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Could Control of Invasive Acacias Be a Source of Biomass for Energy under Mediterranean Conditions?

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Mediterranean summer drought conditions may limit the usefulness of most woody energy crops common in other European regions. Exotic tree species well adapted to summer stress, such as eucalyptus and acacias, may be more promising as biomass producers under such environmental conditions. Eucalypt plantations have been increasing in Portugal, for pulp and paper, over the last decades, and this species may also be considered as an option for bioenergy production. Acacias are becoming an environmental problem due to the invasive character of some species, in Portugal and other Mediterranean countries. According to the Portuguese law, they cannot be introduced anymore and the existing stands must be controlled through large scale eradication plans. The use of their wood for energy may represent an opportunity to reduce the costs of eradication. The aim of this study was the assessment of the potential of acacias to be used as a biomass-for-energy source, taking advantage of their early growth. Clonal rooted cuttings of Eucalyptus globulus were used as a reference and Acacia melanoxylon, A. pycnantha and A. dealbata, which have an invasive behaviour, were privileged as target species. They were propagated in nursery from seeds collected in the wild and a trial consisting of irrigated and rain-fed plots of each species was installed at the Instituto Superior de Agronomia (ISA) campus, in Lisbon. Survival and growth were monitored and plants were harvested 1 and 2 years after planting, sorted into biomass components, and oven-dried. Aboveground dry weight was calculated on an area basis, accounting for survival. A. dealbata and A. melanoxylon had both low survival and poor biomass production, even irrigated. A. pycnantha had higher survival and biomass production than eucalypt, even in rain-fed plots, suggesting that control through biomass harvest for energy purposes may minimize eradication costs.

1. Introduction

Under Mediterranean summer drought conditions, exotic trees well adapted to drought stress, such as eucalyptus and acacias, may be more promising as biomass producers than most short rotation energy crops used elsewhere in Europe (e. g. willows, poplars, or alders).

The area of eucalypt (*Eucalyptus globulus* Labill.) plantations in Portugal significantly increased over the last decades (Borges and Borges, 2007), attainting more than 800,000 ha within a total forested area of ca. 3.2 Mha (ICNF, 2013). This fast growing tree species is usually managed in short rotations (10-14-y long) and used for paper pulp. Some harvest residues are often removed from site for bioenergy purposes (CELPA, 2012) and a more generalised use as an energy crop may be an alternative to consider (Barreiro and Tomé, 2012).

Australian species of the genus *Acacia* Mill. have become an environmental problem in several areas of Europe, especially in France, Spain and Portugal due to the invasive character of some of them (Marchante et al., 2008; Richardson and Rejmánek, 2011). In Portugal, these species are not anymore allowed in plantations, and the restrictive law recommends their control or eradication through large scale plans. The use of biomass for energy and/or bio-products may be an alternative to stimulate the the use of innovative raw-materials (Santos et al., 2004) and to mitigate the eradication costs (Grupo de Trabalho do MADRP de Energias Alternativas, 2005).

The aim of this study is to determine the potential of woody species well adapted to summer drought as energy crops under Mediterranean climate. Rooted cuttings of a *Eucalyptus globulus* clone with high

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biomass production performance were used as a reference. *Acacia melanoxylon*, *A. pycnantha* and *A. dealbata*, frequent invaders of Portuguese abandoned fields and coastal sand dunes, were selected as target invader species, based on bibliography reporting their biomass production and, in the case of *A. melanoxylon*, also owing to its ability for fast growth and high dimension at maturity (Medhurst et al., 2003).

Aiming the establishment of a controlled experiment, these species were propagated in nursery from seeds collected in existing Portuguese stands. The objective was to clarify the feasibility of using the abundant young regeneration that usually follows the harvest of dominant acacia trees as raw material for bio-energy, hypothesising that they might be competitive with eucalypt as a confirmed high performance species for ultra-short rotation coppices dedicated to biomass production (Ceulemans et al., 1996).

2. Methods and Materials

2.1. Plant materials

Seeds of *Acacia dealbata*, *A. pycnantha* and *A. melanoxylon* were collected in wild Portuguese stands, respectively from interior Central Portugal, Algarve, and Sintra Forest Perimeter. They were soaked for 4 h in a hot water (80-90 ºC) pre-treatment to break seed coat dormancy, before sowing in propagation liner trays in November 2010 at Instituto Superior de Agronomia (ISA) nursery. Rooted cuttings of a *Eucalyptus globulus* clone were obtained from the commercial nursery Altri Florestal SA.

2.2. Experimental design

The field trials were established in a biomass-for-energy facility (BioenergISA) at ISA campus in Lisbon. Rooted cuttings (eucalypt) and seedlings (acacias) were established in January 2012 following two treatments: near-optimal drop irrigation and a rain-fed control. Irrigation was performed between 14.6.2012 and 29.10.2012 and from 7.5.2013 to 23.10.2013, amounting respectively to 1,220 and 1,100 L m^{-2}. To avoid effects of water percolation in the soil, the rain-fed plots were installed at higher elevation than those irrigated, following the gentle (< 5 %) W-E slope. The location of species in treatments was randomized. The irrigation rate was regularly set by adjusting the number of hours of water flow (4 L m^{-2} h^{-1}) with an electrical clock commanding a solenoid valve, regarding the evapotranspiration values available online through the webpage of the Portuguese Weather Survey Authority (available at www.ipma.pt/pt/agrometeorologia/mapas/diario/index.jsp?page=deto_co.xml, assessed all along the experiment summer periods). Each species and treatment occupied an area of 6×5 m^2, planted at a compass of 0.5×0.5 m^2, i. e., with a density of 4 m^{-2}.

2.3. Measurements and sampling

Tree height (h) of measurable living seedlings in each plot was assessed with a measuring tape at planting and 7-11, 41-45, 69-73, 128-132, 160-164, 257-261 and 348-352 days after planting; the survival rates were evaluated and after one year plants were partially harvested (except for eucalypt, whose final monitoring and harvest was 317 days after planting, but within the dormant plant season). A similar procedure was applied to the remaining plants in the second year, 512-516 and 660-664 days after planting, except for irrigated *A. dealbata* and rain-fed eucalypt, which did not survive the first year.

Biomass production was evaluated by the harvest method, sampling at least 24 representative plants of each species and treatment in the first year (adjusted to the remaining surviving plants in irrigated *A. dealbata* and rain-fed eucalypt) and 20 in the second (adjusting for survival, i. e., only 17 plants per treatment in *A. melanoxylon* and all the remaining 11 in rain-fed *A. dealbata*). Each plant was divided into 3 components: stem, twigs and branches, and leaves, that were weighed to the nearest 0.001 g and values compiled for total fresh weight biomass. Components of the smaller plants (all of them in the first year harvest, and those *of A. dealbata*, *A. melanoxylon* and *E. globulus* in the second year) were then oven-dried at 80 ºC until constant weight (at least 48 h) and weighted to obtain oven-dry biomass. In the second year harvest, samples of the main components of *A. pycnantha* were fresh-weighted, oven-dried at 80 ºC and dry-weighted; total component dry weights were re-calculated from sample weights. Aboveground dry weights per hectare for each species and year were estimated accounting for mean tree dry weight and tree density in each treatment and year.

2.4. Data handling and statistical analysis

Normality of data distribution and homogeneity of variance were assessed by Kolmogorov–Smirnov test and Levene test, respectively. Differences in mean tree height and mean aboveground total and component biomass across species and treatments were tested through Analysis of Variance (two-way ANOVA; factors: species * treatments). Whenever normality was confirmed, post-hoc analyses were conducted using the Tukey test for multiple comparisons of means; if not, the Games-Howell test was performed. All tests were done using the statistics software package IBM SPSS Statistics 19.0.0 (IBM Corporation, Somers, NY, USA), considering a significance level of 5 % (α=0.05).

3. Results

3.1. Plant survival

Survival rates of the species used in the present study are shown in Figure 1. The results revealed a very low survival, along the first year, in rain-fed plots of eucalypt (25 %) and in both irrigated and rain-fed treatments of *A. dealbata* (30 and 49 %, respectively), which suffered lower mortality rain-fed than under irrigation. Due to the small number of remaining plants, rain-fed plots of eucalypt and irrigated plots of *A. dealbata* were totally (eucalypt) or almost totally (acacia, also affected by further mortality) harvested at the end of the first year, becoming unavailable for monitoring in the second. *A. pycnantha* had the highest survival rate in both areas, irrigated and rain-fed (respectively 94 and 93 % in the first year, and 92 and 95 % in the second), followed by irrigated eucalypt (90 and 81 % in the first and second years) and irrigated *A. melanoxylon* (73 and 57 %).

3.2. Tree growth

Tree growth was evaluated by mean tree height (Figure 2). Both irrigated *A. dealbata* and rain-fed eucalypt were totally harvested after one year and are not represented in the second year. The highest growth performances one year after planting were observed in irrigated eucalypt and *A. pycnantha*, attaining 98±2 and 110±5 cm, respectively. Along the first year these species also had greater height in rain-fed plots (78±2 and 74±4 cm) than all the other *Acacia* species, in both irrigated and rain-fed treatments. In all species except *A. dealbata* irrigation during the first summer significantly ($p<0.05$) contributed to higher growth than that observed in rain-fed treatment plots; *A. dealbata* had a higher growth in rain-fed than in irrigated plot (29±2 cm vs. 26±2 cm), but the difference was not statistically significant ($p>0.05$).

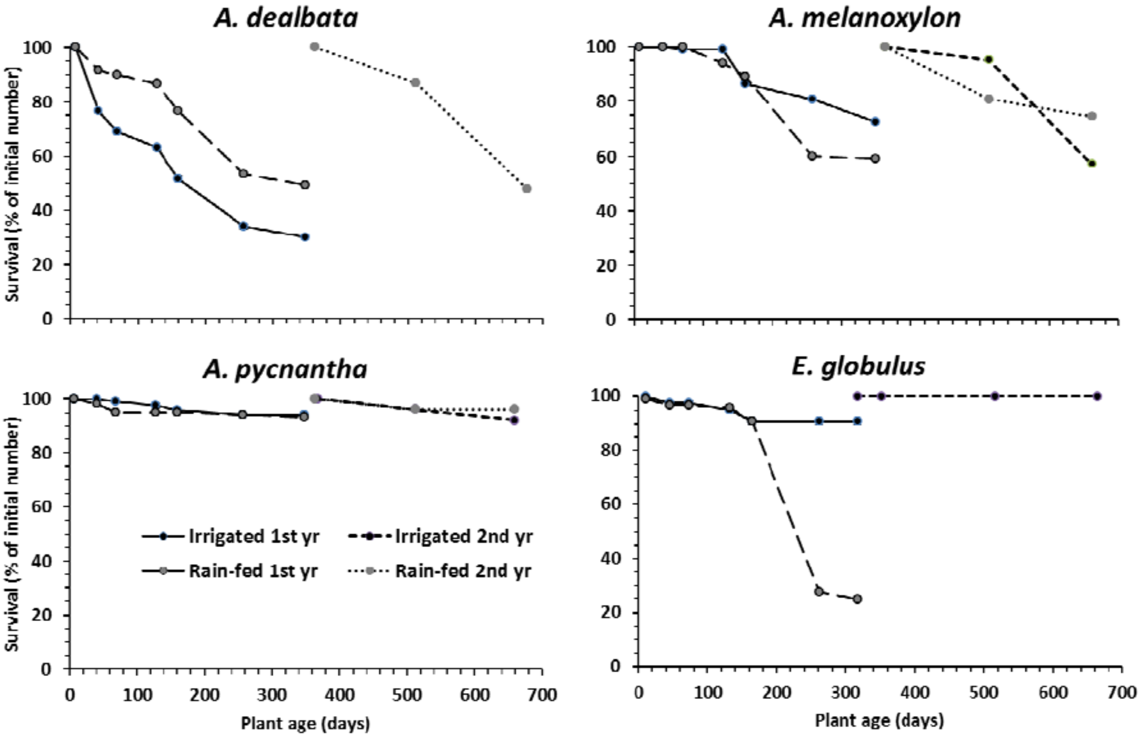

Figure 1: Survival (% of initial seedling or rooted cutting quantities) of Acacia dealbata*,* A. melanoxylon*,* A. pycnantha *and* Eucalyptus globulus *along the first year (close to YY axis) and second year (right side).*

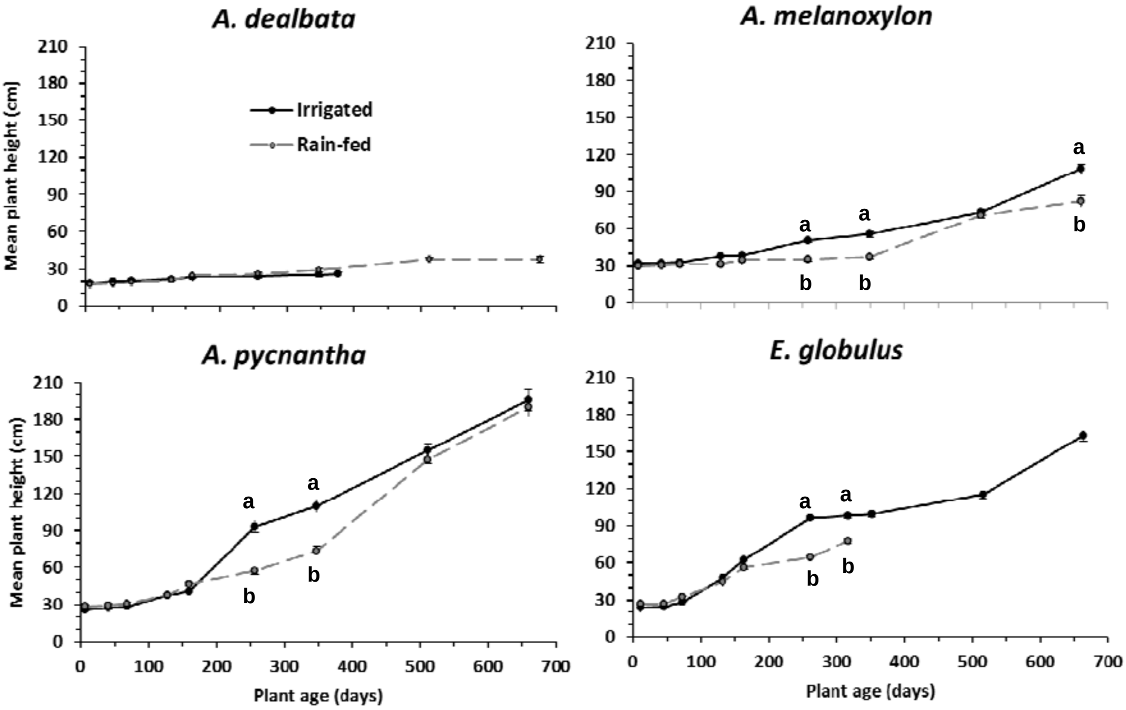

Figure 2: Mean tree height variation along the 2 first years after planting. Vertical bars represent ± 1 SE. Different letters indicate statistically significant differences between treatments (p < 0.05).

Along the second year differences between irrigated and rain-fed *A. pycnantha* lost statistical significance, due to a faster growth rate of the rain-fed plants during the second winter and early spring. A similar trend was observed in *A. melanoxylon* plots, but summer drought decreased the growth rate of rain-fed trees and the difference in mean tree height between irrigated and rain-fed plants become significant again by the end of the second year. Mean tree height was greatest in irrigated and rain-fed *A. pycnantha* (respectively 196±11 and 190±9 cm), followed by irrigated eucalypt (163±4 cm) and irrigated *A. melanoxylon* (109±9 cm), whereas rain-fed *A. dealbata* kept the lowest value (38±4 cm).

3.3. Biomass production

Biomass production after 1 and 2 years, rain-fed and under near-optimal drop irrigation is shown in Table 1, both for the mean tree and on an area basis, adjusted for survival (i. e., considering the remaining tree density in each plot). After 1 year *A. pycnantha* trees showed the potential to accumulate more biomass than all the other species, irrespective of treatment ($p<0.05$), attaining under irrigation 46±9, 13±4, 40±7 and 99±19 g dry biomass tree^{-1} respectively for stem, branches, leaves and total aboveground, and producing an estimated biomass harvest of 3.7 t ha^{-1}. These values further increased after 2 y, attaining 16 t ha^{-1} in the irrigated plot and 13 t ha^{-1} under rain-fed conditions. Irrigated eucalypt, the second best biomass producer and a reference as a fast growing exotic tree species, only produced 1.0 and 3.5 t ha^{-1}, respectively after 1 and 2 y.

Contrarily, *A. dealbata* ranked the lowest biomass producer in both treatments in the first year (8.7 and 37.9 kg ha^{-1}, respectively irrigated and rain-fed) and did not survive under irrigation after the first harvest; its production in the rain-fed plot was lower in the second year than in the first (respectively 12.9 and 37.9 kg ha^{-1}) probably influenced by high mortality leading to heavy tree density loss and site under-occupation.

Acacia melanoxylon ranked intermediate dry biomass production (350 and 52 kg ha^{-1} in the first year, increasing to 862 and 339 kg ha^{-1} in the second, respectively under irrigation and rain-fed), suggesting either poor adaptation to the site (survival decreased regularly in both treatments along the two years of the experiment until slightly more than 25 % of the initial number), or a low early growth performance. Allocation of biomass to woody components (stem plus branches) was higher in the acacia species than in eucalypt in both years, with *A. pycnantha* ranking the highest proportions (ca. 70 %).

Table 1: Biomass production of Acacia dealbata*,* A. melanoxylon, A. pycnantha*, and* Eucalyptus globulus*. Values in the same column and year followed by the same letters do not differ significantly (p > 0.05).*

Species	Treatments	Biomass production (g tree^{-1})				Sample size (ner. of plants)	Estimated harvest (kg ha $^{-1}$)
		Stem	Twigs + branches	Leaves	Abovegr. total		
		After 1 year					
A. dealbata	Irrigated	0.50a	0.05a	0.19a	0.75a	36	8.7
	Rain-fed	0.78ab	0.12ab	1.03a	1.93ab	36	37.9
A. melanoxylon	Irrigated	6.22a	0.83a	5.01ad	12.05a	24	349.5
	Rain-fed	0.89ab	0.11ab	1.21a	2.21ab	24	52.2
A. pycnantha	Irrigated	46.33c	12.98c	39.78c	99.09c	36	3,732.5
	Rain-fed	5.49ab	1.32ab	7.01ab	13.82ab	36	515.9
E. globulus	Irrigated	9.46a	1.64a	16.99bd	28.09a	37	1,039.3
	Rain-fed	7.48ab	2.28ab	19.33b	29.09ab	30	290.9
		After 2 years					
A. dealbata	Irrigated	-	-	-	-	-	-
	Rain-fed	2.04a	0.70a	2.04a	3.51a	11	12.9
A. melanoxylon	Irrigated	35.24bc	9.50b	28.20b	71.82b	17	861.8
	Rain-fed	15.59b	2.52b	11.35b	29.07b	17	339.2
A. pycnantha	Irrigated	274.17bc	202.26c	274.17c	680.79c	20	16,112.0
	Rain-fed	192.43bc	143.09c	200.38c	535.90c	20	13,040.1
E. globulus	Irrigated	60.81bc	15.39c	69.36c	146.53c	20	3,516.8
	Rain-fed	-	-	-	-	-	-

4. Discussion

Our results confirmed the hypothesis that one of the tested acacia species – *A. pycnantha* – may be competitive with eucalypt for biomass production. Nevertheless, the low survival, growth and above ground biomass production observed in *A. dealbata* was surprising, due to the invasive character of this species (Marchante et al., 2005), pointed out as one of the most aggressive in Portuguese terrestrial ecosystems (Ferreira et al., 2011). This suggests that invasiveness may be at least partially related to sprouting, although this species tend to increase its invasive character after fire and/or soil disturbance (Lorenzo et al, 2010), and also in relation to long-term soil-stored seed banks (Gibson et al., 2011). Nevertheless, mutualistic relationships with nitrogen-fixing bacteria were not considered in our study and their absence could influence the low establishment success of this species (Gibson et al., 2011).

Acacia pycnantha confirmed a good potential for early biomass increase even in rain-fed conditions. This may be enough to economically support eradication follow up, as discussed by Kull et al. (2011), through the harvest of young plants to be used as raw material for energy production. Biomass production in this acacia was 1.8-3.4 times higher than that of *E. globulus* 1 year after planting, and almost 5 times in the second year. Eucalypt may have had its production decreased by high soil pH and presence of active calcium carbonate in the soil (a common feature in soils derived from the Lisbon basalt complex), as reported by Aravanopoulos (2010) for irrigated eucalypt plantations in Greece. *Acacia pycnantha* was planted in the past in areas of shallow and dry soils under management of the Forest Authority in Algarve (southern Portugal). It was used for fuel wood, but this type of utilization strongly decreased over the last decades and almost disappeared in that region, allowing good perspectives for bio-energy purposes.

5. Conclusions

Acacia pycnantha had an early biomass production clearly higher than that of *E. globulus* (the reference species in biomass production), suggesting that harvest for bioenergy uses may at least partially support the costs of follow up of seedlings emerging after eradication of larger trees. This may also allow some speculation on the use and conversion of stands of this species that occur in areas of shallow and dry soils in southern Portugal, namely in Algarve, aiming energy production from their biomass. Our results did not confirm a high early biomass production performance of A. *dealbata* and *A. melanoxylon*, apparently due to poor adaptation to the site. Therefore, further research will still be needed to assess whether the site characteristics influence both the feasibility of early harvesting of these species for bioenergy and their mechanisms of invasiveness.

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References

Barreiro S., Tomé M., 2012. Analysis of the impact of the use of eucalyptus biomass for energy on wood availability for eucalyptus forest in Portugal: a simulation study. Ecol Soc, 17(2), 14, DOI:10.5751/ES-04642-170214.

Borges J.G., Borges G.C., 2007. Socio-economic impacts of the expansion of eucalypt stands. In Eucalypt Stands in Portugal: Environmental Impacts and Scientific Research (in Portuguese), Eds. A.M. Alves, J.S. Pereira, J.M.N. Silva, 315-326. ISA Press, Lisbon, Portugal.

CELPA – Associação da Indústria Papeleira, 2012. Statistical Bulletin 2011 of the Portuguese Paper Pulp Industry (in Portuguese). CELPA Editores, Lisbon, Portugal.

Ceulemans R., McDonald A.J.S., Pereira J.S., 1996. A comparison among eucalypt, poplar and willow characteristics with particular reference to a coppice, growth-modelling approach. Biomass Bioenerg, 11, 215-231.

Ferreira S., Gil N., Queiroz J.A., Duarte A.P., Domingues F.C., 2011. An evaluation of the potential of Acacia dealbata as raw material for bioethanol production. Bioresource Technology, 102, 476-473.

Gibson M.R., Richardson D.M., Marchante E., Marchante H., Rodger J.G., Stone G.N., Byrne M., Fuentes-Ramírez A., George N., Harris C., Johnson S.D., Le Roux J.J., Miller J.T., Murphy D.J., Pauw A., Prescott M.N., Wandrag E.M., Wilson J.R.U., 2011. Reproductive biology of Australian acacias: important mediator of invasiveness? Divers Distrib, 17, 911-933.

Grupo de Trabalho do MADRP de Energias Alternativas, 2005. Biomass and Renewable Energy Sources in Agriculture, Fisheries and Forests (Assessment of the Current Situation, June 2005) (in Portuguese). Portuguese Ministry of Agriculture, Rural Development and Fisheries, Lisbon, Portugal.

ICNF, 2013. IFN6 – Areas of Land Use and Forest Species in Continental Portugal. Preliminary Results (in Portuguese). Instituto da Conservação da Natureza e das Florestas, Lisbon, Portugal.

Kull C.A., Shackleton C.M., Cunningham P.J., Ducatillon C., Dufour-Dror J.M., Esler K.J., Friday J.B., Gouveia A.C., Griffin A.R., Marchante E., Midgley S.J., Pauchard A., Rangan H., Richardson D.M., Rinaudo T., Tassin J., Urgenson L.S., Von Maltitz G.P., Zenni R.D., Zylstra M.J., 2011. Adoption, use and perception of Australian acacias around the world. Divers Distrib, 17, 822-836.

Lorenzo P., González L., Reigosa M.J., 2010. The genus Acacia as invader: the characteristic case of Acacia dealbata Link in Europe. Ann Forest Sci, 67, 101-111.

Marchante E., Kjøller A., Struwe S., Freitas H., 2008. Short- and long-term impacts of Acacia longifolia invasion on the belowground processes of a Mediterranean coastal dune ecosystem. Appl Soil Ecol, 40, 210-217.

Marchante H., Marchante E., Freitas H., 2005. Invasive plant species in Portugal: an overview. In International Workshop on Invasive Plants in Mediterranean Type Regions of the World, 25-27 May, Ed. S.Brunel, 99-103. Council of Europe Publishing, Montpellier, France.

Medhurst J.L., Pinkard E.A., Beadlea C.L., Worledge D., 2003 Growth and stem form responses of plantation-grown Acacia melanoxylon (R. Br.) to form pruning and nurse-crop thinning. Forest Ecol Manag, 179, 183-193.

Richardson D.M., Rejmánek M., 2011. Trees and shrubs as invasive alien species – a global review. Divers Distrib, 17, 788–809.

Santos A., Simões R., Pereira H., Anjos O., 2004. Alternative species for the forest industry as forms of diversify the landscape. In II Simposio Iberoamericano de Gestión y Economía Forestal, Barcelona, Spain < www.gruponahise.com/simposio/papers pdf/30 Ofelia dos Anjos.pdf>, assessed 28.7.2009.