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# Short rotation single stem tree crops for energy in the UK – an examination with *Eucalyptus*

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## Summary

Single stem tree crops grown on rotations of less than 10 years have attractions as energy crops. Such rotations appear realistic for many areas of the UK, provided high standards of silviculture are practised. The relatively high basic density of the wood of such crops would have favourable economic impact on delivered cost of the resulting fuelwood. In the UK certain *Eucalyptus* species appear to fulfil the requirements for such crops, and bark-free wood yields of 10-15 oven-dry tonnes $ha^{-1}yr^{-1}$ appear possible on many sites. In 2001 trials of *Eucalyptus nitens, Eucalyptus gunnii* and *Eucalyptus gunnii x Eucalyptus dalrympleana* hybrids were established on six sites in the UK, using high standards of silviculture.

**Key words:** Biomass, fuel wood, renewable energy, short rotation, single stems, United Kingdom, *Eucalyptus*

## Introduction

Forest plantations grown on short (<10 yr) rotations have become a large-scale commercial reality in many parts of the world during the past 20 years. Many of these plantations have been established on agricultural land and the trend of tree crops replacing marginal and loss-making farming seems set to continue. Because these plantations are sited on reasonably fertile and easily worked sites, the types of silvicultural practice that can be applied to them are analogous to those used in arable farming. The rewards are yields and rotation lengths dramatically different to those of traditional forestry. The majority of wood from this new generation of high-yield, short rotation forest plantations is used in the manufacture of pulp for paper, and for reconstituted board products. There are also significant areas devoted to the production of charcoal and some plantations are grown solely for fuel wood. Species are chosen for their ability to respond to intensive establishment silviculture, and for wood properties suited to the intended end use. Yields from these plantations are typically 25 – 45 $m^3$ $ha^{-1}$ $yr^{-1}$ (Bracelpa, 1999; Coetzee & Naiker, 1999; Pereira *et al.,* 1995; J Rodriguez, personal communication). These yields are equivalent to 10 – 22 oven-dry tonnes (odt) $ha^{-1}$ $yr^{-1}$.

*Relevance to the UK*

For energy crops in the UK, this model has several attractions:

- Trees producing high density wood can be grown. Such wood has high calorific value per unit volume. This would have a major impact on the cost of transporting the wood (because transport of wood is usually limited by volume, not weight), and hence on delivered fuel costs. It would also reduce the cost of harvesting.
- Harvesting could be carried out with existing forestry machinery.
- There would be the option of de-branching and de-barking on site, thus permitting the production of clean chips of uniform dimensions, which would be preferred by some customers. There are also good environmental arguments for leaving components such as bark on site.
- The silvicultural requirements of the crops would be analogous to the agronomic requirements of arable crops in the UK. But the general silvicultural requirements would also be applicable on pasture and forestry sites.

The key issues for this model for the UK are the yields and rotations that may be expected, for different genera and species, and for different site types. The authors' experience has been in intensive plantation forestry overseas, particularly in *Eucalyptus*, and we have reviewed relevant information and trials in the light of our experience. We have used this to plan and establish some trial plantings of candidate *Eucalyptus* species and hybrids that we believe are appropriate for the UK.

## Review of existing information

*Forestry Commission trials*

The Forestry Commission established a range of *Eucalyptus* species and provenance trials between 1980 and 1985 (Evans, 1983; Evans, 1986). Following periods of very cold weather in 1981/2, 1984/85 and 1986, the trials demonstrated that the most cold-tolerant species were *Eucalyptus gunnii, Eucalyptus pauciflora* and closely-related species (Evans, 1986). The reported early growth data on the trials would not be a good guide to the potential yield, because weed control was non-existent on some of the trials the authors visited in 1987. Such weeds had very evidently suppressed the tree growth, and would also have greatly exacerbated the effects of frost on more frost-sensitive species (see below). Nevertheless, we have drawn some general conclusions on growth of a number of species, following visits we have made to some of the trials (Table1) since October 2000.

Table 1. *Forestry Commission trials of* Eucalyptus *visited by the authors since October 2000*

| ***Forest/Location name*** | ***County*** | ***Grid Reference*** |
|---|---|---|
| Alice Holt | Hampshire | SU 804423 |
| Exeter | Devon | SX 881826, SX 908829 |
| Neroche | Somerset | ST 224170 |
| Redmarley | Gloucester | SO 747308 |
| Thetford | Norfolk | TL 802901 |
| Tintern | Monmouth | SO 475023 |
| Welbeck | Nottingham | SK 601755 |
| Whiteleigh | Devon | SS 419024 |

*E. pauciflora* and related species. These trees invariably have very low volume growth, good survival and poor form. The form accords with that of all these sub-species in their native ranges in alpine parts of Australia.

*E. gunnii*. Survival of this species is generally good to very good. Where high stocking has been achieved, some very acceptable stands have been produced, for example at Exeter, Redmarley, and Tintern. Form is generally good, and a few individual trees in all trials are large (diameter at breast height (dbh) > 30 cm, height > 20 m). It is unclear whether the variation in growth is a function solely of genetic variation, as suggested by Evans (1986), or also of variation in early growth due to different degrees of weed competition within some sites. Part of the Redmarley site (planted in 1986) was clearfelled for commercial pulpwood in winter 1997/98. At this time the trees were c. 16m, with dbh = 20-25cm: the estimated mean annual increment was c. 25 $m^3$ $ha^{-1}$ $yr^{-1}$ (C Jones, personal communication). The basic density of the wood from trees grown in the UK is 400-500 kg $m^{-3}$ (Evans, 1983).

*E. nitens*. Many trees of this species were killed when young by frosts. However, the survivors are generally large and have excellent form. For example, in December 2000, the larger surviving trees in a small block planted in 1985 at Whiteleigh, near Halwill, Devon (a wet clay site, predominantly planted with Sitka spruce (*Picea sitchensis))* had a dbh >30 cm, despite their growth having been suppressed by weeds in the early years.

*E. delegatensis*. Most trees of this species were killed by frosts when young. However, surviving trees at a site in Exeter Forest, Devon are large with some diameters exceeding 50 cm.

### *Trial established by N Cooling, Devon, in 1993*

Mr Nick Cooling established a trial of *Eucalyptus* species and provenances with ten trees per plot and three replicates north of Tiverton, Devon in 1993. The trial is on a relatively exposed site, c. 130 m a.m.s.l. The site had previously carried western hemlock (*Tsuga heterophylla*) planted in 1961, which had been wind-blown at age 29 yr. The experiment was kept weed-free up to canopy closure, but was not fertilised. In July 2001, the authors measured dbh of all trees, and height of selected trees in order to establish mean and dominant height. Survival was variable, but generally good for the more cold-tolerant species. Trees that had died early in the trial had been replaced, but not always with the same species.

We have not yet fully analysed and interpreted the data, and clearly, the small plots do not allow accurate predictions of the absolute yield potential of particular seed sources. (Richardson & Purse, in preparation). However, it is clear that *E. nitens* has given the greatest volume growth. The potential of this species is indicated by a single line of 18 trees planted in May 1993 on the edge of the trial, alongside an existing stand of Douglas fir (*Pseudotsuga menziesii*), and four months before the main trial was planted. Two trees had died shortly after planting, and had been replaced with *E. delegatensis.* These have vigour similar to the *E. nitens.* Single tree sectioning has not yet been carried out, so volumes have been estimated using yield tables developed by one of us (Richardson) for similar stands of *E. nitens* in Chile. These tables indicated that a form factor of 0.35 would provide a reasonable assessment of merchantable wood (>5 cm top diameter, under bark) volume. Using this, the estimate of yield of the *E. nitens* in the line is 36.7 $m^3$ $ha^{-1}$ $yr^{-1}$ at 8.1 yr (Table 2). Obviously, given the uneven surroundings of these trees, we cannot be confident that this yield could have been achieved with a larger planting on this site. However, the individual trees are evidently vigorous, and thus it is reasonable to assume that merchantable yields of bark-free wood exceeding 30 $m^3$ $ha^{-1}$

$yr^{-1}$ at 8 years can be achieved on this, and more fertile, sites. Assuming the wood at this age has a basic density of 450 kg $m^{-3}$ (Tibbets, Dean & French, 1995; J Rodriguez, personal communication), this equates to >13.5 odt $ha^{-1}$ $yr^{-1}$.

Table 2. *Data on a line planting of 16* Eucalyptus nitens *trees age 8.1 yr, near Tiverton, Devon. Stocking is assumed to be equivalent to 1200 stems $ha^{-1}$, and a form factor of 0.35, which is used in commercial plantations of this species in Chile, has been applied.*

| | |
|---|---|
| Arithmetic mean diameter | 22.3 cm |
| Mean height | 17.4 m |
| Dominant height | 27.8 m |
| Basal area | 49.0 $m^2$ $ha^{-1}$ |
| Volume | 298 $m^3$ $ha^{-1}$ |
| Mean annual increment (merchantable wood) | 36.7 $m^3$ $ha^{-1}$ $yr^{-1}$ |

Other productive seed sources in the trial were *E. dalrympleana, E. fastigata,* and a provenance of *E. delagatensis. E. gunnii* was not included in the trial but a few trees planted at the edge of the trial have survived well, although their growth has been suppressed by a negative edge effect caused by weeds.

### *Shell Research planting of* E. nitens

In autumn 1988, some *E. nitens* seedlings were planted in recently-cut chestnut coppice (Cromers Wood) on the Shell Research farm near Sittingbourne, Kent. The trees subsequently received no maintenance. In October 2000, their mean dbh was 42.4 cm (max. 50 cm), mean height was estimated as 25 m, and merchantable volume calculated to exceed 1.3 $m^3$ per tree.

### *AFOCEL programme in France*

AFOCEL (Association Forêt-Cellulose) began developing and promoting *Eucalyptus* as an energy and pulpwood crop in SW France in 1968 (AFOCEL, 1982). The programme produced some elite clones of *E. gunnii,* and *E. gunnii x E. dalrympleana* hybrids. The former were selected primarily on form and cold-tolerance, but not vigour. The hybrids were selected on growth, form and cold-tolerance, though they are less cold-tolerant than the *E. gunnii* clones. The first year of significant commercial planting was 1984, and most of these plants were killed in severe, cold weather in early 1985. Older trees were damaged by this weather, but generally recovered.

This experience led to the abandonment of the plantation programme in 1985. However, it re-started in 1995, stimulated by industrial demand for *Eucalyptus* pulpwood. This programme is being carried out on set-aside arable land. It includes a risk management strategy to minimise economic consequences of frost damage (Terraux, 2000). Projected yields are 15 $m^3$ $ha^{-1}$ $yr^{-1}$ at 10-11 yr for the *E. gunnii* clones, and 20$m^3$ $ha^{-1}$ $yr^{-1}$ at 8-9 yr for the hybrids. The objective is to produce stems of 20-25cm diameter, because this is preferred by the customer. In the case of the hybrid clones, this means sacrificing considerable yield, because they reach and maintain an annual increment of 30-35 $m^3$ $ha^{-1}$ at c. 8 yr. There is no information available on the basic density of wood of these clones. The annual planting programme in 2001 is approx. 150 ha (J N Marien, AFOCEL, personal communication).

*E. nitens in Chile*

*Eucalyptus nitens* is widely grown as a pulpwood crop by forestry companies and farmers in the XIIIth-Xth regions of Chile, particularly on frost-prone sites. Currently there are 80 000 ha planted (Raga, 2001), mostly on former arable and pasture sites. With good silviculture, it typically produces yields of 35-42 $m^3$ $ha^{-1}$ $yr^{-1}$ when grown on 8-10 yr rotations for pulpwood. Stems have dbh of 20-30 cm at rotation and the basic density of the wood at this age is typically 450-460 kg $m^{-3}$ (J Rodriguez, personal communication).

*Summary, and implications for UK*

The evidence indicates that certain *Eucalyptus* species have the potential to grow well in the UK, and to give yields that are likely to be of interest to growers of energy crops. Rotations of 8-10 years and yields of 10-15 odt $ha^{-1}$ $yr^{-1}$ seem realistic, but shorter rotations may be possible with the more vigorous species on productive sites. The more interesting candidates are *E. nitens, E. gunnii,* and the hybrids generated by AFOCEL. However, it is evident that other species and hybrids may be worth consideration, especially if it appears that they may have denser wood. *E. delegatensis* may be one such candidate, although it has been rejected from most overseas programmes because its inconsistent performance makes it too risky for a commercial venture.

The predominantly maritime climate of the UK, and the quality of many of the sites that could be considered, are more favourable than many of those being used for *Eucalyptus* plantation forestry elsewhere in the world today. The key issue requiring some caution with any *Eucalyptus* taxon is the effect of severe cold weather. The main aspect is the presence of polar air masses since, in most of lowland UK**,** the effect of normal radiation frosts is likely to be small unless the trees are small and unhardened (Evans, 1986). The last occurrence of severe cold weather that caused significant damage to some eucalypts in lowland UK, was in January 1987. Obviously, the next such occurrence, and its severity, are unpredictable. However, as long as the possibility of such events is recognised, appropriate strategies can be developed to minimise the economic impact.

We believe that the use of single-stem biomass crops grown on short rotations deserves further investigation, and that certain eucalypts are good candidates for such crop systems, both practically and economically. Furthermore, because of the past and current experience with eucalypts in the UK, they provide an obvious way to examine the practicalities and economics of growing, harvesting and processing commercial tree crops for energy. In order to test these hypotheses, a multi-site trial has been established, the details of which are presented below.

## Materials and methods

*Eucalyptus gunnii* seed was purchased from Forestry Tasmania. *Eucalyptus nitens* seed was purchased from Forestal y Agricola Monte Aguila Ltda., Los Angeles, Chile. Containerised plants (8000) were raised from this seed by Viveros do Furadouro, Obidos, Portugal, and further *E. nitens* plants were purchased from them. Containerised plants of four *E. gunnii* clones and six *E. gunnii x E. dalrympleana* clones originating from AFOCEL, France were raised by Shell Forestry Technical Services, HRI East Malling, Kent, UK.

There are six major trial sites (brief site description and previous crop in brackets):

Blackmoor Estate, Hants (lower greensand soil, former tree nursery)
Sittingbourne, Kent (clay with flints overlying chalk, apples)
Diss, Norfolk (sandy loam, set-aside)
Thoresby Estate, Notts (two sites, both sandy loam: a) game cover, b) pine)
Retford, Notts (variable depth of sandy loam overlying river gravel, barley)

The sites were prepared in spring 2001. Seedlings were planted by hand in late May and June (August at Blackmoor), and the clones in July and early August. Plant spacing was 2 x 2.5 m (2000 plants $ha^{-1}$) or equivalent for the *E. nitens,* and 1.5 x 2.5 m (2640 plants $ha^{-1}$) for the other material. Spacing trials (1333 – 3700 plants $ha^{-1}$) were included at one of the Thoresby Estate sites and at Diss. The individual seedlots and clones were planted in single blocks on each site, in order to facilitate eventual mechanised harvesting and processing of the different species. Each tree was fertilised with 100g NPK (7:7:7 or similar) shortly after planting. The precise details of site preparation and early silviculture varied according to site conditions, but the procedures used were designed to maximise survival and to maintain weed-free conditions without further soil disturbance, thus maximising the potential for rapid early growth. Part of the Diss site was line-mulched with compost produced from municipal green waste, and part of the Retford site was line-mulched with black polythene sheeting. Unmulched trees were generally planted in 40 or 60cm tree guards to facilitate herbicide use.

## Results

Establishment and early growth of the trials has been excellent. Many of the trees planted by early June were >1.3 m tall by early September 2001 and at Diss, some of the hybrids planted in early July had reached a height of 1.5 m. Weed control has generally been successful, but has required timely interventions. The only establishment problem encountered has been death of plants caused by applying fertiliser too close to the stems; in this case prompt replanting was carried out. We plan to make the first assessments of the trials in 2002.

## Discussion

Clearly, it is too early to draw conclusions from these trials. The survival of trees in their first winter will be an important issue. However, given the precedents, we are confident that these trials will provide a good demonstration of the potential of eucalypts as a biomass crop for the UK.

As noted earlier, we believe that the key to economic success in woody energy crops is to focus on the production of single stems having high basic density. This generally means hardwoods. This standpoint raises a number of other issues. Some of these are summarised below, but full discussion of them is outside the scope of this paper.

- Any tree species that is adapted to the UK climate, and which responds well to high standards of silviculture (particularly fertilisation, and weed control until canopy closure), is a candidate for energy cropping. The potential of native hardwoods, and exotic hardwoods additional to eucalypts, deserves closer attention. However, the low basic density of plantation-grown poplars compared to other hardwoods grown in Europe (Anon., 1999) will tend to make poplars a less attractive option than other responsive hardwood species.

- Clearfelling followed by subsequent coppice rotations is obviously an option, but taking several yields from thinned, longer rotation crops also deserves serious consideration because, like coppicing, it avoids the need for costly re-establishment. Eucalypts are particularly attractive candidates because they will tolerate and respond to high thinning intensities.
- Plantations of mixed species, with thinnings destined for energy and a higher-value final crop, could present interesting economic options to both foresters and farmers.

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