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The effect of organic-matter management on the productivity of *Eucalyptus globulus* stands in Spain and Portugal: tree growth and harvest residue decomposition in relation to site and treatment

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Abstract

Sustainable management of forest resources, including nutrient retention and protection of the soil structure, is required to ensure long-term soil fertility and productivity of later rotations. Potential depletion of soil nutrients is particularly likely in production systems based on fast-growing trees, such as eucalypts. We have studied production of second rotation *Eucalyptus globulus* stands at two sites in northern Spain and two in central Portugal, after replanting or coppicing, under four treatments, in which plant residues from the first crop were utilised. The residues were either removed from the sites (Treatment R), spread over the soil surface (Treatments S, uniform spreading, and W, in which the woody debris was confined to rows between the trees) or incorporated into the soil by harrowing to 15-cm depth (Treatment I). We measured tree height and girth at intervals over three growing seasons, and root biomass at the Portuguese sites. Decomposition of three residue components: leaves-plus-bark, twigs and branches, was measured in litter bags placed in the position corresponding to the placement of the organic residues.

By the end of the experiment, tree height was significantly greater in Treatment I than in Treatment R at both Spanish sites, if planted as seedlings, with intermediate growth in S and W. In Portugal, tree height was smaller in R, though not significantly. DBH showed similar trends, although treatment differences were not significant. Coppiced trees grew faster than seedling trees, but a significant treatment effect on the growth was only observed at the inland Portuguese site, where it was better in Treatment I by the end of the experiment.

The residues decomposed significantly faster in I than S or W at the Portuguese sites, but not in Spain. Leaves-plus-bark decomposed faster than twigs, and twigs faster than branches.

The results are discussed in relation to recommended management options. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Sustainable forestry; *Eucalyptus* production; Organic-matter management; Decomposition rates

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1. Introduction

As in many warm temperate and sub-tropical zones of the world, *Eucalyptus* is widely grown in Spain and Portugal, largely for paper pulp; ≈10 000 km^2 have been planted, mainly with *E.globulus*. Recently, few plantations have been created in Portugal, on account of legal and environmental constraints, and most planting has been second or third rotation. Many coppiced *Eucalyptus* stands have now been cropped three or four times, and need to be replanted to maintain the productivity. If the area of plantations is to be maintained by replanting, it is vital to adopt management practices to protect soil fertility and system sustainability. In Asturias and Galicia in north-western Spain, newly planted areas are still being created; ≈15% more will have been planted between the years 1997 and 2000.

Eucalyptus is very fast growing, and many plantations are now in the second rotation, hence there is concern about the impact on poor soils, such as those of the Mediterranean regions of Europe. Intense *Eucalyptus* forestry may deplete the soil of nutrients and break down the soil structure, which will affect the water-holding capacity of the soil and the long-term sustainability of the plantations, particularly where site preparation is intensive (Madeira, 1989; Madeira et al., 1989; Madeira and Pereira (1990/1991); Hopmans et al., 1993; Ludwig et al., 1997; Khanna, 1997). Desertification can also be a problem where the annual rainfall is low (Darrow, 1994). Soils may be eroded between clear-felling and establishment of the second rotation, especially if the initial planting was on steep slopes. Elsewhere, trees are planted on already degraded agricultural land or on land taken out of other forest production, especially after wildfires. In all these instances, conservation of both organic matter (OM) and soil structure is important. When litter from the previous crop is incorporated into the soil, it can act as a long-term resource, and nutrients released during mineralisation become available to subsequent crops (Schäfer and Krieger, 1994; Johnson, 1995; Tiessen et al., 1994).

At present, there are different ways to deal with the harvest residues from the first rotation. In Portugal, when second, or later rotations are to be replanted, the woody and leaf litter, including the stumps, are frequently removed, which is likely to exacerbate nutrient loss and the risk of erosion, and reduce subsequent tree growth. A decline in tree production after the first rotation has been noted in various parts of the world (Powers et al., 1990; Turner and Gessel, 1990; Proe and Dutch, 1994) and has been measured in other species. For example, *Picea sitchensis* growth was significantly reduced, where harvest residues were removed (Proe et al., 1994). In Spain, residues are often pushed to the side of the site and may be burnt, or used to construct windbreaks. Whereas burning may be a useful tool for weed control in preparing a site, and may also stimulate nitrogen mineralisation (Ellis and Graley, 1983), it can directly volatilise nutrients and increase leaching losses (Raison et al., 1990). Rab (1996) showed that burning altered the physical and hydrological properties of eucalypt plantations, affecting subsequent site productivity, and speeding erosion.

Our objectives were to compare the effect of using the harvest residues from the first rotation in four different treatments on the early height and diameter growth of coppiced and newly planted seedling *E. globulus* at four contrasting sites in Spain and Portugal. We also studied the effect of the treatments on rates of decomposition of the residues, which would affect the rate of release of mineralised nutrients, to determine whether more rapid mineralisation was related to better tree growth.

2. Materials and methods

2.1. Description of the experimental sites

2.1.1. Portuguese sites

The two sites lie in relatively flat areas of central Portugal, to the north of Lisbon. Furadouro is on the coastal plain, close to the Atlantic, and Vale Pequeno on a plateau to the east of the Tagus valley. *Eucalyptus* plantations have been set up in areas previously used for cereal crops and later abandoned. The main climatic difference between the sites is due to the oceanic influence at Furadouro, where early morning fogs are frequent during the summer and the relative humidity in the early part of the day is normally at least 80%. The site specifications are listed in Table 1.

2.1.2. Spanish sites

The two sites in northern Spain were selected to be closely similar in terms of climate and angle of slope

Table 1
Characteristics of the experimental sites

Site	Portugal		Spain	
	Furadouro	Vale Pequeno	Monte Jarrio	Pazo de Villaje
Latitude	39°21′ N	39°22′ N	43°31′ N	43°18′ N
Longitude	9°24′ W	8°20′ W	6°45′ W	7°14′ W
Altitude	86 m	170 m	300 m	320 m
Slope	Flat to undulating		37–46%	37–39%
Mean annual temperature	15.2°C	16.0°C	13.7°C	12.5°C
Mean minimum temperature (Jan.)	11.2°C	9.0°C	9.0°C	6.9°C
Mean maximum temperature (July)	19.3°C	23.0°C	23.0°C	23.0°C
Annual rainfall	607 mm	650 mm	1051 mm	1187 mm
Climate	Mediterranean (oceanic)	(continental)	Mediterranean (+ Atlantic maritime influence)	

(see Table 1). Monte Jarrio is situated on a north-facing slope in Asturias, overlooking the sea, and Pazo de Villaje lies ca. 80 km to the southwest, in Galicia.

2.2. Experimental design and establishment

The four eucalypt residue treatments were laid out in five blocks in a fully randomized design. The treatments were:

- Removal of all organic residues from the soil surface, which is a common management practice in Portugal and elsewhere (Treatment R)
- Organic residues spread over the soil surface (Treatment S)
- Organic residues incorporated in the top soil by harrowing to 15 cm (Treatment I)
- As for treatment S, but woody material accumulated between rows (Treatment W), this treatment was included because earlier observations in *E. grandis* plantations in S Africa had indicated that nutrients were initially locked up in the woody material, which later became a nutrient resource (Jones and Dighton, 1993).

There were some differences in preparation, dependent on the local conditions at each site. At Furadouro, treatments were applied without other soil preparation. At Vale Pequeno, the soil was ripped to 75 cm prior to the application of all treatments, to aid the drainage through the clayey B horizon. It was necessary to sub-soil at Monte Jarrio, because the site had not previously been planted. Pazo de Villaje was a third rotation site, in which the harvesting of the previous crop had taken place in 1992.

Treatments were set up in replanted and coppiced areas in Portugal, and at Pazo de Villaje in Spain. As Monte Jarrio had not previously been planted, the weight of organic residues likely to be derived from an earlier crop was estimated, and it was imported to the site as if it were left from harvesting the first rotation. Also, as it was first rotation, coppiced treatments could not be included. At Pazo de Villaje, the previous crop had not been planted in regular rows, so it was not possible to set up Treatment W. Plot sizes and numbers of measured trees are shown in Table 2.

Before the treatments were set up, random samples of the soils were taken for analysis for bulk density, clay and organic matter content, pH, phosphorus fixation and cation exchange capacity (CEC). Organic carbon was determined by dry combustion (in a Ströhlein apparatus). For phosphorus fixation, soil was extracted with 0.02 M potassium chloride and 30 mg l^{-1} potassium dihydrogen sulphate, and the phosphorus in solution determined by ICP/OES to calculate the degree of fixation of phosphate (Bache and Williams, 1971). CEC was determined by mixing 5 g air-dried soil with 125 ml 0.5 M barium chloride, and, after shaking and filtering, analysing sodium, potassium, calcium, magnesium, aluminium and iron by ICP.

The weight of residues remaining from the first rotation was measured in fifteen random 1 m^2 samples. They were separated into leaves, bark, twigs (diameter <5 mm), branches (diameter >5 mm) and fruits. Weight of the fractions was determined after

Table 2
Plot sizes for replanted and coppiced areas at the experimental sites (at Monte Jarrio, the plots were newly planted)

Site	Plantation type	Measured plot area (m^2)	Buffer zone (m)	Tree spacing (m)	Number of measurable trees
Furadouro	new	18 × 18	6–6	3 × 3	36 (6 × 6)
	coppiced	18 × 18	6–6	3 × 3	36 (6 × 6)
Vale Pequeno	new	24 × 17.5	8–10	4 × 2.5	42 (6 × 7)
	coppiced	24 × 17.5	2.5–4	4 × 2.5	42 (6 × 7)
Monte Jarrio	new	12 × 14	8–8	2 × 2	42 (6 × 7)
	coppiced		not possible at this first rotation site		
Pazo de Villaje	new	12 × 14	8–8	2 × 2	42 (6 × 7)
	coppiced	12 × 14	8–8	irregular	

drying at 80°C and a sub-sample of each component was ground for chemical analysis. Concentration of nitrogen was determined by Kjeldahl analysis. Calcium, magnesium, potassium and phosphorus were measured after the samples were ashed (6 h at 450°C) and dissolved in 3 M hydrochloric acid. Calcium, magnesium and potassium were determined by atomic absorption spectrometry, phosphorus was quantified by the ascorbic acid method (Watanabe and Olsen, 1965) and carbon was estimated by loss on ignition (LOI), assuming it to be 50% of ash-free dry weight.

In Portugal, *E. globulus* seedlings from a single clone (MB89) were planted in March 1993. At Furadouro, 100 g of fertiliser (14% N, 16% P, 17% K), and at Vale Pequeno, 150 g of fertiliser (7% N, 16% P, 17% K), were applied to each seedling. In Spain, seedlings from the same clone were planted in June 1993, after the initial batch succumbed to a fungal disease. One hundred grams of fertiliser (8% N, 24% P, 8% K) were applied to each seedling at both Spanish sites. Rates were those normally used in *Eucalyptus* plantations to improve the establishment of the stand.

2.3. Tree growth parameters

2.3.1. Tree height growth

Tree heights were measured to the nearest cm, at approximately three month intervals between July 1993 and October 1995. In the replanted plots, the base of the measuring rod was placed near the foot of the tree. In the coppiced plots, the telescopic rod was placed on the stump in the middle of the stool, so that there was a constant measuring base to assess the developing shoots.

2.3.2. Tree diameter growth

Diameter was measured at breast height (DBH) to the nearest mm, with calipers in two planes. Trees in the coppiced plots were measured at 1.3 m above the stump level for all the sprouts.

2.3.3. Tree root biomass

Roots were extracted from the main rooting zone (the top 30 cm), in the newly planted areas of the Portuguese sites in October 1993 and 1994, and in June 1995 at Furadouro, in June 1994 and October 1995 at Vale Pequeno. Root cores down to 30 cm were taken from three random trees in each plot. The samples were stored frozen until the roots were extracted. After washing, roots were extracted, oven-dried at 80°C and weighed.

Roots were sampled at the Spanish sites in June 1994, and sent to Lisbon for analysis. However, it was impossible to separate them effectively from the very high quantity of organic residues that was also present, so sampling was not repeated in 1995. There are, therefore, no root biomass data for the Spanish sites.

2.4. Harvest residue decomposition

Decomposition was assessed from weight loss of the residues in litter bags, separated into three fractions: leaves-plus-bark, twigs (<0.5 cm) and branches (>0.5 cm). Ten sub-samples of each were collected and bulked from each site. Approximately 5–6 g of each air-dried sub-sample were placed in 250 × 100 mm nylon bags with a mesh size of 1 mm, and seven bags of each fraction were placed in rows in each plot. They were pinned on the soil surface in treatments S and W, and buried at 15 cm in Treatment I, to correspond with the position of the residues in the respective treatment. No litter bags were set up in Treatment R to correspond with the residue removal. In Portugal, they were placed in April 1993, and in Spain, in July. Every 3–4 months, one litter bag of each type was removed from each plot, cleaned of ingrowth material and humus particles, dried at 80°C and weighed. In Spain, a composite sample was formed from the five replicate bags, hence no errors could be determined. Decomposition rates were calculated as the percent residue of the initial weight.

2.5. Statistical analysis

Treatment differences were tested by ANOVA(Genstat) at each measurement date, and Duncan's multiple range test was used to test for the effects ($p < 0.05$).

3. Results

3.1. Soil types

Table 3 lists some of the soil properties at the four sites. At the Portuguese sites, the soils are derived from sandstones, which, at Vale Pequeno, alternate with layers of pebbles and clays. At Furadouro, they are mostly Eutric Cambisols (FAO-UNESCO, 1988) and at Vale Pequeno, Gleyi-Haplic Lixisols (FAO-UNESCO, 1988). A distinction between the soils at the two sites is the B horizon with a high clay content at Vale Pequeno, which prevents effective drainage. The clay fraction was much lower in the top-soil layer at Vale Pequeno than Furadouro, reflected in the higher bulk density and lower CEC of the former soil.

In Spain, the site at Monte Jarrio is laid out on an 'Asturoccidental' area, within the Lower Paleozoic, and the soil is a dystric regosol (FAO-UNESCO, 1988), overlying black slates, rich in iron sulphide. At Pazo de Villaje, the soils are dystric cambisols (FAO-UNESCO, 1988) on slates, sandstones, quart-

Table 3
Main characteristics of the soils of the experimental sites. Values are the means of six samples, taken before the start of the experiment

Depth (cm)	Horizon	Bulk density ($g\ cm^{-3}$)	Clay ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	pH (H_2O)	P fixation ($\mu g\ g^{-1}$)	CEC [a] ($\mu e\ 100\ g^{-1}$)
Furadouro. . .Portugal							
0–20	Ah	1.47	161	8.8	5.2	200	6410
20–40	Bw	1.52	198	7.3	5.2		
40–60	C1	1.54	172	2.3	5.6		
60–80	C2	1.63	130	1.7	5.8		
Vale Pequeno. . .Portugal							
0–15	Ah1	1.67	85	10.2	5.2	225	2075
15–25	Ah2	1.68	63	5.1	5.3		
25–45	AB	1.59	201	2.6	5.4		
45–65	Bt1	1.64	452	1.6	5.4		
65–90	Bt2	1.73	572	0.6	5.5		
90–120	C	n.d.	510	0.5	5.9		
Monte Jarrio. . .Spain							
0/10–20	Ah	0.74	290	6.5	4.7	990	10 135
10–20/28	AC		280	26.5	4.4		
28–45	BC		150	15	4.6		
45–75	C		110	4	4.9		
Pazo de Villaje. . .Spain							
0–20	Ah	0.66	290	53	4.6	1020	5510
20–60	Bw	1.11	250	11	4.6		
60–100	C	1.63	190	5	4.7		

[a] Cation exchange capacity.

Table 4
Weight (t ha^{-1}) and percent of total residues of the litter components and content (kg ha^{-1}) and concentration of the main mineral nutrients

Site	Residue component	Weight		Residue component	N		P		K		Ca		Mg	
		(t ha^{-1})	(%)		(kg ha^{-1})	(%)	(kg ha^{-1})	(%)	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
Furadouro														
				leaves	100	1.16	6	0.06	22	0.25	136	1.57	15	0.17
	leaves + bark	11.4	28.3	bark	8	0.29	1	0.02	3	0.12	29	1.09	3	0.11
	twigs	3.8	9.5	twigs	11	0.28	1	0.03	3	0.17	29	1.43	3	0.08
	branches	23.7	59.3 [a]	branches	22	0.09	6	0.03	31	0.13	93	0.39	9	0.04
Vale Pequeno														
				leaves	103	1.08	3	0.03	9	0.10	91	0.95	9	0.09
	leaves + bark	11.2	36.5	bark	6	0.36	1	0.02	2	0.14	32	1.88	3	0.16
	twigs	4.5	14.6	twigs	13	0.30	1	0.03	10	0.23	84	1.83	9	0.20
	branches	14.1	45.7 [a]	branches	20	0.14	2	0.01	18	0.13	107	0.76	15	0.11
Monte Jarrio [b]														
	leaves + bark	12.2	51.1	leaves + bark	78	0.64	5	0.04	40	0.33	80	0.66	19	0.16
	twigs	4.0	16.8	twigs	11	0.32	2	0.05	18	0.45	26	0.65	3	0.08
	branches	7.6	32.1	branches	4	0.06	1	0.01	9	0.12	6	0.08	3	0.04
Pazo de Villaje														
	leaves + bark	21.9	37.0	leaves + bark	141	0.64	10	0.04	73	0.33	144	0.66	35	0.16
	twigs	7.7	13.1	twigs	21	0.28	3	0.05	35	0.45	50	0.65	6	0.08
	branches	29.5	49.9	branches	14	0.06	2	0.01	35	0.12	21	0.08	11	0.04

[a] Fruits were measured separately in Portugal (ca. 3% of total weight), but added to the leaf-and-bark fraction in Spain.
[b] Residues were added to the site.

zite and black slates corresponding to the lower and middle Cambrian and Ordovician periods. Phosphorus fixation was approximately five times higher in the Spanish as compared to the Portuguese soils, and organic carbon contents in the A and B horizons were also two-to-four times higher.

3.2. *Amount and chemical composition of the organic residues*

The data on weight and nutrient content and concentration of the organic residue components collected at the start of the experiment are shown in Table 4.

3.3. *Tree growth parameters*

3.3.1. *Assessment of tree growth by height and diameter*

The effect of treatment on tree growth generally showed that, by the end of the monitoring period, Treatment I, where litter was incorporated into the soil, was the most favourable for tree production. Also, tree growth in Treatment R, where residues were removed, was generally poorer than in the other treatments.

Height of the trees planted as seedlings in July 1993 is shown in Tables 5 and 6 for Portugal and Spain, respectively. In both the Portuguese sites, tree height attained by July 1995 in treatment R was less than in Treatment I, with the height being intermediate in other treatments, although the differences were not significant. In Spain, the growth of these trees was significantly better in Treatment I than in R, S or W for the same period of growth at Monte Jarrio and significantly better than Treatment R at Pazo de Villaje. However, in general, the effects of OM treatments on the height growth at this stage of the crop rotation were quite small, and differences in earlier measurements were not significant.

Coppiced trees were, on average, more than a metre taller by the end of the experiment as compared to those planted as seedlings. As in the replanted trees, the poorest growth at both the Portuguese sites was in Treatment R, though the difference was only significant at Vale Pequeno and between treatments R and I (Table 7). At Pazo de Villaje in Spain, there was little difference in coppiced tree growth between the three treatments. These measurements were made before canopy closure, so the data relate to the period of tree growth before the most intensive competition between the trees.

Diameter at breast height (DBH) of the newly planted trees is shown in Fig. 1 for the last harvest in 1995. There were no significant effects of the OM treatment at any of the sites, although, overall, Treatment R tended to result in smaller girth. In contrast to height growth, DBH at Monte Jarrio was similar to the two better sites. Thus, timber volume here would be greater than might be predicted from height alone.

Table 5
Height (cm) of trees planted as seedlings at the Portuguese sites between May 1993 and July 1995.

	Dates [a]								
	28.5.93	29.7.93	30.9.93	2.2.94	5.5.94	1.8.94	19.11.94	20.2.95	29.7.95
Furadouro treatment									
R	43(7)	104(20)	183(38)	236(60)	300(85)	421(125)	474(148)	530(163)	706(217)
S	43(5)	101(20)	178(40)	221(49)	285(65)	411(100)	469(118)	535(123)	756(181)
W	38(2)	97(16)	184(38)	239(51)	312(78)	447(123)	512(141)	575(152)	770(182)
I	41(7)	96(13)	158(16)	213(22)	291(31)	426(49)	497(58)	565(69)	762(103)
	4.6.93	2.8.93	1.10.93	4.2.94	29.4.94	18.7.94	21.11.94	6.3.95	26.7.95
Vale Pequeno treatment									
R	23(2)	68(5)	117(9)	154(9)	214(16)	300(27)	347(42)	379(49)	488(66)
S	25(2)	70(7)	124(11)	168(13)	233(22)	333(27)	380(24)	413(31)	529(27)
W	24(2)	68(7)	121(9)	163(5)	227(5)	325(11)	378(18)	414(22)	535(31)
I	23(2)	71(7)	124(9)	166(13)	231(16)	327(27)	385(40)	413(47)	550(51)

[a] Standard deviations are in parentheses.

Table 6
Height [a](cm) of trees planted as seedlings at the Spanish sites between August 1993 and November 1995

	Dates [b]								
	24.8.93	3.11.93	18.1.94	18.3.94	14.7.94	27.10.94	22.3.95	11.7.95	7.11.95
Monte Jarrio treatment									
R	49(13)	74(11)	87(16)	97(13)	174(31)	265(49)	291(44)	402(54)	534(29)a [c]
S	49(11)	75(13)	87(13)	97(16)	177(24)	269(44)	296(45)	406(58)	536(36)a [c]
W	47(9)	75(7)	92(7)	100(8)	180(7)	275(20)	302(42)	412(31)	540(42)a [c]
I	59(10)	88(20)	102(8)	111(7)	199(12)	303(13)	340(11)	462(13)	591(31)b [c]
	1.9.93	15.11.93	13.1.94	17.3.94	7.7.94	26.10.94	23.3.95	17.7.95	7.11.95
Pazo de Villaje treatment									
R	39(7)	60(13)	72(13)	82(18)	180(40)	310(63)	372(69)	541(69)	666(66)a [c]
S	32(5)	51(11)	60(10)	70(13)	177(36)	344(65)	416(78)	602(88)	736(87)ab [c]
I	38(9)	64(16)	73(17)	87(19)	208(41)	376(64)	446(71)	628(83)	751(34)b [c]

[a] Heights are means for the 32 tallest trees per plot.
[b] Standard deviations are in parentheses.
[c] Different letters in the same column indicate significant treatment differences for the final harvest.

3.3.2. *Assessment of tree-root biomass*

Fine (<2 mm) and total root biomass in the top 30 cm in the Portuguese sites are shown in Fig. 2. There was no evidence of a treatment effect on the below-ground biomass at this early stage, in either category.

3.4. *Decomposition of the residues*

At all the sites, decomposition rate depended on the residue component, with leaves and bark decomposing more rapidly than twigs, and branches the most recalcitrant (Figs. 3 and 4). There was no difference in the pattern and degree of decomposition of residues placed in the replanted or coppiced plots. As the residues used in the bags were taken from the corresponding site, decomposition rates may show intrinsic site differences, if the nutrient quality varies.

Treatment had a significant effect on decomposition rate in Portugal. All residues decomposed more rapidly when buried in Treatment I at both sites than when positioned on the surface ($p < 0.001$).

In Spain, the amount of litter decomposed in Treatment I also appeared greater than in the surface treatments, but the difference was less than in the Portuguese sites, possibly because the surface soils were moist enough not to inhibit microbial activity. Because litter bags were bulked before weighing in Spain, it was not possible to determine whether the measured differences were significant. We have included them for comparison with the pattern shown in the Portuguese data.

Table 7
Mean height [a] (cm) of trees in the coppiced plots at three sites at the final sampling in 1995

Site treatment	Portugal [b]		Spain [b]	
	Furadouro	Vale Pequeno	Monte Jarrio	Pazo deVillaje
R	838 (33)a [c]	608 (29)b [c]	–	854 (121)d [c]
S	880 (96)a [c]	630 (51)b [c]	–	814 (56)d [c]
W	860 (92)a [c]	636 (49)b [c]	–	–
I	868 (105)a [c]	680 (20)c [c]	–	843 (40)d [c]

[a] Portugal, July and Spain, November 1995; Monte Jarrio, no data from this first rotation site. No Treatment W at Pazo Villaje.
[b] Standard deviations are shown in parentheses.
[c] Different letters in the same row indicate significant treatment differences.

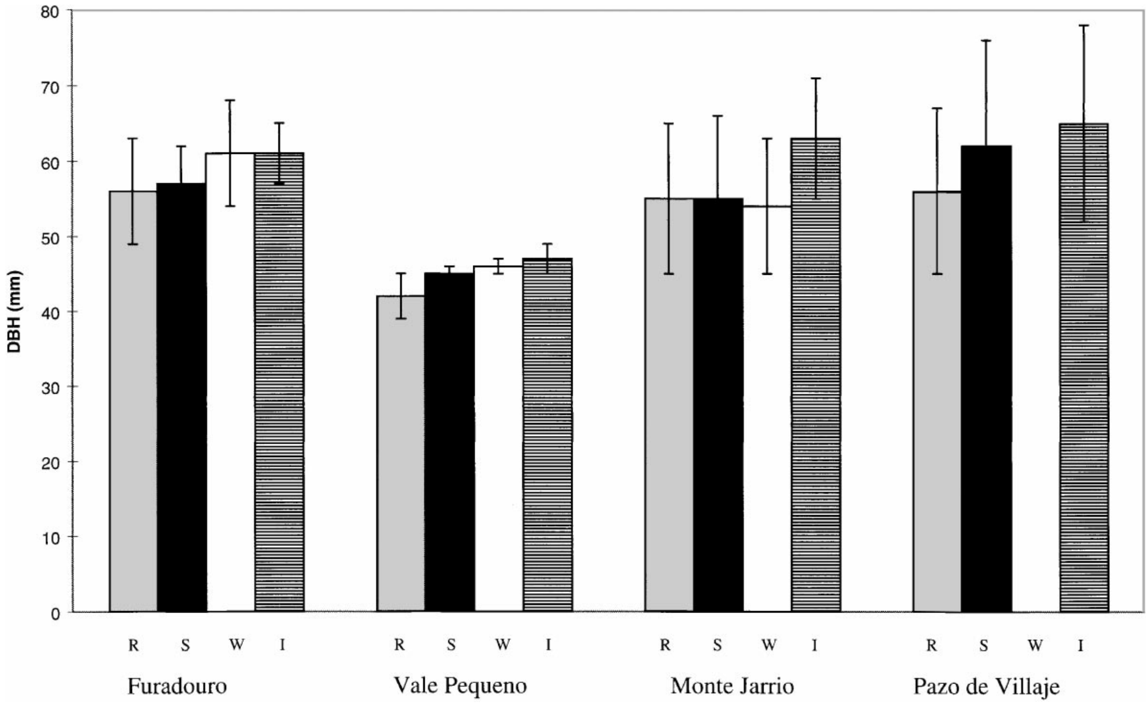

Fig. 1. DBH (mm) of *Eucalyptus globulus* in the replanted plots at the four sites (newly planted at Monte Jarrio) at the final sampling in 1995. Standard deviations are shown as bars. R = residues removed; S = residues spread; W = residues spread with wood in rows; and I = residues incorporated.

Weight loss in Treatment I was more rapid from the start of the experiment in the Portuguese sites, but appeared to be more delayed in Spain. Weight loss in the leaf-plus-bark fraction was greater in the early stages; in the woody fractions, particularly the branches, it accelerated later.

4. Discussion

There was relatively little effect of the different OM treatments on tree growth at any of the four sites by the end of the third growing season, although it was still early in the crop rotation, and canopy closure had not yet occurred. However, by this time, Treatment I, where residues were incorporated, produced better growth, particularly at the Spanish sites. The removal of organic residues (Treatment R) had a slight, but not significant, negative effect on growth, when compared with the treatments in which the organic matter was spread on the soil surface (Treatments S and W), in spite of the large amounts of the nutrients removed from the sites in the former treatment, particularly nitrogen and calcium.

The weight loss of all the litter components was highest in the driest site (Vale Pequeno). For example, for the leaf-plus-bark fraction, the weight loss was about 44–45% in two years, compared with 71% in Spain. These data tally with decay of *Pinus sylvestris* needles, which lost about 20% after one year at dry inland Mediterranean sites, but 40–45% at wetter ones (Berg et al., 1993). The effect of position of the litter, either on the surface or buried in the soil was particularly marked in Portugal. It has been reported elsewhere (Schomberg et al., 1994; Holland and Coleman, 1987) that organic residues incorporated into the soil showed a higher dry weight loss than those placed on the soil surface, and this was also clear in the Portuguese sites. Rovira and Vallejo (1997) attributed a more rapid decomposition of *E. globulus* litter at depth to the dry conditions in the top layers of Mediterranean soils. In northern Spain, however, possibly due to the

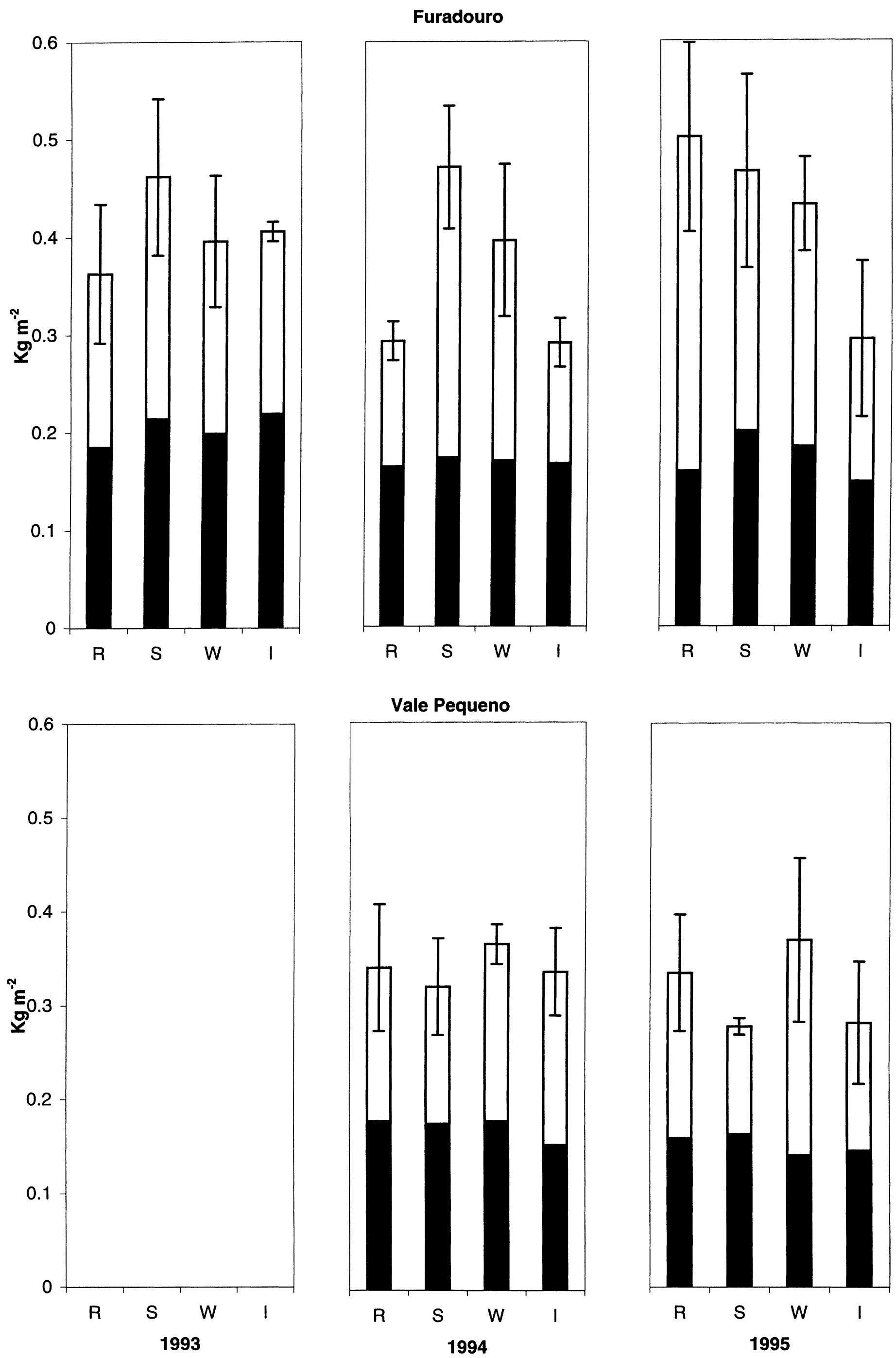

Fig. 2. Fine- and total-root biomass of *Eucalyptus globulus* in the top 30 cm in the residue treatments at the Portuguese sites. Biomass was not measured at Vale Pequeno in 1993. *R* = residues removed; *S* = residues spread; *W* = residues spread with wood in rows; and *I* = residues incorporated.

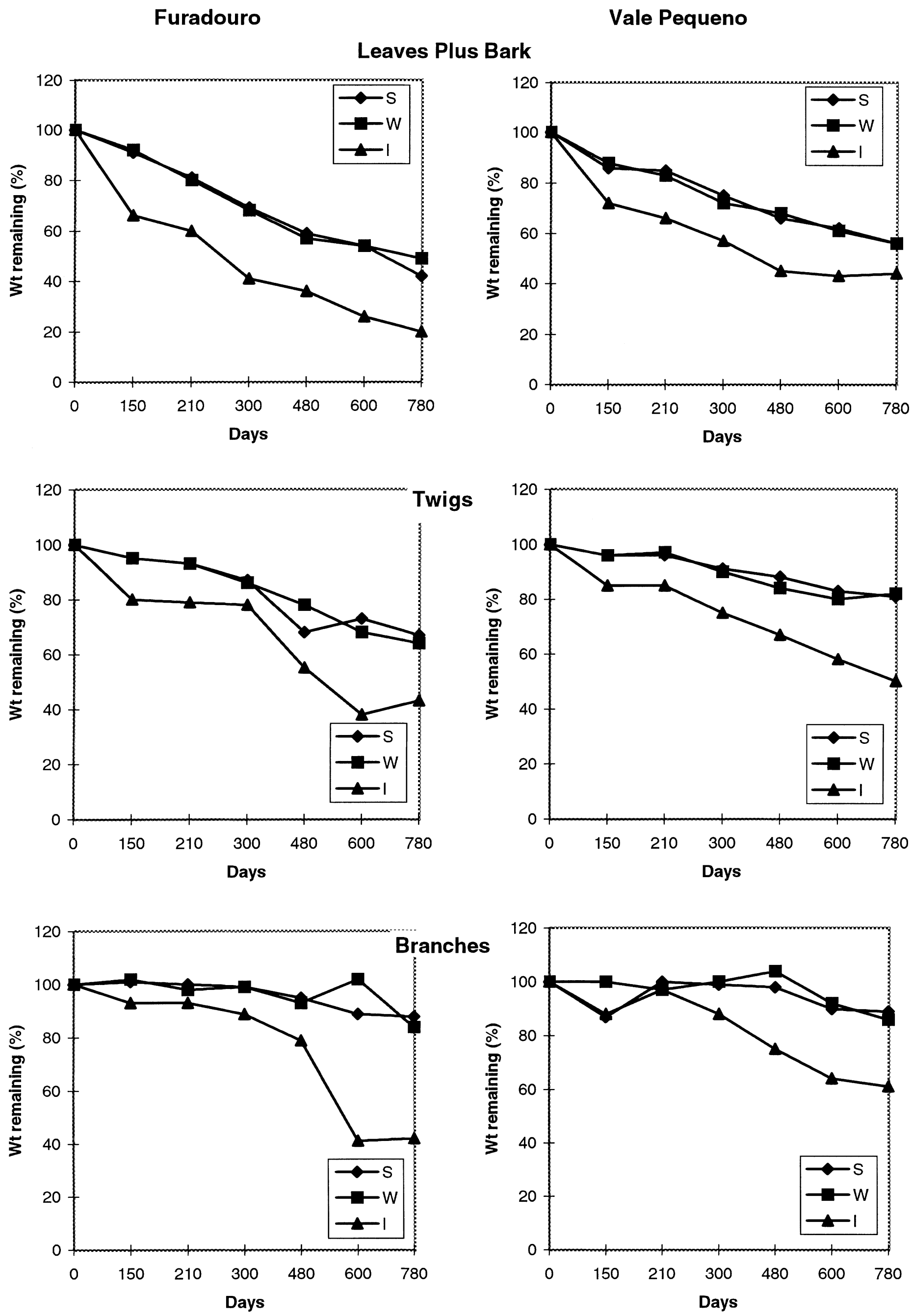

Fig. 3. Decomposition rate as mean percentage weight remaining of eucalypt residues (leaves-plus-bark, twigs and branches) over the experimental period in Portugal in the replanted areas. *S* = residues spread; *W* = residues spread with wood in rows; and *I* = residues incorporated.

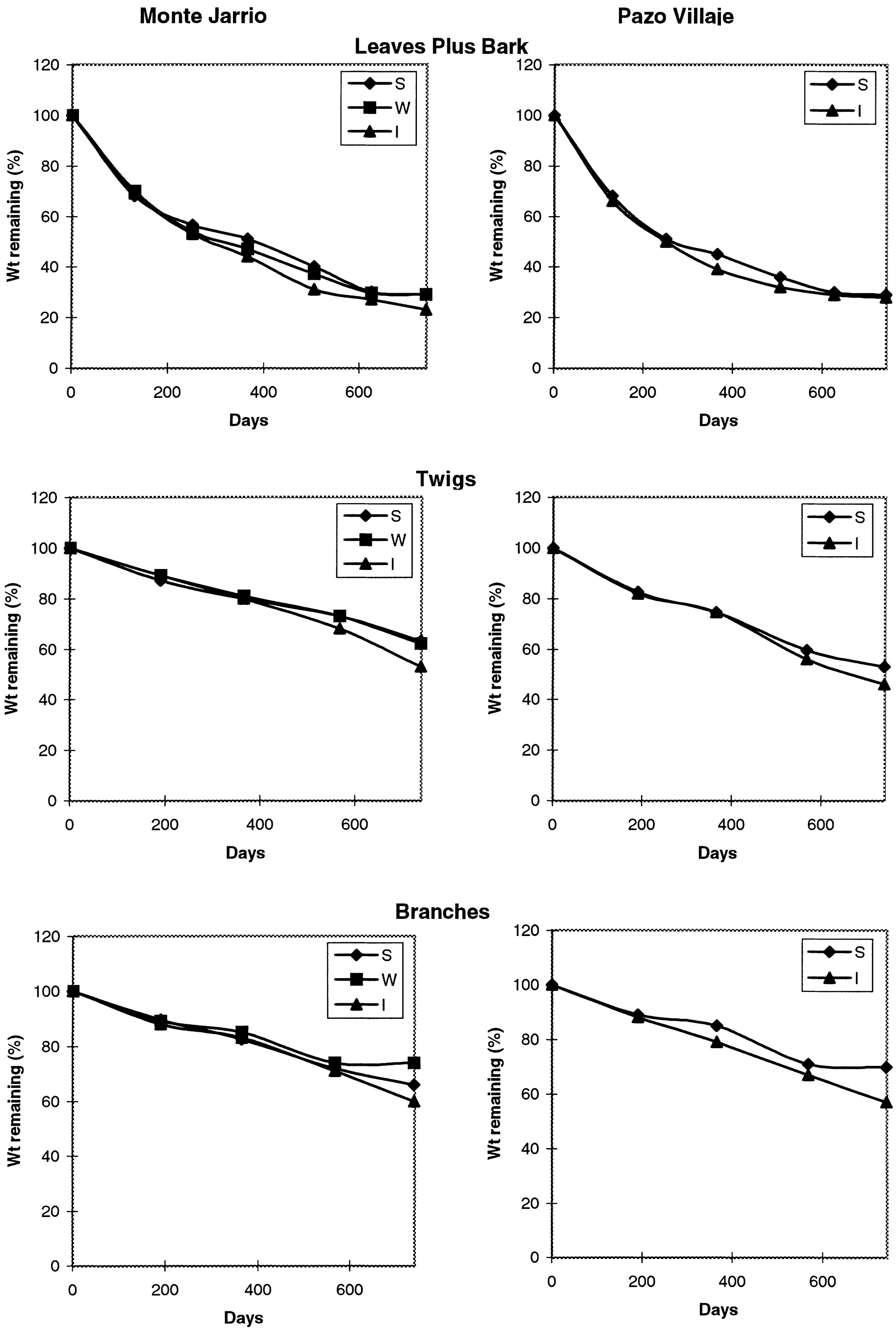

Fig. 4. Decomposition rate as percentage weight remaining of eucalypt residues (leaves-plus-bark, twigs and branches) over the experimental period in Spain in the replanted area (Pazo de Villaje) and newly-planted area (Monte Jarrio). S = residues spread; W = Residues spread with wood in rows; and I = residues incorporated.

continuously moist conditions on the soil surface, incorporation of the residues into the soil did not enhance decomposition to the same extent.

Although many of the differences were not yet significant, it is tentatively possible to rank the tree performance in relation to treatment as: Treatment I > S = W > R. Thus, the results show that, in general, maintenance of organic residues on the site induced better tree growth than their removal, and the effect appeared to be more marked when the residues were incorporated in the soil. The reason may be due to the two following factors:

- faster rate of release of nutrients; and
- a better soil-moisture regime, especially in the dry summers in Portugal. However, interpretation of the impact of potentially higher soil moisture levels would need to be made in the light of information on soil water retention and the wilting point.

The small tree growth response to treatment, particularly in these early years, may be partly explained by the application of fertilisers at planting. At Furadouro, these amounted to 15.5, 17.8 and 18.9 kg ha^{-1} of nitrogen, phosphorus and potassium. At Vale Pequeno, they amounted to 10.5, 24 and 25.5 kg ha^{-1}, and at both the Spanish sites to 20, 60 and 20 kg ha^{-1}. Although the nitrogen fertiliser input would only amount to between 7% and 21% of that in the residues, potassium amounted to approximately half, except at Pazo de Villaje, and the phosphorus in the fertiliser was much greater, particularly at the Spanish sites.

Thus, in summary, significant differences between treatments were only beginning to become evident in some sites and only at the end of the second year of the experiment. This suggests a slow build-up in the effect of the different treatments and the need for a longer period for evaluation. Nevertheless, the treatment in which the residues were incorporated appeared to constitute a better way to maintain the nutrient capital in the plantations and to enhance tree growth.

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