Forest Ecology and Management 107 (1998) 183–190

Forest Ecology and Management

# Dynamics of a broadleaved (*Castanea sativa*) conifer (*Pseudotsuga menziesii*) mixed stands in Northern Portugal

Jaime F. Sales Luis [a,*], Maria do Loreto Monteiro [b]

[a] *Forest Department, Universidade de Trás-os-Montes e Alto Douro, 5000 Vila Real, Portugal*
[b] *Forest Area, Escola Superior Agrária de Bragança, 5300 Bragança, Portugal*

Accepted 10 November 1997

**Abstract**

In nature, forest ecosystems are composed by mixtures of species located in the understorey, intermediate and overstorey layers and a potential increase in productivity with mixed stands and plantations, compared to pure stands of the component species is widely accepted, although this has not generally been incorporated into forestry practice. In this experimental planting study, the types of mixtures tested includes three row mixtures with species changing in the planting line, two line mixtures with species changing between the planting line and two monocultures. The species growth pattern was analysed and productivity comparisons between mixed stands and pure stands of the component species were made using the relative yield (RY) and relative yield total (RYT) concepts. The species shows different top height growth patterns which are not influenced by the mixtures tested. *Castanea sativa* responds well to competitive pressure from *Pseudotsuga menziesii* which shows a higher productivity. In the row mixtures, the positive effect of interspecific competition yields to RYT values greater than 1.0. Mixture RYT values are steadily increasing with time and *C. sativa* monoculture has been the most attractive economic solution, although its importance compared with the most productive mixtures is diminishing over time. This species mixture represents a flexible silvicultural system, which will be in the future, a very important land use alternative in mountain areas. © 1998 Elsevier Science B.V.

*Keywords:* *Castanea sativa*; *Pseudotsuga menziesii*; Mixed stands; Relative yield total

## 1. Introduction

Over the last two decades, there is a renewed and growing interest in the mixed stands installation and, when site conditions allow, in the gradual change from pure to mixed stands. This interest is based on the knowledge that mixed stands are, in general, biologically more stable and less susceptible to natural hazards (Kenk, 1992), make a better use of the different soil horizons, produce a high quality forest floor (Brown, 1992), enhance the stands natural regeneration and ensure many indirect forest benefits (Matthews, 1989).

Based on fundamental niche theory, Kelty (1992) states that there is potential increase in productivity with mixed stands and plantations, compared to pure stands of the component species, although this has not generally been incorporated into forestry practice.

* Corresponding author.


*PII* S0378-1127(97)00341-1

Boudru (1989) considers the existence of economical benefits with mixed stands, mentioning that there is a social stratification among the component species, classified by Oliver and Larson (1990) as dominant (crop) and trainer species.

Species characteristics such as shade tolerance, height and volume growth rates and root pattern development, have to be taken into account in the species components selection of mixed stands and plantations. Successful mixed plantations will combine fast-growing intolerant with slow-growing shade tolerant species. The first species provides a protective nursing effect in the early stand development stages of the second one, that favours the stem form and self pruning of the former in the advanced stand development stages.

The significant nursing benefit of conifer trees components (*Larix japonica* and *Pinus sylvestris*) in the height growth of several broadleaves components (*Castanea sativa*, *Quercus petrea*, *Fagus sylvatica*, *Betula pendula* and *Alnus incana*) of a mixed stand in the North Yorkshire Moors was demonstrated by Gabriel (1986), for a period of 25 years.

Wierman and Oliver (1979) observed a greater yield with mixed stands of *Pseudotsuga menziesii* and *Tsuga heterophylla* when compared with the pure stands of either species.

*C. sativa* is a native species in Portugal, known since the Miocenic period and cultivated since the Roman times. Nowadays, it covers an area of about 32,000 ha and has a double vein, once it produces a highly demanded sweet fruit as well as wood (Maia, 1988).

*P. menziesii* is an exotic species, introduced in Portugal in 1846, in Sintra. Since then it has been used in reforestation projects, covering nowadays about 10,000 ha, and proved to be well adapted to mountain sites and showing a large potential for timber production (Luis, 1989).

In mountain Silviculture, *C. sativa* and *P. menziesii* are two very interesting species for timber production in Portugal. In the seventies, both species were extensively planted, in pure stands, in mountain areas with promising results. Under these circumstances, the next and natural step was to observe and analyse its long term development in mixture.

In this experimental study, the research plots are designed to analyse the growth and potential productivity of *C. sativa* (Cs) and *P. menziesii* (Pm) mixed stands and the long term individual performance of *C. sativa* component (Maia, 1988).

## 2. Materials and methods

In mixed stands silviculture, beyond the choice of species, it is also important to define the species proportion, which are the 'conditions' that Kelty (1992) raises and finds necessary to know for a particular set of species.

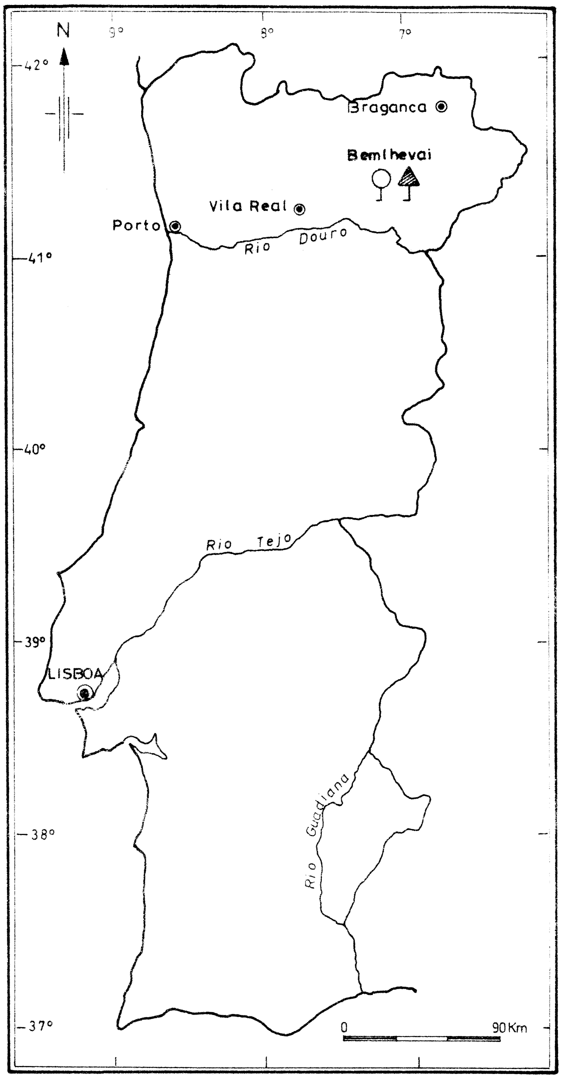


Fig. 1. Location of mixed stand research site at Bemlhevai.

The species mixture may vary, from plant by plant or ‘intimate mixture’ (Boudru, 1989), passing through mixture in alternate lines or in strips, to mixture in groups, depending the choice upon the ecological and/or economic objectives, as well as on the available silvicultural skills.

Due to species silviculture and to economics related with the logging operations of feasible alternatives, the mixtures tested in this study considers: (a) row mixtures with species changing in the planting line; M1—1 Cs and 3 Pm in the line; M2—1 Cs and 2 Pm in the line; M3—1 Cs and 1 Pm in the line; (b) line mixtures with species changing between planting lines; M4—1 line of Cs and 1 line of Pm; M5—1 line of Cs and 2 lines of Pm; and (c) monocultures; M6—pure Cs; M7—pure Pm.

### 2.1. Research site

In the Winter of 1981, a set of twenty-one 512 $m^2$ permanent research plots were installed in an almost flat (2°), NE turned (60°) experimental site, 710 m above sea level, 41°24′N and 7°6′W, in a private land, at Bemlhevai, Vila Flor, Bragança, Portugal (Fig. 1).

The ecological zone is SA × SM (Alves, 1982), the soils are litolic non-humic from serecitic schist, the annual average temperature is 13° and the annual rainfall is 685 mm.

The research plots are installed in a replacement series of a ‘substitutive’ (Harper, 1977) randomized block design, with seven types of mixtures and three replications (blocks). The trees’ spacing is 4 × 2 m, meaning that each plot has 64 plants (Fig. 2).

### 2.2. Data collection and plot operations

All trees were numbered in each block and repeated measurements of tree parameters such as diameter at base level, $d$ and $h$ were made in 1988, 1992 and 1996. The trees missing in each measurement were also recorded and tree and plot maintenance operations such as understorey removal (1988, 1992 and 1996), penetration pruning, up to 1.8 m, in *P. menziesii* to allow horizontal measurements (1992), pruning in *C. sativa* crop trees and trees to manage (1992), as well as trees number repainting (1996) were also made.

### 2.3. Analysis

#### 2.3.1. Height growth

The height of dominant trees in pure even-aged stands is an index of a site’s growth potential (Oliver

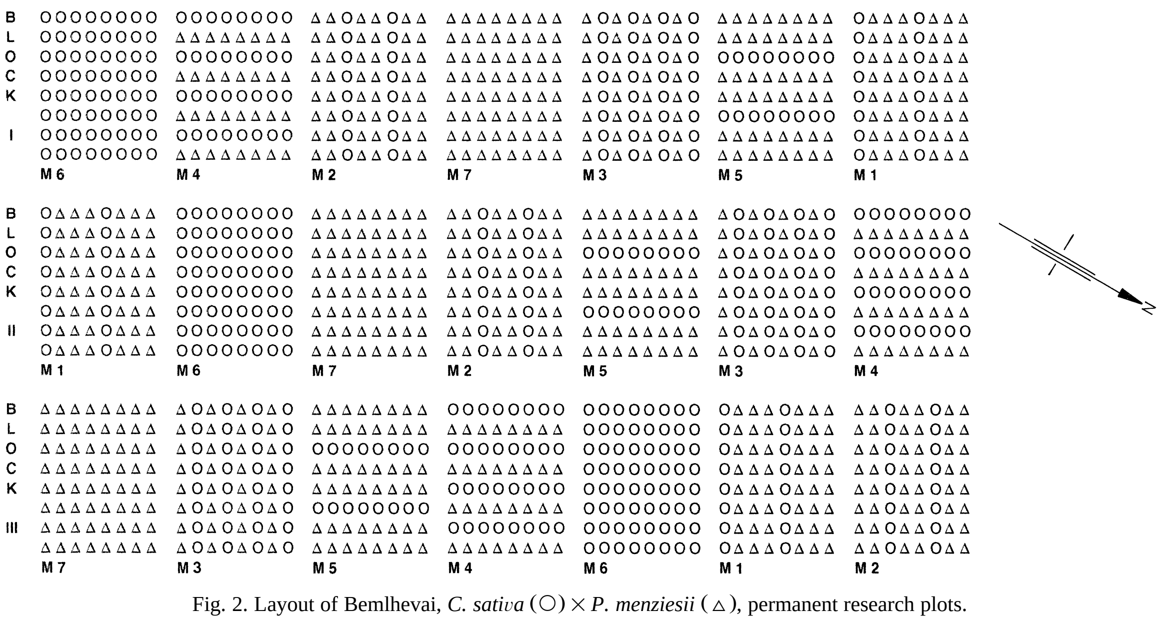


Fig. 2. Layout of Bemlhevai, *C. sativa* (○) × *P. menziesii* (△), permanent research plots.

and Larson, 1990) and, in mixed stands, the top height definition (Assmann, 1970) is applied to every tree species (Zingg, 1994).

Given the plots data and design structure, the species height growth pattern was analysed in a two-way split–split plot ANOVA to determine the main effects and the interactions significance (Little and Hills, 1990). In this design, the blocks represent a random effect, whereas the mixtures (main plots), species (sub plots) and measurement years (sub–sub plots) are fixed effect factors.

Previous data inspection for homogeneity of variance and normality, as well as for factors additivity showed no violation of these assumptions. When appropriate, comparisons were performed using Student's $t$ or Tukey's test (Snedecor and Cochran, 1980).

### 2.3.2. Yield and revenue

The effects of combining two species in a replacement series can be analysed by comparing the yield of each species in mixture with its yield in monoculture (Harper, 1977). For any particular mixture of species Cs and Pm, a relative yield (RY) of each species, and a relative yield total (RYT) can be calculated by: RY(Cs) = yield of Cs in mixture/yield of Cs in monoculture; RY(Pm) = yield of Pm in mixture/yield of Pm in monoculture; and RYT = RY(Cs) + RY(Pm).

Yield comparisons between mixed stands and pure stands of the component species depends upon the units of measure used (Smith, 1986). Comparisons in volume units is technically not free from objection, because the species presents considerable differences between dry wood weight, being more adequate to use weight units instead (Assmann, 1970). The local determination of the species specific gravity ($g/cm^3$) provided the following results: *C. sativa* 0.547 and *P. menziesii* 0.424 (Maia, 1988).

The trees spacing and the type of mixture are two key factors, in defining the mixed stands alternatives and, in analysing their yield responses (Buresti and Frattegiani, 1995). The trees spacing was held constant, in this study, at 4 m between the planting lines and 2 m within the planting lines, causing that in young ages, the competition between different tree species is mostly concentrated within the planting lines than between planting lines (Luis, 1989). The type of mixtures tested are divided in two groups: (a) row mixtures with species changing in the planting lines (M1, M2 and M3) and, (b) line mixtures with species changing between planting lines (M4 and M5).

Row mixtures 1, 2 and 3 reflect, primarily, interspecific competition and, line mixtures 4 and 5 intraspecific competition. These types of competition are, for the moment, the two main effects of combining these two factors. In this study, row mixtures are also known as interspecific mixtures and, line mixtures as intraspecific mixtures.

For the revenue calculations, the following prices per cubic meter were assumed: *C. sativa*, 61.5 Ecus and *P. menziesii*, 20.5 Ecus (J. Bento, personal communication, 1997). One Ecu equals one US dollar.

## 3. Results and discussion

### 3.1. Height growth

In young ages, with species competing for light, the potential effect of different mixtures is on height growth, once priority of photosynthetate energy allocation is given to height growth over diameter growth (Kramer and Kozlowski, 1960).

For *C. sativa*, the top height values ranged from 3.1 to 7.4 m, in monoculture, and from 2.6 to 7.5 m in mixture. For *P. menziesii*, these values range from 3.2 to 10.4 m, in monoculture, and from 2.8 to 10.3 m in mixture (Table 1).

For each species, the top height was not affected by the different mixtures ($P \geq 0.05$) in all the measurement years (Table 2). On the other hand, the species differ in its top height growth ($P < 0.001$). In the first measurement (at age 7), they are barely equal ($P = 0.063$) but, in the second (at age 11) and third (at age 15) measurements, they became significantly different ($P < 0.001$), once the species has different height growth patterns (Fig. 3).

As in each species, height growth was similar both in monocultures and mixtures, a nursing effect (Kerr et al., 1992) from the conifer over the broadleave is not apparent. On the other hand, as the species have, in fact, different height growth rates, a

Table 1
Species top height (m) in the different mixtures, blocks and measurement years

| Measurement year | Blocks | Species | Mixtures | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1988 | I | Cs | 2.9 | 2.8 | 3.1 | 2.9 | 2.6 | 3.1 | – |
| | | Pm | 3.2 | 2.8 | 2.9 | 3.1 | 2.8 | – | 3.2 |
| | II | Cs | 4.3 | 3.8 | 4.0 | 4.0 | 3.1 | 3.8 | – |
| | | Pm | 4.8 | 3.6 | 4.0 | 3.5 | 3.6 | – | 3.5 |
| | III | Cs | 4.0 | 4.8 | 4.2 | 4.2 | 3.9 | 4.5 | – |
| | | Pm | 4.2 | 4.9 | 4.8 | 5.2 | 4.8 | – | 5.2 |
| 1992 | I | Cs | 3.2 | 4.0 | 4.0 | 3.8 | 3.5 | 3.8 | – |
| | | Pm | 5.4 | 4.5 | 4.3 | 4.6 | 4.4 | – | 4.7 |
| | II | Cs | 5.9 | 4.8 | 4.5 | 5.0 | 4.6 | 5.6 | – |
| | | Pm | 8.6 | 6.2 | 6.1 | 5.6 | 6.1 | – | 6.5 |
| | III | Cs | 6.1 | 6.1 | 6.1 | 5.7 | 5.3 | 5.9 | – |
| | | Pm | 7.7 | 8.2 | 7.9 | 8.2 | 8.0 | – | 8.0 |
| 1996 | I | Cs | 4.0 | 4.0 | 4.2 | 4.5 | 3.6 | 4.2 | – |
| | | Pm | 6.8 | 6.1 | 5.7 | 6.7 | 5.7 | – | 6.2 |
| | II | Cs | 6.6 | 5.0 | 4.9 | 5.4 | 4.6 | 6.2 | – |
| | | Pm | 10.3 | 7.8 | 8.1 | 7.3 | 7.7 | – | 8.1 |
| | III | Cs | 6.7 | 7.4 | 7.5 | 6.7 | 6.2 | 7.4 | – |
| | | Pm | 9.5 | 9.4 | 8.6 | 9.8 | 10.3 | – | 10.4 |

suppression effect is also not visible from *P. menziesii* over *C. sativa*.

### 3.2. Yield

Table 3 summarizes the species volume ($m^3$ $ha^{-1}$) and weight (tonnes $ha^{-1}$) values and, RY and RYT calculations for the different mixtures tested in the three measurement years, corresponding to 7, 11 and 15 years of age. The RY expected values are also indicated.

*C. sativa* responds well to interspecific pressure from *P. menziesii* reflected, for instance, in the 1996 actual RY(Cs) values in mixtures 1 and 2, respectively, 132% and 148% higher than the expected ones. In mixture 3, the response (0.49) is almost the expected. In the intraspecific mixtures 4 and 5, the response (0.41 and 0.17) is below the expected. This indicates that *C. sativa* clearly benefits in interspecific mixtures involving *P. menziesii* (Table 3).

*P. menziesii* shows a higher yield than *C. sativa*, both in pure and comparable mixtures (3 and 4), and

Table 2
*F* values and significance for top height growth ANOVA

| | *F* statistic | Significance |
|---|---|---|
| Blocks | 60.497 | * * * |
| Mixtures | 1.257 | n.s. |
| Species | 104.563 | * * * |
| Mixtures x Species | 0.896 | n.s. |
| Measurement year | 317.601 | * * * |
| Mixtures x Measurement year | 0.548 | n.s. |
| Species x Measurement year | 46.172 | * * * |
| Mixtures x Species x Measurement year | 0.248 | n.s. |

Note: n.s. $\geq 0.05$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

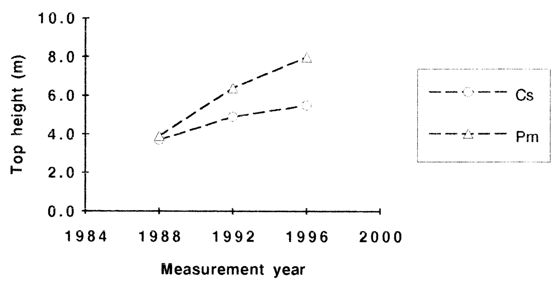


Fig. 3. Species height growth in monoculture.

performs well under different degrees of interspecific and intraspecific competition, with the 1996 actual RY (Pm) values always above the expected ones (Table 3).

The species difference in height growth, as well as in time of foliage production and duration of photosynthetic activity cause interspecific competition to be less intense than intraspecific competition (particularly for *C. sativa*), with the key to the reduction in competition often being a spatial stratification of foliage or roots (Kelty, 1992).

Mixtures 1, 2 and 3 reflects the beneficial effect (Brown, 1992) of interspecific competition on both species, with RYT values greater than 1.0, mainly in mixtures 1 and 2, suggesting that, for *P. menziesii*, a certain degree of crowding is preferable. On the contrary, mixtures 4 and 5, for the moment, reflect mostly the negative effect of intraspecific competition on *C. sativa* component, resulting in RYT values equal or lower than 1.0, although the *P. menziesii* component is performing at acceptable levels (Table 3).

Mixture RYT values are steadily increasing with time (Fig. 4), showing that interspecific competition within planting lines is developing towards adjacent planting lines direction, once the species are maintaining or expanding the use of available resources.

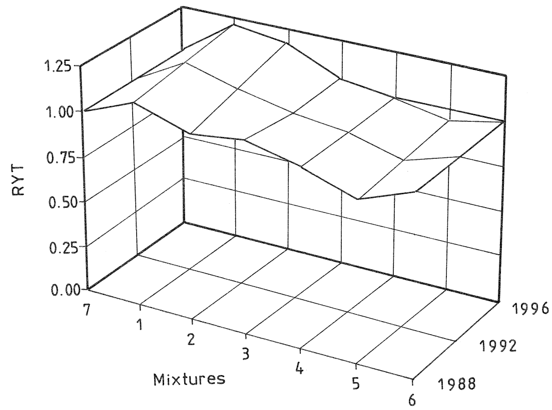

Fig. 4. Mixtures RYT change over time.

In interspecific mixtures 1, 2 and 3, RY(Cs) values are almost constant, in mixtures 1 and 2, and slightly decreasing in mixture 3, and RY(Pm) values are consistently increasing, confirming the different growth pattern of the two species already suggested by the height growth (Table 3).

Table 3
Volume ($m^3$ $ha^{-1}$) and weight (tonnes $ha^{-1}$) in the different mixtures and measurement years

| Mixtures | Species | RY (e.v.) | Measurement year 1988 Volume ($m^3$ $ha^{-1}$) | 1988 Weight (tonnes $ha^{-1}$) | 1988 RY RYT | 1992 Volume ($m^3$ $ha^{-1}$) | 1992 Weight (tonnes $ha^{-1}$) | 1992 RY RYT | 1996 Volume ($m^3$ $ha^{-1}$) | 1996 Weight (tonnes $ha^{-1}$) | 1996 RY RYT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Cs | 0.25 | 1.1 | 0.6 | 0.33 | 5.6 | 2.9 | 0.32 | 7.4 | 3.9 | 0.33 |
| | Pm | 0.75 | 3.2 | 1.4 | 0.79 | 20.7 | 8.8 | 0.85 | 38.5 | 16.3 | 0.88 |
| | | | | | 1.12 | | | 1.17 | | | 1.21 |
| 2 | Cs | 0.25 | 1.3 | 0.7 | 0.39 | 5.9 | 3.1 | 0.34 | 8.3 | 4.4 | 0.37 |
| | Pm | 0.75 | 2.6 | 1.1 | 0.63 | 18.2 | 7.7 | 0.75 | 34.8 | 14.8 | 0.80 |
| | | | | | 1.02 | | | 1.09 | | | 1.17 |
| 3 | Cs | 0.50 | 2.0 | 1.1 | 0.60 | 9.0 | 4.7 | 0.51 | 10.9 | 5.8 | 0.49 |
| | Pm | 0.50 | 1.9 | 0.8 | 0.46 | 12.4 | 5.3 | 0.51 | 24.2 | 10.3 | 0.55 |
| | | | | | 1.06 | | | 1.02 | | | 1.04 |
| 4 | Cs | 0.50 | 1.7 | 0.9 | 0.50 | 7.7 | 4.1 | 0.44 | 9.3 | 4.9 | 0.41 |
| | Pm | 0.50 | 2.0 | 0.9 | 0.49 | 13.3 | 5.7 | 0.55 | 25.7 | 10.9 | 0.59 |
| | | | | | 0.99 | | | 0.99 | | | 1.00 |
| 5 | Cs | 0.25 | 0.8 | 0.4 | 0.23 | 3.4 | 1.8 | 0.19 | 3.8 | 2.0 | 0.17 |
| | Pm | 0.75 | 2.7 | 1.1 | 0.66 | 17.4 | 7.4 | 0.71 | 33.8 | 14.3 | 0.77 |
| | | | | | 0.89 | | | 0.90 | | | 0.94 |
| 6 | Cs | 1.00 | 3.4 | 1.8 | 1.00 | 17.5 | 9.2 | 1.00 | 22.5 | 11.9 | 1.00 |
| 7 | Pm | 1.00 | 4.1 | 1.7 | 1.00 | 24.3 | 10.3 | 1.00 | 43.7 | 18.5 | 1.00 |

RY expected values (e.v.). Actual RY(Cs), RY(Pm) and RYT.

Table 4
Revenue (Ecus $ha^{-1}$) in the different mixtures and measurement years

| Mixtures | Species | Measurement year | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1988 | | 1992 | | 1996 | |
| | | Revenue (Ecus $ha^{-1}$) | MTR/CsR (%) | Revenue (Ecus $ha^{-1}$) | MTR/CsR (%) | Revenue (Ecus $ha^{-1}$) | MTR/CsR (%) |
| 1 | Cs | 69.5 | | 342.8 | | 453.0 | |
| | Pm | 65.8 | | 424.9 | | 789.9 | |
| | | 135.3 | 65 | 767.7 | 71 | 1242.9 | 90 |
| 2 | Cs | 80.7 | | 363.0 | | 507.9 | |
| | Pm | 52.8 | | 372.7 | | 713.7 | |
| | | 133.5 | 64 | 735.8 | 68 | 1221.6 | 88 |
| | Cs | 124.9 | | 551.5 | | 672.4 | |
| | Pm | 38.5 | | 255.0 | | 496.3 | |
| | | 163.4 | 78 | 806.5 | 75 | 1168.7 | 84 |
| 4 | Cs | 103.9 | | 474.4 | | 571.4 | |
| | Pm | 41.2 | | 273.4 | | 526.5 | |
| | | 145.1 | 69 | 747.8 | 69 | 1079.9 | 79 |
| 5 | Cs | 47.6 | | 208.9 | | 232.9 | |
| | Pm | 54.9 | | 356.0 | | 693.0 | |
| | | 102.5 | 49 | 564.9 | 52 | 925.9 | 67 |
| 6 | Cs | 208.8 | 100 | 1079.0 | 100 | 1385.6 | 100 |
| 7 | Pm | 83.5 | 40 | 498.7 | 46 | 896.0 | 65 |

Note: Ecu equals US dollar.
Percentage of mixture total revenue (MTR) on *C. sativa* monoculture revenue (CsR).

In intraspecific mixtures 4 and 5, RY(Cs) values are slightly decreasing and below the expected ones, reflecting the negative effect of intraspecific competition on *C. sativa*, but an initial closer spacing (2 m) between planting lines (increasing the interspecific competition) will reduce, very likely, this circumstance. On the other hand, the RY(Pm) values are increasing, once *P. menziesii* is still expanding for resources use (Table 3).

### 3.3. Revenue

Sound silvicultural prescriptions concerning mixed stands should also take into account economic considerations. Based on volume calculations and evaluating the wood produced at current market prices, it is possible to compare in a revenue scale the different forest land use alternatives (Table 4).

*C. sativa* monocultures has been the most attractive economic solution, but its importance compared with the most productive mixtures is diminishing over time. For instance, a small increase of 5 Ecus in *P. menziesii* wood price will make the first and second mixtures to be economically more attractive than *C. sativa* monoculture.

## 4. Conclusions

*C. sativa* and *P. menziesii* show significantly different top height growth patterns which are not influenced by the mixtures tested. Neither a nursing effect nor a suppression effect are apparent from *P. menziesii* on the *C. sativa* height growth.

A clear benefit on both species productivity is visible in the mixtures 1, 2 and 3 in which the interspecific competition effect is present, corresponding to RYT values greater than 1.0. Species having important differences in characteristics which allow them to coexist in mixtures with high productivity are said to have good ‘ecological combining ability’ (Harper, 1977).

The low productivity in mixtures 4 and 5, mostly in the *C. sativa* component, is associated to an intraspecific competition pattern due to the species spatial distribution and not to an antagonistic relationship between them. An initial closer spacing between planting lines will reduce, very likely, this circumstance, once an earlier interspecific effect will compensate the intraspecific pattern.

From the economic point of view, the most productive mixtures (1 and 2) are also very competitive when compared with the traditional solution of *C. sativa* monocultures in most rural areas. These mixtures are also performing better over time, both in productive and economic terms, suggesting that this flexible silvicultural system will represent in the future, where changes in the types of wood demanded and corresponding prices are expected, a very interesting and useful land use alternative in mountain areas.

## Acknowledgements

The 1992 and 1996 tree measurements and plot maintenance operations were made under the financial support, respectively, of RECITE Compostela-Forest CN/T-4.2/5 project and of JNICT-PBIC-AGR-2280/95 project.

## References

Alves, A.A.M., 1982. Técnicas de Produção Florestal. INIC, Lisboa, 331 pp.

Assmann, E., 1970. The Principles of Forest Yield Study. Pergamon, New York, 506 pp.

Boudru, M., 1989. Foret et Sylviculture: Traitement des Forets. Les Presses Agronomiques de Gembloux, Gembloux, 356 pp.

Brown, A.H.F., 1992. Functioning of mixed-species stands at Gisburn, N.W. England. In: Cannell, M.G.R., Malcolm, D.C., Robertson, P.A. (Eds.), The Ecology of Mixed-Species Stands of Trees. Blackwell Scientific Publications, Oxford, pp. 125–150.

Buresti, E., Frattegiani, M., 1995. Impainti misti in arboricoltura da legno. Sherwood-Foreste ed Alberi Oggi 3, 11–17.

Gabriel, K.A.S., 1986. Crown broadleaved trees on the North Yorks moors. Q. J. For. 80, 27–32.

Harper, J.L., 1977. Population Biology of Plants. Academic Press, New York, 892 pp.

Kelty, M.J., 1992. Comparative productivity of monocultures and mixed-species stands. In: Kelty, M.J., Larson, B.C., Oliver, C.D. (Eds.), The Ecology and Silviculture of Mixed-Species Forests. Kluwer Academic Publishers, Dordrecht, pp. 125–141.

Kenk, G.K., 1992. Silviculture of mixed-species stands in Germany. In: Cannell, M.G.R., Malcolm, D.C., Robertson, P.A. (Eds.), The Ecology of Mixed-Species Stands of Trees. Blackwell Scientific Publications, Oxford, pp. 53–64.

Kerr, G., Nixon, C.J., Matthews, R.W., 1992. Silviculture and yield of mixed species stands: the UK experience. In: Cannell, M.G.R., Malcolm, D.C., Robertson, P.A. (Eds.), The Ecology of Mixed-Species Stands of Trees. Blackwell Scientific Publications, Oxford, pp. 35–52.

Kramer, P.J., Kozlowski, T., 1960. Physiology of Trees. McGraw-Hill, Tradução Portuguesa, Fundação Calouste Gulbenkian, Lisboa, 745 pp.

Little, T.M., Hills, F.J., 1990. Métodos estadisticos para la investigación en la agricultura. Editorial Trillas, México, 270 pp.

Luis, J.F.S., 1989. Crescimento e Competição em Povoamentos de *Pseudotsuga menziesii* (Mirb.) Franco em Portugal. Tese de Doutoramento, UTAD, Vila Real, 278 pp.

Maia, M.L.M., 1988. A Silvicultura do Castanheiro na Região de Trás-os-Montes. Resultados Preliminares. Dissertação de Investigação. INIA, EFN, Bragança, 241 pp.

Matthews, J.D., 1989. Silvicultural Systems. Oxford Science Publications, Oxford, 284 pp.

Oliver, C.D., Larson, B.C., 1990. Forest Stand Dynamics. McGraw-Hill, New York, 467 pp.

Smith, D.M., 1986. The Practice of Silviculture. Wiley, New York, 572 pp.

Snedecor, G., Cochran, W., 1980. Statistical Methods. Iowa State University Press, Ames, IA, 507 pp.

Wierman, C.A., Oliver, C.D., 1979. Crown stratification by species in even-aged mixed stands of Douglas-fir-western hemlock. Can. J. For. Res. 9, 1–9.

Zingg, A., 1994. Top height in mixed stands. Their definition and calculation. In: Costa, M.E.P., Preuhsler, T. (Eds.), Mixed Stands. Research plots, Measurements and Results. Models. Universidade Técnica de Lisboa, Instituto Superior de Agronomia, Lisboa, pp. 67–80.