better). The AIC was calculated as $-2\log(\text{REML}) + 2(q + p)$, where REML stood for residual likelihood, and q and p were related to covariance and mean structure parameter number, respectively. Models were estimated using SAS PROCMIXED version 9.3 (SAS Institute, 2006). The initial cherry tree sizes were compared among plantations, and except in Los Lagos, non-significant differences were found ($p > 0.05$). Initial size was used as covariate to compare treatments in Los Lagos. Pairwise comparisons between species associations were tested with the adjusted LSMeans; p-values for LSMeans were adjusted for multiplicity using the criteria of Benjamini and Yekutieli (2001). Pearson's Chi-squared test ($\alpha = 0.05$) was used to test homogeneity of proportion of pest and disease damage among treatments and qualitative variables (straightness and forking). Damage intensity was assessed by means of Chi-square statistics for ordinal data. Kaplan–Meier survival curves and Long Rank Test ($\alpha = 0.05$) were used to compare stand survival among treatments at each site.

3. Results

3.1. Growth curves

3.1.1. Height

The analysis considered average cherry tree heights. The population average profiles for each treatment built from the predicted values of fitted models are shown in Fig. 1. The interaction between species associations and growth year was not statistically significant for height at the sites Yacal ($p = 0.7990$), Curanilahue ($p = 0.2428$) and Los Lagos ($p = 0.1433$). Changes in relative differences among species associations over time were observed at the sites Alupenhue, Linares and Saval ($p < 0.0001$). These interactions suggest that ranking of different treatments or their relative effects changed over time. The treatment-time interaction was influenced by the relatively slow growth of the monoculture towards the end of the study. However, there was not an important cross-over interaction between treatment and growth year. In Alupenhue, relative differences between the association T12 (with black alder (*Alnus glutinosa*)) and the monoculture were significantly higher at the end of the study period ($p = 0.0006$). In Linares, height growth differences of associations with black locust (*Robinia pseudoacacia* L.) compared to the monoculture were significant ($p = 0.0344$) 6 years after plantation for both black locust densities; however, in the black locust at low density differences were observed before that period. In Saval in the mixed plantation with black alder, cherry tree growth was relatively low during the first years, but at age 7, they were higher than monoculture trees.

Species association yielding a different cherry height growth curve in Curanilahue ($p = 0.0344$) showed smaller growth in pure plantations than in mixed plantations with black alder and quillay (*Q. saponaria*) as companion species. Table 3 shows the AIC for the alternative covariance models fitted at each site. In this site, AR1, ARH1 and UN models met convergence criteria, with UN model being the best one. Pairwise comparisons of adjusted LS Means showed statistical differences among expected cherry height growth under the following species associations (treatments): T1 ≠ T3 ($p = 0.0236$); T1 ≠ T5 ($p = 0.0503$); T2 ≠ T3 ($p = 0.0275$); T3 ≠ T4 ($p = 0.0145$); T3 ≠ T5 ($p = 0.0033$). There was a slight but significant difference between the pure treatment and the most complex one, the latter being 6% higher.

In Yacal, Alupenhue and Saval covariance UN model did not meet convergence criteria, with the ARH1 being best for Yacal, AR1 for Alupenhue and CSH for Saval, suggesting significant

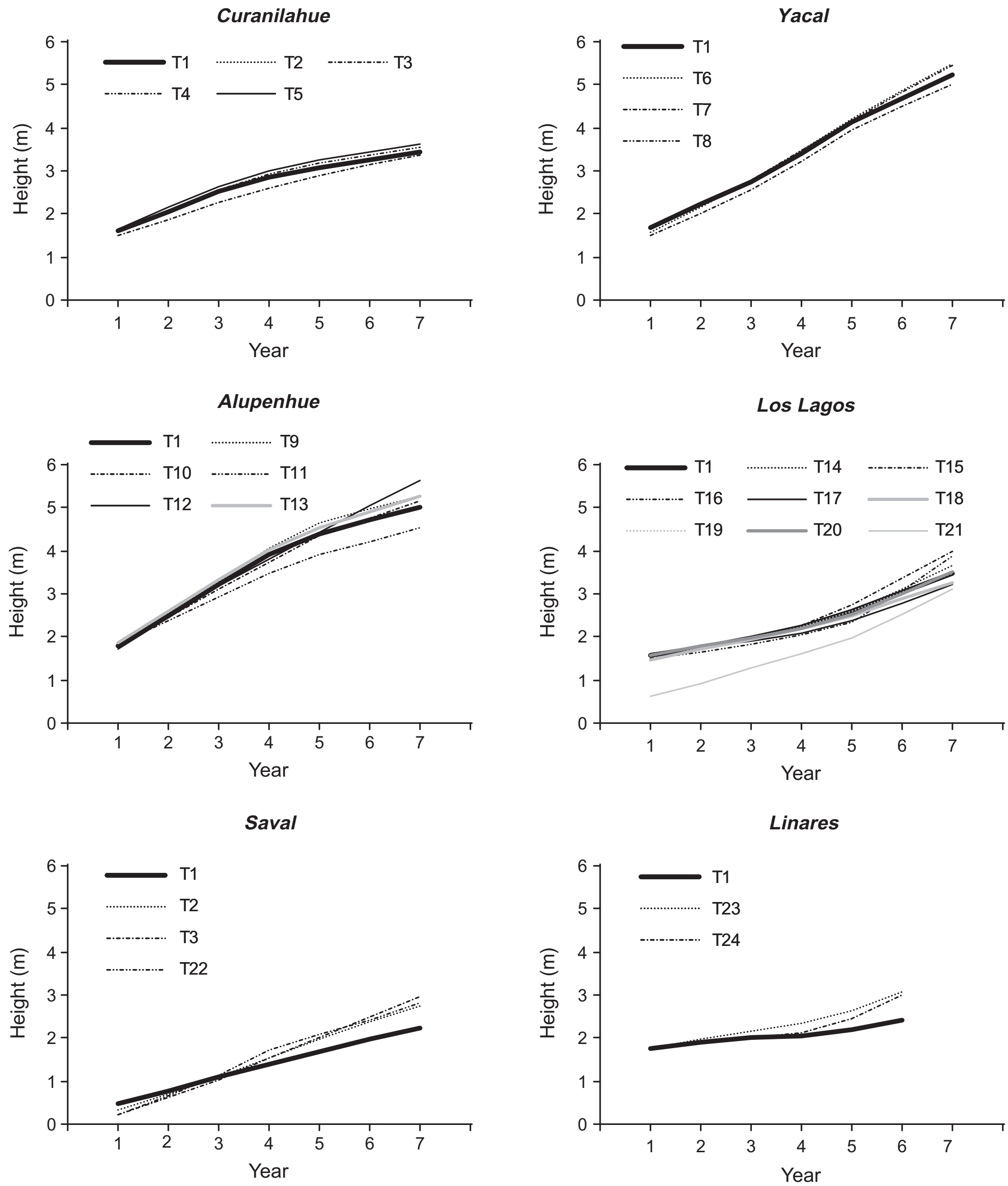

Fig. 1. Cherry tree height growth curves fitted under pure cherry plantations (T1) and several associations generating mixed plantations at six sites of central and south Chile (3 plots per treatment).

Table 3
Covariance models fitting information for height (AIC values).

Site	Covariance models				
	UN	CS	AR1	CSH	ARH1
Curanilahue	666.1	nc	1691.9	nc	1245.2
Yacal	nc	nc	6297.8	nc	5736.5
Alupenhue	nc	1878.6	1878.2	nc	nc
Los Lagos	nc	946.1	946.5	nc	nc
Saval	nc	871.7	898.0	749.2	nc
Linares	nc	1254.4	1249.6	1031.7	1035.1

nc: Non-convergence.

changes in height variance at higher arboreal age. Pairwise comparisons of adjusted LS Means showed no statistical differences among treatments seven years after establishment.

In Los Lagos, CS covariance model showed the best fit according to AIC. Pairwise comparisons of adjusted LS Means showed statistical differences among species associations, showing that T1 $\neq$ T21 ($p = 0.0079$); T14 $\neq$ T21 ($p = 0.0081$); T15 $\neq$ T21 ($p = 0.0033$); T16 $\neq$ T21 ($p = 0.0180$); T17 $\neq$ T21 ($p = 0.0399$); T18 $\neq$ T21 ($p = 0.0392$); T19 $\neq$ T21 ($p = 0.0132$); T20 $\neq$ T21 ($p = 0.0104$). Pure plantations and mixed plantations including notro (*E coccineum*) and piche showed lower performance in height.

In Linares, CSH covariance model was the best according the fitting criterion, with greater variances in the response variable for the last years. Statistical differences between pure and mixed plantations with low density of black locust (T23) were significant ($p = 0.0344$), the latter presenting a 28% greater height.

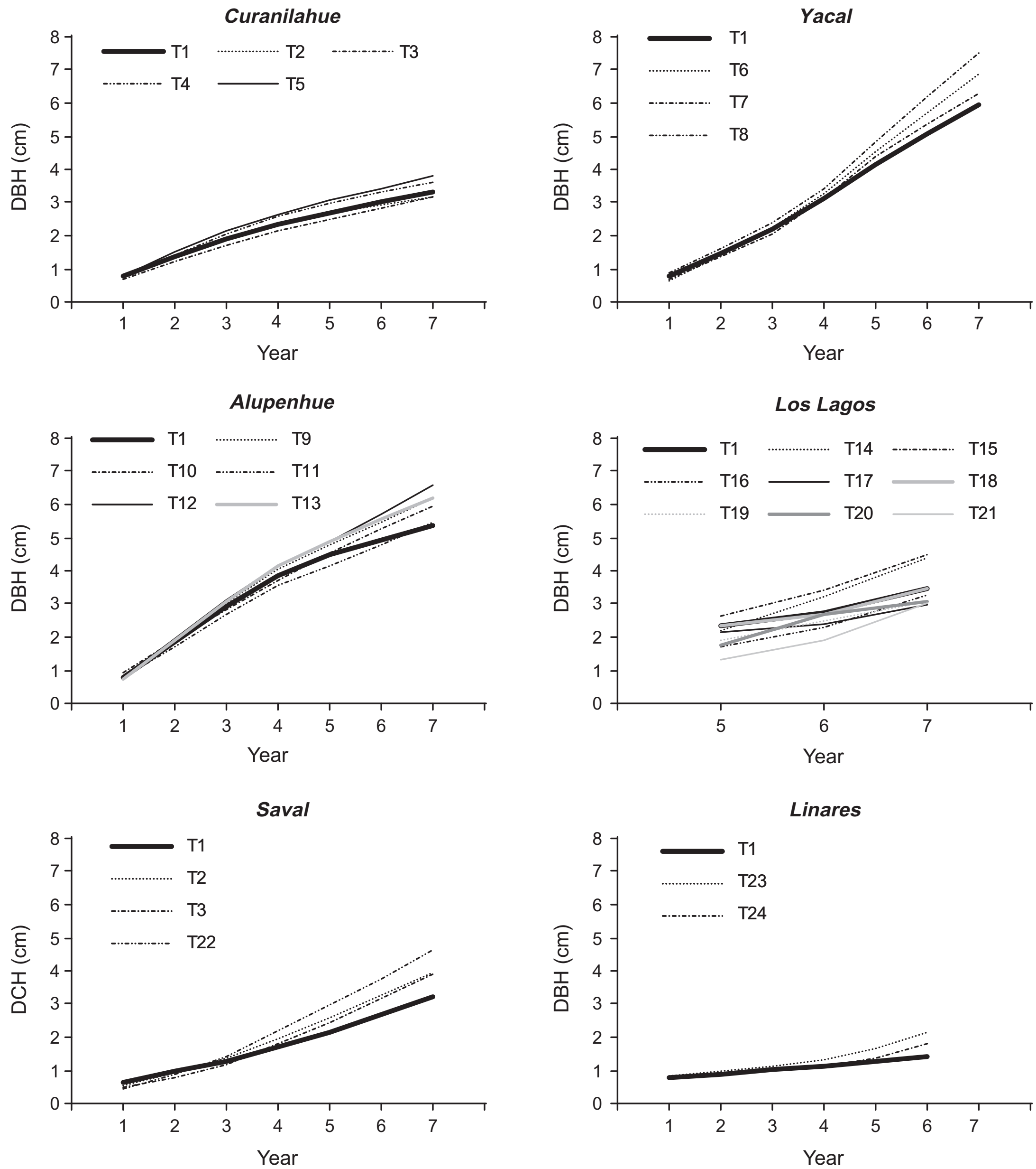

Fig. 2. Cherry tree Diameter growth curves under pure cherry plantations (T1) and several associations generating mixed plantations at six sites of central and south Chile (3 plots per treatment).

3.1.2. Diameter

In Yacal ($p = 0.0001$), Linares ($p = 0.0183$), Curanilahue ($p = 0.0064$) and Saval ($p < 0.0001$) the effects of species associations interacted with time (Fig. 2). However, the ranking of different treatments did not change with time; in all these sites the significance of the interaction was related to the increase of the positive effects of some mixed-species plantations over monoculture over time.

Differences among treatments over time were statistically significant in Curanilahue ($p = 0.0105$) and marginally significant in Linares ($p = 0.0612$). Table 4 shows AIC for the covariance models fitted at each site. In Curanilahue ARH1, covariance model showed the best fit. Pairwise comparisons of adjusted LS Means exhibited statistical differences among treatments, showing that T1 $\neq$ T4 ($p = 0.0260$); T1 $\neq$ T5 ($p = 0.0029$); T2 $\neq$ T4 ($p = 0.0387$); T2 $\neq$ T5 ($p = 0.0053$); T3 $\neq$ T4 ($p = 0.0265$); T3 $\neq$ T5 ($p = 0.0052$). DBH was greater in mixed plantations including quillay (T4 and T5). Diameter of cherry trees under T5 was 17% greater than in pure plantation. T5 showed greater diameter values during the whole study period. No differences in average diameter growth among treatments were found in Yacal, Alupenhue, Los Lagos or Saval. In Lin-

Table 4
Covariance models fitting information for DBH (AIC values).

Site	Covariance models				
	UN	CS	AR1	CSH	ARH1
Curanilahue	nc	nc	3179.8	nc	2177.3
Yacal	nc	nc	7364.8	nc	nc
Alupenhue	nc	2709.5	2709.4	nc	nc
Los Lagos	nc	745.9	747.3	782.2	786.9
Saval (DCH)	nc	1381.1	1386.4	nc	1088.7
Linares	nc	1088.9	1086.8	646.8	650.6

nc: Non-convergence.

Table 5
Percentage of damage caused by cherry Slugworm in pure and mixed plantations.

Plantation type	Curanilahue	Yacal	Alupenhue	Los Lagos	Saval	Linares
Sites						
Pure (T1)	47.5 a	91.3 a	100 a	100 a	49.5 a	74.3 a
Mixed plantations	37.9 b (T5)	90.9 a (T6)	91.7 a (T9)	100 a (T14)	68.6 a (T2)	55.6 b (T23)
	34.4 b (T4)	88.2 a (T8)	75.0 a (T10)	100 a (T15)	55.6 a (T3)	25.7 c (T24)
	33.3 b (T3)	82.3 a (T7)	75.0 a (T11)	100 a (T17)	55.6 a (T22)	
	28.2 b (T2)		65.3 a (T12)	100 a (T18)		
			58.3 a (T13)	100 a (T19)		
				100 a (T20)		
				100 a (T21)		
				83.3 b (T16)		
Pearson's X^2	41,01	1.6	7.3	17.2	5.1	26.5
d*f*	8	3	10	8	3	2
p Value	<0.0001	0.7128	0.6925	0.0285	0.1662	0.0001

Different letters indicate statistically significant differences ($p \leqslant 0.05$).

Table 6
Absolute and relative frequency of cherry trees with cherry Slugworm, per treatment and damage intensity.

Site	Treatment	Low (⩽30%)	Medium (40–55%)	Strong (⩾60%)	Total
Curanilahue	T1	10 (9.2)	45 (41.3)	54 (49.5)	109
	T2	16 (34.8)	25 (54.3)	5 (10.9)	46
	T3	5 (27.8)	11 (61.1)	2 (11.1)	18
	T4	7 (36.8)	9 (47.4)	3 (15.8)	19
	T5	7 (33.3)	11 (52.4)	3 (14.3)	21
Linares	T1	21 (42.0)	15 (30.0)	14 (28.0)	50
	T23	2 (40.0)	1 (20.0)	2 (40.0)	5
	T24	3 (25.0)	7 (58.3)	2 (16.7)	12

Row percentages are indicated between parentheses.

Table 7
Percentage of damage caused by Bacterial Canker in pure and mixed plantations.

Plantation type	Site	
	Yacal	Alupenhue
Pure (T1)	78.8 ab	81.3 a
Mixed plantations	94.1 a (T8)	91.7 a (T12)
	80.8 a (T6)	83.3 a (T10)
	58.8 b (T7)	80.6 a (T9)
		75.0 a (T13)
		58.3 a (T11)
Pearson's X^2	6.7	4.9
d*f*	3	5
p Value	0.0808	0.4309

Different letters indicate statistically significant differences ($p \leqslant 0.05$).

Table 8
Percentage of damage caused by lichen adhered to trunks in pure and mixed plantations in Curanilahue.

Treatment	Curanilahue
T1	25.2 a
T2	28.4 a
T3	27.5 a
T4	21.7 a
T5	15.4 b
D*f*	4
p-Value	0.0413

Different letters indicate statistically significant differences ($p \leqslant 0.05$).

ares, the best covariance model was CSH, suggesting heterogeneity of variances among treatments over time. Pairwise comparisons of adjusted LS Means showed statistical differences between diameter growth in pure plantation and T23 ($p = 0.0256$). Mixed plantation with low density of black locust presented 35% greater DBH than pure plantation.

3.2. Pest and diseases data

3.2.1. Cherry slugworm

In Curanilahue, Los Lagos and Linares there were statistically significant differences among treatments regarding percentage of damage. In five out of six environments the pure plantation showed a higher percentage of affected trees, showing significant differences in Curanilahue and Linares (Table 5). In all sites, except for Los Lagos (site of highest productivity), there was a mixed plantation that showed a better performance than the monoculture, suggesting the improvement of disease resistance. In Curanilahue and Linares, damage intensity values are shown in Table 6. An association among degree of cherry slugworm attack and treatment was observed in Curanilahue (Pearson's $\chi^2 = 41.0$; d$f = 8$, $p = 0.0001$). The pure plantation presented a higher proportion of trees with strong attack and lower proportion of trees with low attack than mixed treatments. In Linares, no association among degree of cherry slugworm attack and treatment was observed (Pearson's $\chi^2 = 4.1$; d$f = 4$, $p = 0.3902$).

3.2.2. Bacterial canker

Canker was abundant only in Yacal and Alupenhue (Table 7). With the exception of Linares, in all field trials in which the disease was present there was always at least one mixed plantation that had a better sanitary performance than the pure one. However, the differences among treatments were statistically significant only in Yacal, with T7 being the mixed plantation with lowest percentage of affected trees (58.8%). In Curanilahue, bacterial canker was absent in all treatments. T11 in Alupenhue had the lower per-

Table 9
Absolute and relative frequency of cherry trees with Lichen in trunks, per treatment and damage intensity in Curanilahue.

Treatment	Low (⩽30%)	Medium (40–55%)	Strong (⩾60%)	Total
T1	82 (68.9)	23 (19.3)	14 (11.8)	119
T2	39 (62.9)	17 (27.4)	6 (9.7)	62
T3	15 (75.0)	5 (25.0)	0 (0.0)	20
T4	10 (50.0)	10 (50.0)	0 (0.0)	20
T5	11 (84.6)	0 (0.0)	2 (15.4)	13

Table 10
Stem form as percentage of straight trees in Alupenhue and Linares.

	Alupenhue	Linares
Pure (T1)	56.0 a	17.1 ab
Mixed plantations	51.4 a (T12)	29.6 a (T23)
	50.0 a (T9)	3.6 b (T24)
	36.4 b (T10)	
	33.3 b (T11)	
	8.3 b (T13)	
Pearson's X^2	11.3	6.7
d*f*	5	2
p Value	0.03457	0.0352

centage of affected trees and in Saval and Los Lagos, all mixed plantations showed disease absence, except T17.

3.2.3. Lichen in trunks

Lichens adhered to the trunk were found in Curanilahue. The smallest percentage of affected trees was found in one of the mixed plantations (T5) (Table 8). A negative association among the degree of lichen attack and tree height was also observed (Pearson's $\chi^2 = 28.8$; d$f = 9$, $p = 0.0007$), with higher and more vigorous trees being less affected. Additionally, a damage intensity analysis conducted (Table 9) showed an association between the degree of lichen presence and treatment (Pearson's $\chi^2 = 17.2$; d$f = 8$, $p = 0.0283$). No cherry tree in association with black alder was strongly affected, and a high proportion presented low damage intensity. The association with quillay (T3) did not present strongly affected trees. Mixed plantations with both black alder and quillay (T5) presented the highest proportion of trees with low damage intensity.

3.3. Stem Form

3.3.1. Straightness

In Alupenhue and Linares, there were statistical differences regarding trunk straightness under different treatments (Table 10). The higher percentage of straight trees was found in the pure plantation, with T9 and T12 also exhibiting high values. In Linares T24, the association with high density of black locust had the lowest percentage of straight trees.

3.3.2. Forking

Statistical differences between treatments considering percentage of non-forked trees were found only in Los Lagos (Table 11). With the exception of T15, all mixed plantations showed higher percentage of non-forked trees than monoculture. On average, forking was 33.3% in the pure plantation and 19.8% in mixed plantations.

3.4. Survival analysis

The Long Rank Test applied to the estimated survival curves for each treatment showed significant statistical differences among

Table 11
Stem form as percentage of non-forked trees in Los Lagos.

	Los Lagos
Pure	66.6 b
Mixed plantations	100.0 a (T17)
	100.0 a (T18)
	100.0 a (T19)
	83.3 a (T16)
	83.3 a (T21)
	66.7 b (T14)
	66.7 b (T20)
	50.0 b (T15)
Pearson's X^2	17.1
d*f*	8
p Value	0.0288

Different letters indicate statistically significant differences ($p \leqslant 0.05$).

plantation types considering survival of cherry trees (Alupenhue, $\chi^2 = 44.2$, $p < 0.0001$; Yacal, $\chi^2 = 45.2$, $p < 0.0001$; Los Lagos $\chi^2 = 218.1$, $p < 0.0001$ and Saval $\chi^2 = 26.4$, $p < 0.0001$), with the exception of Curanilahue and Linares (Fig. 3). In Curanilahue and Alupenhue, mortality was negligible. In Yacal, T6 showed a statistically higher survival than the pure plantation across time ($\chi^2 = 39.6$, $p < 0.0001$). In Saval both T3 and T22 showed significant statistical differences with T1, exhibiting higher survival across time ($\chi^2 = 8.3$, $p = 0.0037$; $\chi^2 = 19.7$, $p < 0.0001$). In Los Lagos T21, the association that includes Notro and Piche showed statistically significant differences with all treatments, exhibiting lower survival across time.

4. Discussion

4.1. Height and diameter growth

Differences in cherry height between seven-year old pure and mixed plantations were only marked in Linares and Saval. With the exception of Yacal, in all environments there were interactions between treatment and time, suggesting changes in the differences between plantation types over time. Other studies have shown that broad-leaved species in mixed plantations could reach heights up to 24% greater than in pure plantations (Gabriel et al., 2005). Our results show that some associations improve cherry height growth compared to the pure plantation, such as the combination with black locust at high density, which was 28% higher than the pure plantation in Linares. cherry had better height behaviour in association with walnut (*Juglans regia* L.), black alder and quillay than in pure plantation in Curanilahue. Both sites show a medium productivity; this information is consistent with findings of Forrester et al. (2006), who state that interactions involving facilitation or competitive reduction generally predominate in poor sites where the resource that is influenced by species interactions is scarce. Data suggest that the N-fixing species fix significant quantities of Nitrogen at these sites, although it was not quantified. The Nitrogen fixation mechanisms both for *Robinia* and *Alnus* species are well described in Forrester et al. (2006). Richards et al. (2010) stated that red alder (*Alnus rubra* Bong.) increased the rate of Nitrogen fixation in two associations, and Binkley (2003) showed that its significant effect remains very strong even after seven decades, greatly increasing the ecosystem productivity. Schlesinger and Williams (1984) reported that interplanting black locust and black alder increased black walnut (*Juglans nigra* L.) growth in certain locations.

The fitted height growth curves for cherry suggest an annual growth rate from 0.50 to 0.92 m in the six mixed plantations, whereas the growth rate was 0.37 to 0.83 m/year in pure plantations at the same six sites. Therefore, the observed height growth in Chile was greater than results obtained in cherry agroforestry plantations after 8 years in five locations in Languedoc, France, which showed an annual height increment ranging from 0.31 to 0.69 m/year (Balandier and Dupraz, 1999).

The fast initial growth of cherry found in mixed plantations corroborates previous findings with this species (Kerr, 2004) and with black cherry (*Prunus serotina* Ehrh.) (Gauthier et al., 2013).

Regarding diameter, in four out of the six evaluated sites (Saval, Linares, Yacal and Alupenhue) the pure treatment had the lowest diameter performance over time. These four sites are characterized by regular or low productivity, showing that in these cases interspecific competition was lower than intraspecific competition, as stated by Forrester et al. (2006). In Curanilahue and Linares, there was a significant gain in cherry diameter in mixed plantations. However, differences between plantation types depended on the year of evaluation, as suggested by the significant interaction between treatments and time.

We found some associations that improved cherry diameter growth compared to the pure plantation, such as the one with

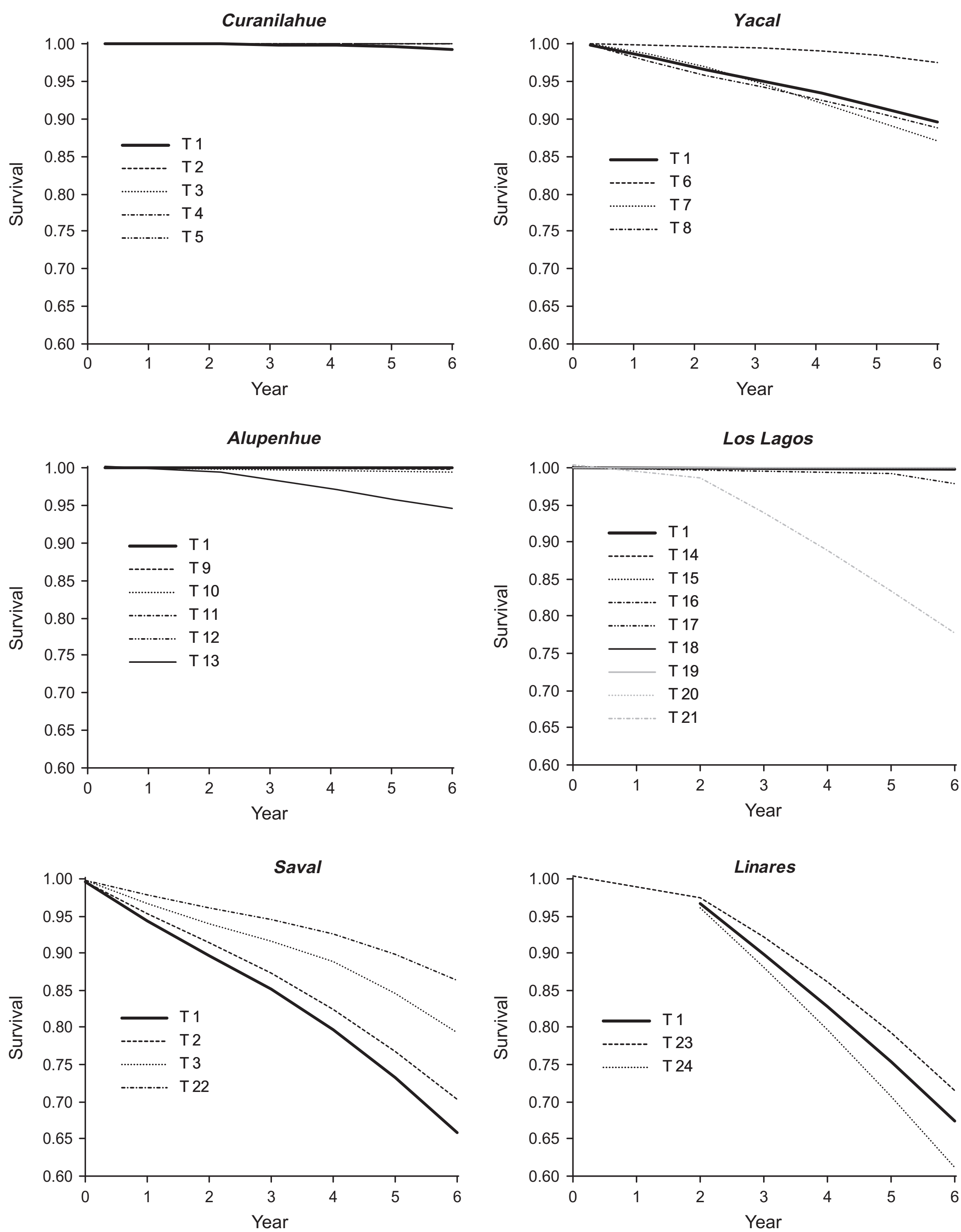

Fig. 3. Cherry tree survival curves for pure (T1) and several types of mixed plantations at six sites of central and southern Chile (3 plots per treatment).

black locust at low density, in which cherry diameter was 35% higher than monoculture in the same site. The poorer result in association with black locust at high density is coincident with findings reported by Schlesinger and Williams (1984), who observed that the rapid growth of black locust was detrimental to black walnut. In Curanilahue, the associations with walnut and quillay (T4) and with walnut, black alder and quillay (T5) were better than the pure plantation and other mixtures. Such results suggest that the association with alder-quillay and quillay as secondary species are positive for cherry diameter growth.

Because mortality changes the amount of competition and plot density (Vanclay, 2006), differences in mortality rates among species could have potentially confounded the effect of spacing and association, which may limit the interpretation of growth estimates at tree and plot level if mortality of associated species is high, leading to misinterpretation of findings.

Quantifying the amount of competition would have helped to account for mortality and facilitated interpretation of mixture effects. Because we do not have spatial data to calculate competition indices such as the crown competition factor (CCF), the reader should consider this as a limitation of our study.

These findings agree with information from Tani et al. (2006) and Loewe (2003), who reported best performances in cherry trees grown with accessory trees, especially if associated with N-fixing species. These positive effects are probably due to many co-occurring favourable causes, with the higher Nitrogen availability being a remarkable aspect. Mohni et al. (2009) indicated that growth in dense plantation with companion species has often demonstrated greater height and diameter growth than pure stands. In soils with reduced fertility, the role of companion species is more important than in fertile soils (Chifflot et al., 2005 and Balandier et al., 2008). Accordingly, in our study, Yacal, Linares and Saval were the poorest sites, where both height and DBH were improved through associations. Hazelnut (*C. avellana*), which rapidly covers the soil and reduces weed competition, is mentioned as one of the most appropriate shrubs for high-value timber plantations (Mohni et al., 2009). In fact, in Alupenhue, the only site that included two treatments with hazelnut, both had the best DBH and height performance, which is also consistent with findings of Clark et al. (2008). These authors also indicated that the architecture of Russian olive (*Elaeagnus umbellata* L.) has a significant positive effect on black walnut height. Pedlar et al. (2006) indicate that *E. umbellata* stimulated black walnut growth better than any other nurse species, but several authors highlighted its invasive nature (Yates et al., 2004 and Johnson et al., 2006), which we have not observed in Chile. In our study in two out of three sites (Yacal and Saval, poor and regular productivity, respectively) treatments that included *Elaeagnus angustifolia* had the best cherry height performance. Similarly, Schlesinger and Williams (1984) reported that *E. umbellata* stimulated black walnut growth in 80% of the studied sites, being especially effective at sites where the species growth was slowest in pure plots. This stimulation on cherry can be due to the N-fixing ability of *Elaeagnus*, being more effective on poorer sites; *E. angustifolia* rates of Nitrogen fixation peak at 2–3 years of age and decline subsequently at 4–5 years (Richards et al., 2010).

Forrester et al. (2004) found that 3 and 6.5 year-old *E. globulus* Labill. and *A. mearnsii De* Wild. trees in mixtures have lower H/D, which is characteristic of dominant trees. In our study we found coincident results only for 13 out of 23 associations (57%).

The fact that survival of cherry trees was high in most mixtures in 4 out of 6 sites indicates that inter-specific competition in mixture was lower than intra-specific competition in monocultures. In Los Lagos, one association (including notro and piche) had a lower survival across time, showing that competition in this case was higher than facilitation or competitive reduction effects (Forrester et al., 2004, 2006).

4.2. Pest and diseases

Cherry slugworm is a significant destructive pest because as larvae feed on the upper surface of the leaf, larger leaf veins are avoided and larvae rarely penetrate the lower leaf surface, creating the characteristic lacy or skeletonized appearance. In heavy infestations, trees may suffer from the loss of foliage. Control strategies rely to a large extent on the use of chemical insecticides (Aslantaş et al., 2008), which is a problem in forest oriented plantations. We found that cherry slugworm in Curanilahue, Linares and Alupenhue had a higher percentage of affected trees in the pure plantations (up to 19.3%, 41.7% and 48.6%, respectively, considering the best association for this parameter at each site). In Los Lagos, the association with Chilean hazelnut (*G. avellana*) (T16) had a significantly lower disease attack. Regarding Bacterial canker, there were statistical differences among treatments only in Yacal, with T7, the association with Black alder, having a protective effect; in fact, other similar cases have been reported, i.e., planting poplar (*Populus sp.* L.) with red alder induced more resistance to pests and diseases (Miller et al., 1993). In Alupenhue T11, the association with Russian olive showed a considerably low presence of bacterial canker. These findings agree with results reported by Montagnini et al. (1995); thus, growth conditions in pure or mixed stands can affect the appearance of pests and diseases, depending on the causal agent. For example, fungal diseases spread rapidly in pure plantations, reaching high infestation levels. Although insect damage intensity depends both on the tree species and on the type and species of insect, mixed plantations with several species can contribute to damage reduction. The severity of insect damage would be reduced in mixed plantations, because pure plantations would favour the spread of insects, presenting a higher phytosanitary risk, which is still higher if clones are used (Hubert, 1993). To reduce this risk, multi-clonal plantations should be established, even at the expense of stand homogeneity.

In Chile, in four-year old pure and mixed plantations of common walnut and cherry tree with other principal species (pear tree (*Pyrus communis* L.) and apple tree (*Malus communis* L.)) and secondary species (black alder and russian olive), significant differences in the frequency and intensity of damage of serious diseases have been observed, such as walnut blight (*Xanthomonas campestris var. juglandis* (Pammel) Dowson), phytophtora (*Phytophtora* sp.) and bacterial canker. Attack of walnut blight in walnut trunks was observed in 100% of cases in pure plantations. Damage caused by phytophtora in walnut was less serious in mixed plantations (24%) than in pure plantations (76%); and bacterial canker attacks observed on cherry-tree trunks were less frequent in mixed plantation (30%) than in pure plantations (70%) (Loewe and González, 2006). Noticeably, other authors reported cases in which pure stands are more resistant to certain insects than mixed associations (Watt, 1992 cit. by Montagnini et al., 1995).

Lichens rarely develop on fast growing trees, because new bark is constantly being formed before lichens have an opportunity to grow over much of the surface. Because of this, in certain species the presence of lichens may indicate poor tree growth. In some plantings, most vigorous trees have been found to have fewer lichens than nearby trees of the same age that are in a state of decline (Hartman, 2005). Lichens were detected in trunks only in one site (Curanilahue); T5, the association with trees and shrubs, presented a significantly lower (50%) lichen presence. This attack was related to tree vigor (higher vigor and lower attack) and to the complexity of the associations (lower presence with increasing mixture complexity). Regarding lichen damage intensity, in the association with alder (T3) no tree was strongly affected and a high proportion presented low damage intensity. The association with quillay (T4) did not present strongly affected trees either. The association with alder and quillay (T5) presented the highest proportion of trees with low damage intensity.

4.3. Stem form and survival

Straightness, one of the most important variables related to stem form, showed statistical differences between treatments in two sites (Alupenhue and Linares). In Linares T23, the association with low density of black locust showed significantly higher number of straight trees than the pure plantation. The association with high density of black locust was the worst, which is consistent with findings of Mohni et al. (2009), who stated that problems can arise when the distance between plants leads to intraspecific or interspecific negative competition. In these situations, cherry can exhibit poor growth with very competitive species, such as black locust.

Regarding forking, which can markedly affect both the quality and quantity of timber produced from a particular stem (Hung et al., 2011), presented significant differences were observed only in one site (Los Lagos), most probably due to the lower stand density (in average cherry forking was 33.3% in the pure plantation and 19.8% in the associations; T17, T18 and T19 had no forked trees). In other sites, we consider that forking was reduced due to both the higher stand density and pruning. This is particularly important given that the high market value for this timber requires clear wood of high quality. Companion species allow the length of the log potentially harvested to increase without additional efforts (Balandier et al., 2008).

The analysis of survival curves showed significant differences among treatments for cherry trees. In Curanilahue and Saval the pure stand was the treatment with highest mortality over time. Considering that mortality changes the amount of competition and plot density, differences in mortality rates among species could have potentially confounded the effect of spacing and association, which may limit the interpretation of our findings.

5. Conclusions

Mixed plantations have advantages for several parameters of economic importance in cherry. The results presented are early stage, and therefore preliminary; it would be interesting to take measurements at a later tree age to understand the changing dynamics of species interactions.

Although this study was not designed to determine which combination of the factors potentially altered by companion species (soil influence, microclimate changes, vegetation and/or pest habit changes) contributed to the cherry response observed, we can conclude that only Piche was a negative companion species, and that all the other species tested improved growing conditions of cherry under some soil types and topographic conditions. Therefore, companion species can play an important role in cherry cultivation, especially in the poorest sites. Our results showed greater height (up to 28%) and DBH (up to 35%) than in pure plantations, as well as less severe damages by pest and diseases and better stem form in terms of straightness and absence of forking.

However, it is necessary to select and match growth characteristics of companion and main species under different site conditions. Mixed cherry tree plantations can favor the species development, high quality timber production and management practices, making a better use of plantation potential.

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References

Anonymous, 2008. Native Cherry, Short Guide to Planting and Use. Online database. <http://www.robinia.nl/leafletter/cherry.htm> (cited 10.03.08).

Arriagada, R.V., 2010. Methodology for Creating Phytosanitary Hazard Profiles for Plants, Plant Products, and Other Regulated Articles. IICA, San José, 96 p.

Aslantaş, R., Eken, C., Hayat, R., 2008. Beauveria bassiana pathogenicity to the cherry slugworm, *Caliroa cerasi* (Hymenoptera: Tenthredinidae) larvae. World Journal of Microbiology and Biotechnology 24 (1), 119–122.

Balandier, P., Dupraz, C., 1999. Growth of widely spaced trees. A case study from young agroforestry plantations in France. Agroforestry Systems 43 (1999), 151–167.

Balandier, P., Allegrini, C., Jay, D., 2008. Des réactions similaires a l'accompagnement ligneux pour le frene et le noyer hybride. Foret-entreprise 178 (2008), 21–25.

Balzarini, M., Macchiavelli, R., Casanoves, F., 2005. Aplicaciones de modelos mixtos en agricultura y forestería. Notas de clase Curso Internacional Aplicaciones de Modelos Mixtos en Agricultura y Forestería. CATIE. Turrialba, Costa Rica, 189 p.

Benjamini, Y., Yekutieli, D., 2001. The control of the false discovery rate in multiple hypotheses testing under dependency. The Annals of Statistics 29 (4), 1165–1188.

Berti, S., Brunetti, M., Rescic, L., 2003. Manuale sulla valutazione della qualità degli assortimenti legnosi ritraibili dalle specie legnose pregiate. Regione Lombardia. CNR-IVALSA, ARSAF. 48 p.

Binkley, D., 2003. Seven decades of stand development in mixed and pure stands of conifers and N-fixing red alder. Canadian Journal of Forest Research 33, 2274–2279.

Buresti, E., 1995. Walnut trees in mixed stands with shrubs and trees. In: European Development of Walnut and Fruit Production as an Alternative and Extensive System to Agricultural Crops. Workshop of EU AIR/Walnut Project, Thessaloniki, Greece, March 27–30, 1995.

Buresti, E., Mori, P., Ravagni, S., 2001. Arboricoltura da legno con il ciliegio: ridurre i rischi adottando la doppia pianta. Sherwood 73, 11–16.

Calegario, N., Maestri, R., Leal, C., Daniels, R., 2005. Estimativa do crescimento de povoamentos de *Eucalyptus* baseada na teoria dos modelos não lineares em multiníveis de efeito misto. Ciência Florestal 15, 285–292.

Carrero, O., Jerez, M., Macchiavelli, R., Orlandoni, G., Stock, J., 2008. Ajuste de curvas de índice de sitio mediante modelos mixtos para plantaciones de *Eucalyptus urophylla* en Venezuela. Interciencia 33, 4.

Chifflot, V., Bertoni, G., Cabanettes, A., Gavaland, A., 2005. Beneficial effects of intercropping on the growth and nitrogen status of young wild cherry and hybrid walnut trees. Agroforestry Systems 66 (1), 13–26.

Clark, J.R., Hemery, G.E., Savill, P.S., 2008. Early growth and form of common Walnut (*Juglans regia* L.) in mixture with tree and shrub companion species in southern England. Forestry, doi: 10.1093/forestry/cpn036. Online database. <http://forestry.oxfordjournals.org/cgi/content/abstract/cpn036> (cited 10.03.08).

Diggle, P.J., Heagerty, P., Liang, K.Y., Zeger, S.L., 2002. Analysis of Longitudinal Data, 2nd ed. Oxford University Press, Oxford.

Donoso, P.J., Navarro, C.O., Soto, D.P., 2009. A Conceptual Model for Silvicultural Systems in Pure and Mixed Plantations of Native Species in Chile. World Forestry Congress, Buenos Aires, Argentina.

Fioravanti, M., Signorini, G., Ducci, F., 2009. *Prunus avium* L.: uno studio sull'ereditabilita del colore del legno. Atti del Terzo Congresso Nazionale di Selvicoltura per il miglioramento e la conservazione dei boschi italiani. Accademia Scienze Forestali, pp. 1498–1503.

Forrester, D.I., Bauhus, J., Khanna, P.K., 2004. Growth dynamics in a mixed-species plantation of *Eucalyptus globulus* and *Acacia mearnsii*. Forest Ecology and Management 193, 81–95.

Forrester, D.I., Bauhus, J., Cowie, A.L., Vanclay, J.K., 2006. Mixed-species plantations of *Eucalyptus* with nitrogen fixing trees: a review. Forest Ecology and Management 233, 211–230.

Forrester, D.I., Vanclay, J.K., Forrester, R.I., 2011. The balance between facilitation and competition in mixtures of *Eucalyptus* and *Acacia* changes as stand develop. Oecologia 166, 265–272.

Gabriel, K., Blair, I.F., Mason, W.L., 2005. Growing broadleaves trees on the North York Moors, results after nearly 50 years. Quarterly Journal of Forestry 99, 21–30.

Gauthier, M.M., Zellers, K.E., Löf, M., Jacobs, D.F., 2013. Inter- and intra-specific competitiveness of plantation-grown American chestnut (*Castanea dentata*).

Hajnala, M., Lstibůrek, M., Kobliha, J., 2007. First evaluation of growth parameters in clonal tests with wild cherry. Journal of Forest Science 53 (2), 57–65.

Hartman, J., 2005. Lichens infesting tree trunks and branches. Kentucky Pest News from the University of Kentucky College of Agriculture.

Hubert, M., 1993. La ligniculture. Foret Entreprise 88, 23–28.

Hung, T.D., Herbohn, J.L., Lamb, D., Nhan, H.D., 2011. Growth and production varies between pair-wise mixtures and monoculture plantations in North Viet Nam. Forest Ecology and Management 262, 440–448.

INRA, 2008. Gardeline, Monteil and Ameline: a revolution in the cultivation of wild cherry trees. Online database. <www.international.inra.fr/layout/set/print/partnerships/with_the_private_sector> (cited 17.06.08).

Johnson, V.S., Litvaitis, J.A., Lee, T.D., Frey, S.D., 2006. The role of spatial and temporal scale in colonization and spread of invasive shrubs in early successional habitats. Forest Ecology and Management 228, 124–134.

Kelty, M.J., 2006. The role of mixtures in plantation forestry. Forest Ecology and Management 233, 195–204.

Kerr, G., 2004. The growth and form of ash (*Fraxinus excelsior*) in mixture with cherry (*Prunus avium*), oak (*Quercus petraea* and *Quercus robur*), and beech (*Fagus sylvatica*). Canadian Journal of Forest Research 34, 2340–2350.

Knoke, T.C., Ammer, B.S., Mosandl, R., 2008. Admixing broadleaved to coniferous tree species: a review on yield, ecological stability and economics. European Journal of Forest and Research 127, 89–101.

Laurent, C., 2003. Gestión forestal y cambio climático en la Región Valona de Bélgica. Revista internacional de silvicultura e industrias forestales. FAO. Unasylva 54 (214–215), 64–67.

Littell, R.C., Milliken, A.G., Stroup, W.W., Wolfinger, R.D., Schabenberger, O., 2006. SAS for Mixed Models, 2nd ed. SAS Institute Inc., Cary, NC, USA.

Loewe, M.V., 2003. Perspectivas de Desarrollo de la Arboricultura para Producción de Madera de Alto Valor en Chile. Santiago, 289 p.

Loewe, M.V., González, O.M., 2004. Cerezo común: alta cotización mundial. Chile Forestal 303, 41–43.

Loewe, M.V., González, O.M., 2006. Plantaciones Mixtas, Un modelo productivo con potencial para Chile. INFOR-FIA, 299 p.

Loewe, M.V., Pineda, G., Delard, C., 2001. Cerezo común (*Prunus avium* L.), una alternativa para producir madera de alto valor. INFOR-FIA. 105 p.

Manson, D.G., Schmidt, S., Bristow, M., Erskine, P.D., Vanclay, J.K., 2013. Species-site matching in mixed species plantations of native trees in tropical Australia. Agroforestry Systems 87, 233–250.

Miller, R.E., Reukema, D.L., Max, T.A., 1993. Size of Douglas-fir trees in relation to distance from a mixed Red Alder – Douglas-fir stand. Canadian Journal of Forest Research 23 (11), 2413–2418.

Mohni, C., Pelleri, F., Hemery, G.E., 2009. The modern silviculture of *Juglans regia* L.: a literature review. Die, Bodenkultur 59 (Sondernummer) 19–32.

Montagnini, F., González, E., Porras, C., Rheingans, R., 1995. Mixed and pure forest plantations in the humid neotropics: a comparison of early growth, pest damage and establishment costs. Commonwealth Forestry Review 74 (4).

Pedlar, J.H., McKenney, D.W., Fraleigh, S., 2006. Planting Black Walnut in southern Ontario: mid-rotation assessment of growth, yield and silvicultural treatments. Canadian Journal of Forest and Research 36, 495–504.

Piotto, D., 2008. A meta-analysis comparing tree growth in monocultures and mixed plantations. Forest Ecology and Management 255, 781–786.

Pretzsch, H., Schütze, G., 2009. Transgressive over yielding in mixed compared with pure stands of Norway spruce and European beech in Central Europe: evidence on stand level and explanation on individual tree level. European Journal of Forest Research 128, 183–204.

Richards, A.E., Forrester, D.I., Bauhus, J., Scherer-Lorenzen, M., 2010. The influence of mixed tree plantations on the nutrition of individual species: a review. Tree Physiology 30, 1192–1208.

Roberts, S.J., 2001. Bacterial canker of cherry (*Prunus avium*): biology, epidemiology and resistance. Review Report WD0224/WD0234 Horticulture Research International.

SAS Institute Inc., 2006. SAS® Data Integration Studio 3.3: User's Guide. Cary, NC: SAS Institute Inc.

Schlesinger, R.C., Williams, R.D., 1984. Growth response of Black Walnut to interplanted trees. Forest Ecology and Management 9, 235–243.

Tani, A., Maltoni, A., Mariotti, B., Buresti Lattes, E., 2006. *Juglans regia* L. Tree plantations for wood production in mining area of S. Barbara (AR). Evaluation of N-fixing accessory trees effect. In: Lingua, E., Marzano, R., Minotta, G., Motta, R., Nosenzo, A., Bovio, G. (Ed.), Proceedings of the V SISEF Congress: "Forests & Society – Changes, Conflicts, Synergies".

Vanclay, J.K., 2006. Experiment design to evaluate inter and intra-specific interactions in mixed plantings of forest trees. Forest Ecology and Management 233, 366–374.

Yates, E.D., Levia, D.F., Williams, C.L., 2004. Recruitment of three non-native invasive plants into a fragmented forest in southern Illinois. Forest Ecology and Management 190, 119–130.