9/96

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CEC CONTRACT AIR3-CT92-0492

ORGANIC MATTER MANAGEMENT IN EUCALYPTUS FORESTRY TO ENHANCE SOIL STRUCTURE, STABILITY AND NUTRITION

EXECUTIVE SUMMARY

Final Report to Commission of the European Communities

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September 1996

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EXECUTIVE SUMMARY

1. OBJECTIVES

To determine the optimum organic matter treatment in Eucalyptus plantations:

- to prevent damage to soil structure and fertility;
- to optimise the input to the stand from the remains of the trees left on site;
- to maintain the productivity of the second rotation stands;
- to protect the long-term sustainability of the sites.

2. BACKGROUND

Eucalyptus species are grown extensively in mediterranean and sub-tropical regions of the world as a cash crop, largely to provide pulp for paper production. *Eucalyptus globulus* is the most widely grown species in Europe. In Portugal and Spain, it has been planted over approximately 4380 and 5000 square kilometres respectively, and crop rotation time varies between 10 and 13 years in Portugal, and 12 and 14 years in N. Spain.

Many areas are now in their second rotation in Portugal. In the past, trees were grown from the coppiced stools of the previous harvest, but increasingly replanting with young trees of improved genetic stock takes place. Trees have been planted on already degraded agricultural land, or on fragile land taken out of native forest production, eg of cork oaks, although few new areas have been planted in the last five years, However, in Spain, the expansion of newly planted areas has recently increased at the rate of about 15% per year and it is envisaged that another 15% will be planted by the year 2000. Regrowth of old stools in second rotation stands planted with young trees is inhibited by covering with soil, or treatment with the herbicide, glyphosate.

Present management practices at felling differ. In Portugal, woody and leaf litter, including the stools of the previous crop are often burnt or removed, which may exacerbate nutrient loss and the likelihood of erosion. In Spain, the debris and non-harvestable material is left at the edge of the plantation, where it may be burnt or used to construct windbreaks.

As Eucalyptus is a fast-growing exotic, there is concern that planting it on the poor soils of the mediterranean regions of Europe will lead to:

- a decline in soil fertility, particularly leaching of nutrient bases;
- a breakdown in the soil physical structure, especially where site preparation is intensive;
- a loss of water-holding capacity of the soil, and therefore a tendency to drought;
- a potential risk of soil erosion in plantations on steep slopes, or in the time between clear-felling and establishment of the second rotation. Erosion may be more acute in areas where the initial planting replaced native vegetation;

- a risk of desertification, where the rainfall is low, as in some parts of Portugal.

These potential problems could jeopardise the long-term sustainability of the plantations. In all cases, it is important to conserve the organic matter and to maintain the nutrient and moisture content.

3. *EXPERIMENTAL SITES*

In this project, we established experimental *E. globulus* plantations at four sites, two in central Portugal, north of Lisbon, owned by the forestry company CELBI and two in N. Spain in Asturias and Galicia, owned by the forestry company CEASA. CELBI and CEASA participated in establishing and maintaining the plantations. The sites differ in climatic and soil conditions, and in degree of slope (Table 1).

***Table 1*. Description of the experimental Eucalyptus plantations**

	Portugal		Spain	
Site	Furadouro	V. Pequeno	Monte Jarrio	P. Villaje
Latitude	39°21' N	39°22' N	43°31' N	43°18' N
Mean annual temp. (°C)	15.2	16.0	13.7	12.5
Rainfall (mm)	607	650	1051	1187
General climate	Humid in summer due to proximity to Atlantic.	More extreme heat in summer and cold in winter. Very dry in summer.	Warm and moist, most precipitation in winter months.	
Slope	----------Flat to undulating---------		37-46%	37-39%
Aspect facing	---	---	N facing	N-NW
Soils	Derived from sandstones; more clay at Furadouro and large stones at Vale Pequeno, where there is a dense clay horizon		On black slates	On slates, sandstone and quartzite
pH (in water)	5.2	5.3	4.6	4.6
Bulk density (g cm-3)	1.50	1.65	0.74	1.20
Organic carbon (%)	0.9 (0-20 cm) 0.7 (20-40 cm) 0.2 (40-60 cm)	1.0 (0-15 cm) 0.5 (15-25 cm) 0.3 (25-45 cm) 0.2 (45-65 cm)	11.3 (0-20 cm) 5.3 (20-28 cm) 3.0 (28-45 cm) 0.8 (45-75 cm)	10.7 (0-20 cm) 2.2 (20-60 cm) 1.0 (60-100cm)

At the Portuguese sites and Pazo Villaje in Spain, areas were chosen where newly planted treatments of the same genetic stock could be established as second rotation plantations, adjacent to coppiced ones, so that the effect of the treatments could be monitored on both young trees and coppiced stools. The other Spanish site, Monte Jarrio, was a newly planted first rotation, so there were no coppiced plots, and Eucalyptus debris was imported to the newly planted plots at a rate thought to be equivalent to debris that would have been left from a previous crop.

4. *EXPERIMENTAL TREATMENTS*

Four methods of organic matter management were studied to determine the optimum treatment for tree growth, to counteract the adverse effects of previous management practice and to reduce the need for application of inorganic fertiliser (Table 2).

Table 2. **Treatments set up to examine the effects of different organic matter management at experimental Eucalyptus sites in Spain and Portugal**

Notation	Treatment
R	Removal of all plant debris from the soil surface, which is the standard practice in Portugal, and elsewhere
I	Incorporation of the organic residues of the previous crop into the soil by harrowing
S	Spreading the organic residues over the soil surface
W	Spreading the smaller residues over the soil surface, but concentrating the larger woody remains in rows between the trees. Minerals may be immobilised in the slowly decomposing remains of the wood component, but become available for uptake by the trees through slow release at a later stage of the rotation.

At each site, the different treatments were replicated in five blocks in a fully randomized design. At Pazo Villaje in Spain, trees in the first rotation had been planted in an irregular way, so it was not possible to install Treatment W, with the wood in rows.

Before the treatments were set up, the amount of organic matter in the forest floor and the tree residues was estimated and chemically analysed.

The trees from a single clone (MB89) were planted in March 1993 in Portugal. In Spain, the first batch of seedlings which was planted at the same time, was attacked by a fungus. Replanting of seedling trees from a local nursery took place in June. As each seedling was planted, it was supplied with fertiliser to assist establishment. In Spain, the application was 100 g of 8:24:8 NPK. In Portugal, the application was 100 g of 14:36:21 at Furadouro, and 150 g of 7:36:21 at Vale Pequeno.

5. *FACTORS MONITORED*

Recordings of the various parameters of tree growth and soil conditions were made between the date of planting and November 1995 in the replanted plots (Table 3). Tree growth and decomposition rates were also monitored in the coppiced plots.

Table 3. **Measurements made at the individual sites**

Measurements	Portugal F	VP	Spain MJ	PV *
Tree height	+	+	+	+
Tree diameter	+	+	+	+
Root biomass in top 30 cm	+	+	-	-
Nutritional assessment	+	+	+	+
Soil micromorpholgy	-	+	-	-
Soil aggregation	+	+	+	+
Soil chemistry	+	+	+	+
Decomposition rates of residues	+	+	+	+
Mineralisation rates of residues	+	+	+	+
Soil leaching rates	+	-	-	+
Soil erosion rates	-	-	+	+
Understorey vegetation recording	+	-	-	-

* **F** Furadouro; **VP** Vale Pequeno; **MJ** Monte Jarrio; **PV** Pazo Villaje

6. *FINDINGS*

6.1 Tree growth

6.1.1 Site response The best overall tree growth in both height and diameter at breast height (DBH) occurred at Furadouro, where the overall mean height of the trees planted as seedlings was 748 cm in July 1995, compared with only 525 cm at Vale Pequeno. Tree height at the Spanish sites at the final recording in November 1995 was intermediate between these two extremes: 681 cm at Pazo Villaje and 550 cm at Monte Jarrio. Coppiced trees showed more rapid growth than the replanted ones, and were approximately 1 metre taller by the end of the experiment.

6.1.2 Treatment response The effects of the organic matter treatments were small at this early stage of the rotation, before canopy closure. There was no significant treatment effect at Furadouro, although at Vale Pequeno, trees in Treatment R were significantly smaller than in Treatment I. In Spain, the growth of all trees planted as seedlings was significantly better in Treatment I than in the other treatments. Coppiced trees show less difference between treatments, but stools in Treatment R produced the poorest growth in both Portuguese sites. Thus at this early stage it appears that incorporating the organic matter from the previous crop into the topsoil favours tree growth, while removing it is disadvantageous. The treatment differences in this early stage in the rotation may have been masked by the fertiliser applied at planting, although this complication would not have been a factor in the coppiced plots.

6.2 Root biomass

6.2.1 Site response Tree root biomass, measured at the Portuguese sites, showed little difference between the sites, although drought conditions in 1994 and 1995 may partly explain the lack of increase in root biomass over the experimental period. Overall mean weight of the fine roots in the top 30 cm was 182 g m^{-2} at Furadouro and 162 g m^{-2} at Vale Pequeno, while total root biomass to the same depth was 398 and 329 g m^{-2} respectively. It was not possible to separate the fine roots from the organic matter particles at the Spanish sites, so no realistic estimates were obtained.

6.2.2 Treatment response There were no statistically significant differences between treatments in the biomass of roots to 30 cm, but there was a greater weight in the top 10 cm in Treatment S in 1995. As the lowest root biomass at the end of the experiment was measured in Treatment I at both sites, they may have been adversely affected by the dry soil conditions, but were able to develop better where the soil surface was protected from drying out by a layer of organic matter.

6.3 Tree nutrition

6.3.1 Site response Tree nutrition was assessed by means of root bioassays, which provide integrated measurements of the balance between the demand of the tree for the major nutrients, nitrogen, phosphorus and potassium, and the available supply of the corresponding element in the soil. The bioassays were applied to roots sampled annually in October/ November. Nitrogen uptake was generally higher in roots from the Portuguese sites, although not at levels that would suggest deficiency, but phosphorus uptake was higher in trees from the Spanish ones, possibly due to the much higher phosphorus fixation capacity of the Spanish soils. Phosphorus uptake increased markedly over the three years at both Spanish sites and at Vale Pequeno but the generally low root demand at Furadouro may be a reflection of the low phosphorus fixation at the site, indicating that it is not a limiting nutrient. Rubidium uptake (used as an analogue for potassium) was more variable between sites. Uptake at Furadouro showed little change over the 3 years, but at Vale Pequeno there was a sharp increase in demand over the three years. In Spain, uptake was much higher in 1994 that 1993, but declined again in the third year.

6.3.2 Treatment response There were no significant differences in uptake by the roots of trees in the different treatments, possibly because it was too early in the crop rotation for nutrient release from the litter residues to be reflected in differences in tree nutrient response. In addition, the inorganic fertiliser applied at planting will almost certainly have masked some of the more subtle nutritional effects of mineralisation of the decomposing litter in these early years.

6.4 Soil micromorphology

Micromorphology was examined at Vale Pequeno in Portugal, using light microscopy of thin sections to clarify the effects of the organic matter treatments on the soil structure and processes involved in breakdown of the organic matter. The site has a dense clay-rich subsoil which may inhibit root development, especially in those areas where it is close to the surface. Disturbance of the soil during site preparation sometimes caused the clay layer to be brought near to the surface.

6.4.1 Treatment response Microscopic examination was made of thin resin-impregnated sections sampled from Treatments R, I and S and a Reference profile, just outside the boundary of the experimental area in June of each of the three years of the experiment. Root distribution, organic matter, soil faunal activity and fungal hyphae were quantified. They showed that incorporation of the organic matter is essential for root growth, and that treatments where the litter was removed or spread (R and S) were the least effective in promoting root growth, although in the latter, the effect was exacerbated by the dense clayey subsoil which was very close to the surface (12 cm) in this plot. Root growth was also good in the untreated Reference plot, where there was no dense clayey subsoil close to the surface. Faunal activity, measured by the number of faecal pellets, was also higher in Treatment I and the Reference site than in the other treatments.

6.5 Soil aggregation

6.5.1 Site response Soil aggregate size distribution was examined over the period of the experiment. Aggregation indices which measure the proportion of large to small aggregates were considerably higher in Spain than Portugal, due to the higher organic matter content of the soils. Vale Pequeno soils in Portugal showed a higher overall index than those from Furadouro. There were also a higher number of stable aggregates at Monte Jarrio than Pazo Villaje in Spain.

6.5.2 Treatment response The number of stable aggregates did not appear to be increasing over the period of the experiment, as a response to differential organic matter treatment effects. However, at Furadouro there was a significantly lower aggregation index in Treatment S than R. At Monte Jarrio, there were a higher number of aggregates in Treatment I, particularly in the top two size classes.

6.6 Soil chemistry

6.6.1 Site response The main difference was much higher phosphorus fixation capacity in the Spanish soils, which possibly explained the higher uptake in the phosphorus bioassay (6.3.1) there than in the Portuguese sites. The high phosphorus fixation was linked to the high aluminium content of the Spanish soils, which would bind it in the soil. Cation exchange capacity which was measured on the same samples was higher in Furadouro than Vale Pequeno, because of its higher clay content.

6.6.2 Treatment response Soil phosphorus fixation and cation exchange capacity showed no response to treatment over the short monitored period.

6.7 Litter decomposition

6.7.1 Site response Decomposition was measured as the weight loss of samples of litter placed in bags in the experimental plots, buried in Treatment I and placed on the surface in S and W. Leaves plus bark always decomposed more rapidly than twigs, and branches were the slowest. It was significantly faster at Furadouro than Vale Pequeno. Although there was little difference between the two Spanish sites, it was faster there than at the Portuguese sites.

6.7.2 Treatment response Decomposition was significantly faster in Treatment I in the Portuguese sites than in S or W. It was also faster in Treatment I in Spain, but the difference was less marked, presumably because surface conditions were more moist there, so conditions were more favourable for decomposition in S and W. Rates recorded in the bags placed in the coppiced plots were very similar to those in the replanted plots.

6.8 Mineralisation rates

6.8.1 Site response Mineralisation of the litter material showed a rapid leaching of potassium and to a lesser extent of magnesium, particularly in the leaves plus bark at all the sites. By the end of the experiment, less than 5% of the initial potassium remained in this component in the Spanish sites, and about 12% in the Portuguese ones. In Portugal, net immobilisation of nitrogen and calcium occurred, particularly at Furadouro, and particularly in the branch component. Thus, this woody component of the litter residues would only become a nutrient resource at a later stage of the rotation, which may have implications for the longer term effect of Treatment W in acting as a nutrient resource. Phosphorus tended to be lost from the leaf and twig litter and immobilised in the branch litter.

6.8.2 **Treatment response** There was little difference between the treatments at either of the Portuguese sites. Where phosphorus and nitrogen immobilisation occurred, it tended to be more marked in Treatment I than where the litter bags were situated on the surface.

6.9 Leaching rates

6.9.1 **Site response** Measurements made of the nutrient leaching rates at Furadouro and Pazo Villaje showed a very high variability, and no clear pattern over the course of the experiment. Calcium ion concentration and pH of the leachates both tended to decline at Furadouro in Portugal, and pH also declined at Pazo Villaje in Spain. Generally, nitrogen losses were much higher at Pazo Villaje than Furadouro, where the concentrations of both nitrate and ammonium were very low, suggesting that N leaching was not a problem.

6.9.2 **Treatment response** There were no treatment effects.

6.10 Downslope erosion

6.10.1 **Site response** Downslope erosion was measured by Gerlach troughs placed in some plots in the steep Spanish sites. There was no evidence from the material collected in the troughs that erosion was a general problem, but it is unlikely to be serious unless there are severe storm events, which did not occur during the monitored period.

6.10.2 **Treatment response** Occasionally a few grammes of soil was retrieved from the troughs, but where this occurred, it was in plots where there was no surface organic matter i.e. a plot of Treatment I at Monte Jarrio, and three plots of Treatment R at Pazo Villaje. It was more serious at the beginning of the experiment than later, so may also be due to the disturbance of setting up the plantations.

6.11 Understorey vegetation

Cover and diversity of the ground flora is reputed to be adversely affected in Eucalyptus plantations, but there was no evidence that this was so in the monitoring at Furadouro. However, this was before canopy closure, when shading would have a more serious impact.

6.11.1 **Treatment response** Initially, the grass *Holcus lanatus* and a small legume, *Ornithopus pinnatus* were abundant on the replanted plots, and ground vegetation in Treatment R, where vegetation was removed, exceeded 80%. The cover of *H.lanatus* increased in 1995, but *O. pinnatus* had virtually disappeared. As a nitrogen-fixing legume, it could have provided an early boost to the nitrogen supply in the plantation, particularly in Treatment R. Understorey vegetation cover was lower in the coppiced plots than the replanted ones, with about 50% bare ground, compared with a mean of about 22% in the replanted plots.

7. *SUMMARY FINDINGS*

i. There were differences in the tree production between the sites, with the best and the poorest growth at the two Portuguese sites, Furadouro and Vale Pequeno, respectively.

ii. Tree growth in the first three years was more rapid from the coppiced stools than from the seedling plants.

iii. Tree growth was more rapid in Treatment I than in the other treatments at the Spanish sites, although not in Portugal. At Vale Pequeno, the poorest growth in the replanted plots occurred in Treatment R. There was no effect of treatment in the coppiced trees at any of the sites.

iv. Root biomass, measured at the Portuguese sites, did not show a treatment effect, but detailed studies on the soil micromorphology at Vale Pequeno showed that more roots were formed in Treatment I than in R or S. Faunal activity was also higher in this treatment.

v. Phosphorus fixation capacity was much higher in soils of the Spanish sites than in Portugal, probably associated with the higher aluminium content of these soils. Cation exchange capacity in Furadouran soils where the clay content was fairly high, was similar to the Spanish ones, but much higher than at Vale Pequeno.

vi. Litter decomposition was more rapid in the Spanish sites than in Portugal, except in Treatment I. In Portugal, litter decomposed significantly faster in this treatment than in the surface organic matter ones, so that the rate was similar to the overall rate in Spain. At all the sites, the leaves plus bark component decomposed more rapidly than the twigs which were also more rapid than the branches.

vii. Mineralisation rates differed markedly between different nutrient and different litter components. Potassium and, to a lesser extent magnesium, was leached rapidly in the first few months. Nitrogen and calcium were immobilised in the woody fractions.

viii. Ground vegetation was abundant in the replanted plots at this early stage of the rotation, particularly in Treatment R, although there were marked changes in the species composition between the years. Cover in the coppiced plots was lower.

8. *RECOMMENDATIONS*

While it is too early in the crop rotation for the long-term effects of the different treatments to be detected, continued monitoring would enable incipient differences to be confirmed. Initial results suggest that Treatment I (crop residue incorporation) has advantages for the second rotation crop. Early fertilisation of the seedling trees has overshadowed the slow and more subtle changes in nutrition due to the mineralisation of the organic matter. It would be unnecessary to continue to monitor all the factors measured during this programme, but it would be most helpful if certain factors could be monitored at later stages of the rotation.

i. At this stage, it appears from the Spanish data, that Treatment I is more favourable for tree growth and, as decomposition is also more rapid, it is likely that mineralisation rates will also lead to a faster turnover of nutrients. Removal of litter in Treatment R may have an adverse impact. Longer-term monitoring is recommended to establish whether these initial observations are indicative of more permanent effects. If Treatment I is of benefit throughout the rotation, then it would be necessary to balance any additional costs in site preparation against the higher tree production. It would not be necessary to continue to monitor all factors on a regular basis, but tree height and DBH should be measured at canopy closure, in year 5 or 6, and again after approximately 12 years.

ii. Assessment of the tree nutrition by root bioassays later in the rotation is required, at year 5 or 6 and at year 12 to study the potential impacts of the faster rate of litter decomposition in the incorporated residues (Treatment I), and also the impact of the longer term reservoir of nutrients in Treatment W. At the present stage of the rotation, some key nutrients, phosphorus, calcium and particularly nitrogen, are immobilised in the branch component. The tree nutrition may also still be modified by the inorganic fertiliser applied at planting.

iii. Further studies on the soil micromorphology of Treatment I and the Reference profile at Vale Pequeno later in the rotation would indicate whether more roots develop in the harrowed upper horizons than in the undisturbed soil, and whether subsoiling by ripping has any significant effect on the development of the deeper roots. It would also clarify the discrepancy between these data and the root biomass measurements, which did not show that Treatment I resulted in better root growth. Tree growth on an untilled reference site should be monitored to determine whether the apparent benefits to the soil here are reflected in greater production, and the soil profile examined in an area where the organic matter was incorporated without subsoiling. This treatment was set up by the forestry company at the same time as the other treatments.

iv. Downslope erosion did not appear to be a serious problem, but the Gerlach troughs were rather small. A longer period of recording, or larger-scale measurements would be required to confirm the preliminary findings. Also, it would be helpful to monitor erosion after storm events, when it is most likely to occur.

v. Reassessment of understorey vegetation after canopy closure at Furadouro would indicate the impact of the Eucalyptus shade and root competition.