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# Hill weed compensatory allowances: very alternative crops for the uplands

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Aur dan y rhedyn
Arian dan yr eithyn
Newyn dan y grug

A saying of Welsh hill farmers meaning 'Gold under bracken, silver under gorse, famine under heather' (Condry 1966)

*1 Summary*
UK agriculture receives £2.2 billion in subsidies, and various forms of price support permit more than one Mha in the UK to produce food which is surplus to current requirements. Rather than paying grants to drain bogs or control bracken (*Pteridium aquilinum*), it seems possible to introduce a hill weed compensatory allowance (HWCA) to permit farming to continue in the uplands, in a manner that contributes to conservation, and assists fuel rather than food production.

The potential production of biofuels in the UK is examined, and it is suggested that a number of productive weeds like bracken, gorse (*Ulex europaeus*), broom (*Cytisus scoparius*), laurel (*Prunus* spp.) and rhododendron (*Rhododendron ponticum*) could be exploited as energy crops. Some weed species increase soil fertility, or are particularly well adapted to growth in the shade. It is suggested that they could be planted as a coppiced energy crop beneath pruned and widely spaced plantations of light-demanding trees like larch (*Larix* spp.), pine (*Pinus* spp.), or ash (*Fraxinus excelsior*). Co-production of food, fuel and timber would be termed 'agrenforestry'.

*2 Introduction*
Grants of up to 60% of improvement costs are available from the Ministry of Agriculture, Fisheries and Food in the Agricultural Improvement Scheme under 67 headings ranging from 'aprons' to 'yards'. Hill livestock compensatory allowances (HLCA) of up to £62.48 ha$^{-1}$ are payable in Less Favoured Areas, and can be payable on land planted with trees for 15 (soon to be 20) years after the last animal was removed. Grants totalling around £6 million are imminent as a payment for desisting from 'improvement' in Environmentally Sensitive Areas (Beard 1987). The Countryside Commission pays £1.75 M for amenity tree planting (Taylor 1987), and financial and fiscal subsidies for forestry may total around £30 M (Stirling-Aird 1987).

Also, there are the payments for price support and market regulation. Net farming income (NFI) first fell below the level of obvious subsidies in 1983 (Figure 1), and in 1985 the apparent agricultural deficit had widened to £1,060 M (Table 1). Farm incomes were atypically low in 1985, but no account has been taken in these figures of hidden payments to farmers, like tax concessions and free Agriculture Development Advisory Service (ADAS) advice. Furthermore, the use of NFI, rather than management and investment income, makes no allowance for the labour provided by the farmer and his family.

The 1985 figures in Table 1 represent an average subsidy of £58.45 ha$^{-1}$ yr$^{-1}$ on agricultural land (excluding woodlands), and an annual payment of £7,612 to each full-time or part-time farmer.

Given such munificence, what possible objection could there be to paying farmers to grow weeds? Such a payment could fit into Articles 15, 19 or 20 of the European Community (EC) Structures Regulation

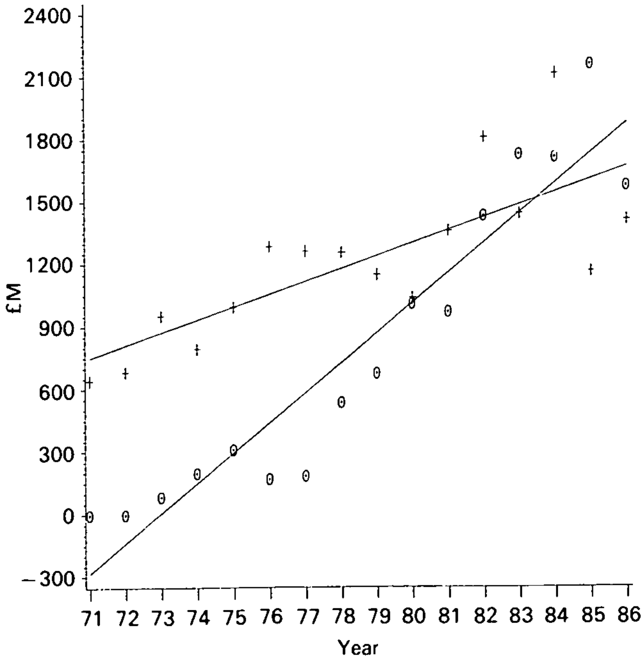


*Figure 1.* Changes in the relationship between net farming income (+) and Government support to agriculture (O) (source: MAFF, DAFS & DANI 1986)

*Table 1.* Support to UK agriculture (£M) (source: MAFF, DAFS & DANI 1986)

| | 1983 | 1985 |
|---|---|---|
| CAP market regulation | 1,374 | 1,893 |
| Support for special areas | 123 | 141 |
| Capital and other improvement grants | 221 | 145 |
| Price guarantees | 10 | 8 |
| Total | 1,729 | 2,215 |
| Net farming income | 1,508 | 1,154 |

(797/85), but Article 20 (Pilot schemes) would probably be the most appropriate. Necessary payments could be given the title 'hill weed compensatory allowance'.

The agricultural surpluses of the EC should be contrasted with the fact that 60% of the timber volume and 45% of the fuel used in the Community must be imported. Clearly, the current use of rural land is not based on sound economics. Yet it is unlikely that the free trade lobby (Howarth 1985) will achieve a significant reduction in the grant support given to rural communities. The farm impoverishment thesis, which propounds price controls as the main check on levels of production, seems even to have lost backing within the present Government. Agricultural subsidies will, therefore, continue as a means of social support, but this paper suggests that they should be partially diverted towards non-food crops. A hill weed compensatory allowance could make these alternative land uses viable on a proportion of the land (up to 2.6 Mha in some estimates (Brown 1987)), which may be 'set aside' from UK agriculture.

## 3 *Fundamental uses of land*

There are 4 fundamental uses of rural land:

- food (animal or vegetable)
- fibre (animal or vegetable)
- fuel
- pharmaceuticals

and a fifth use, fun, which incorporates a number of minor uses like fell-walking and field-sports.

Whilst this publication deals principally with the first 'f', farming for food, this paper will concentrate on the potential of a HWCA to stimulate the production of indigenous biofuel. Brief mention will also be made of the potential use of weeds as a source of chemical raw material.

## 4 *Growing a chemical feedstock*

Until displaced by coal and oil, all organic chemicals were made from biomass. The change took place because of the high and unstable price of biomass, and its dispersed and unreliable availability. Today, many of these factors have changed. In the developed world, plant products (like sugar, soya oil or fuelwood) are cheaper, relative to other raw materials, than they have been at any time this century. Industrial-grade ethanol can be fermented from sugar or grain crops at a price which is comparable with alcohol produced from petroleum. Direct polymerization of lactic acid, and acetic acid fermentation products offer theoretical advantages over the routes using ethanol. The dehydration of lactic acid, for example, could lead the way to cheaper production of acrylics (Sheppard & Lipinsky 1983). Many chemicals could, therefore, be produced more cheaply using the organic acid building blocks contained in biomass, rather than synthesizing them from simple hydrocarbons contained in petroleum. The technology used to produce industrial chemicals is only now improving on techniques which were available before the oil boom (Overend *et al.* 1985). In the long term, therefore, biochemical production may come to be viewed as a more valuable use for biomass than biofuel production.

## 5 *Biofuel production*

### 5.1 Theoretical potential

The total primary productivity of UK terrestrial vegetation is estimated to be 252 million tonnes of dry matter (Mt)[1]. This figure is an average of 10.5 t $ha^{-1}$ $yr^{-1}$, of which above-ground production represents 6.9 t $ha^{-1}$ $yr^{-1}$. Within these totals, intensive agriculture contributes 60%, productive woodland 8%, natural vegetation 26% and urban vegetation 5%. However, only 25% of total plant production is cropped by man and animals, and most of this is subsequently discarded as wastes and residues (Lawson & Callaghan 1983).

Dry biomass contains an average of 18 Gigajoules (GJ)[2] per tonne, compared with approximately 26 GJ and 42 GJ in a tonne of coal and oil respectively. If the annual growth of all vegetation in the UK were to be harvested for energy purposes, the yield would be 2.97 Exajoules (EJ)[3] of energy equivalent, compared to the 1985 UK energy demand of 8.8 EJ. It is hardly practical to use every blade of grass in Britain for energy, so another scenario is presented (Table 2), based on the complete utilization of natural vegetation, wastes, residues and catch crops. This option is purely theoretical, but it suggests that a maximum of 2.11 EJ could be harvested annually, whilst sustaining current levels of agricultural and timber production.

Coming closer to a realistic assessment of the future impact of biofuels is a recent collaborative study, based on the Institute of Terrestrial Ecology's Merlewood land classification (Mitchell *et al.* 1984), in which 6 institutes co-operated to predict the comparative profitability of a number of land uses on statistically selected areas of land throughout the country. The uses considered were: agriculture, conventional forestry, energy forestry, and a modified form of forestry which maximizes the utilization of residues. A wide range of agricultural and forestry costs and returns was modelled, together with several scenarios for movements in energy prices and discount

[1] Unless otherwise mentioned, yield figures refer to above-ground dry weights

[2] One Gigajoule = 109 joules

[3] One Exajoule = 1018 joules

*Table 2.* Maximum biomass resources available whilst maintaining current levels of food and timber production (source: Lawson & Callaghan 1983)

| Type of biomass | Energy content (PJ) |
|---|---|
| Natural vegetation | 700 |
| Catch fuel crops | 382 |
| Crop residues and wastes | 234 |
| Industrial and commercial refuse | 221 |
| Domestic refuse | 170 |
| Urban vegetation | 152 |
| Dual-purpose crops | 80 |
| Sewage sludge | 29 |
| Forest residues and thinnings | 34 |
| Seaweed and freshwater weeds | 8 |
| Total | 2121 |

PJ, Petajoule = $10^{15}$ Joules; 1 Mt coal equivalent = 26.9 PJ; 1 Mt oil equivalent = 49.9 PJ

rates. Constraints on a change of land use were imposed in sensitive areas like National Parks. The results from a central set of assumptions (Table 3) show that up to 4.6 Mha would, at 1977 prices, be more profitably used in energy forestry or in the dual production of timber and fuelwood from residues.

5.2 Energy from trees

Typically, around one-third of the weight of a tree is contained in its stem. The remainder is contained in unharvested portions of lop, top and stump. During the past 10–15 years, rapid technical progress has taken place to increase the recovery of these felling residues. North American whole-tree chipping uses mainly feller-bunchers, skidders and heavy landing chippers; the European approach employs manual felling, forwarder transport and truck-mounted landing chippers. Slash may be chipped with special chippers or crushers; or tree sections may be hauled to the mill and then processed to recover a mixture of bark and branch biomass for fuel. Continuous swath harvestors are being designed to recover slash and small-diameter coppice (Plates 4 & 5). Stump extraction is also an increasingly common part of intensive harvesting.

Using the central economic assumptions in the land availability study (Anon 1984), 8 $Mm^3$ is the maximum 'economic' annual yield of residues which can be achieved from modified forestry in Britain (Table 3). This figure compares to estimates of annually recoverable wood residues in the United States of 170 $Mm^3$ (Erickson 1975), and in Finland of 15.3 $Mm^3$ (Hakkila 1984). In Sweden, around 13 $Mm^3$ of thinnings, lop and top are currently available, but this figure would increase to 28 $Mm^3$ if felling techniques were modified to maximize the recovery of residues (Hakkila 1985).

Energy coppice has been investigated in temperate regions principally using clones of fast-growing species like willow (*Salix* spp.), poplar (*Populus* spp.), alder (*Alnus* spp.), eucalyptus (*Eucalyptus* spp.) and sycamore (*Acer pseudoplatanus*). Its potential in the UK will be principally in the lowlands, but it was estimated in the land availibility study that 300 000 ha of high-grade pasture could profitably be replaced by fast-growing coppice. A reduction in agricultural subsidies would increase the area of land which could be used for energy coppicing, but this increase has not been quantified.

The best UK study of energy coppice comes from Northern Ireland (McElroy & Dawson 1986), where annual yields of 12–15 t $ha^{-1}$ have been achieved over a 9-year rotation of *Salix* x *'Aquatica-gigantea'* (a clonal willow). These experiments were performed on surface mineral-gley soils, which are marginal for agriculture. Nutrients were conserved by harvesting after leaf-fall, but nitrogen fertilizer did produce a 17% increase in yield. However, the value of this increase in production did not offset the cost of fertilizer application. It is interesting to note that the energy output from these experiments is 136 GJ $ha^{-1}$ $yr^{-1}$, compared with a net energy output (utilizable metabolic energy) from grass on comparable land used for beef production of 40 GJ $ha^{-1}$ $yr^{-1}$.

The UK Department of Energy have estimated that fuelwood consumption could increase from 10.4 PJ[4] at present (0.12% of gross energy consumption), to 17.5 PJ by the year 2000. This prediction assumes a continuation of current trends of agricultural and wood production; radical policy changes in favour of forestry or bioenergy production were not considered (Price & Mitchell 1985).

More than 500 000 wood-burning appliances are installed in Britain (Stevens 1984), but many of these are now fueled by coal or anthracite because of difficulties in obtaining and storing a reliable supply of fuelwood. Yet these supply problems are not universal. ADAS in Lancashire, for example, has established a scheme which induced local stove-owners to form a 'co-operative' market for fuel from an area of derelict farm woodland. The householders were guaranteed a regular supply of

[4]One Petajoule = $10^{15}$ joules

*Table 3.* Potential areas of land to be used for energy forestry, and its production before (and after) considerations of non-agricultural land uses (source: Mitchell *et al.* 1983)

| Forest system | Area (Mha) | Weight (Mt) | Volume ($Mm^3$) |
|---|---|---|---|
| Modified conventional forestry | 2.90 (1.1) | 16.0 (7) | 28 (11) |
| Single stem | 1.15 (0.4) | 14.0 (4) | No timber |
| Coppice | 0.65 (0.3) | 8.0 (5) | No timber |
| Total | 4.60 (1.8) | 38.0 (16) | 28 (11) |

seasoned wood, which they could collect as required, and the farmer gained a reliable market (Scott *et al.* 1986).

Mention should be made of the possible exploitation for fuelwood and timber of hardwood species, like birch (*Betula* spp.) and aspen (*Populus tremula*), which are currently regarded as little more than weeds. Birch woods covered 170 000 ha, or 42% of our hardwood forests in 1965 (Phillip 1978), but by the 1979-82 census their contribution had decreased to only 17.5%. Breeding and selection are proceeding to improve the form of birch (Brown 1983), and it is hoped that greater use can be made in the future of the latent advantages of this species, including rapid juvenile growth, self-thinning, and a good tolerance of infertile conditions. In catchments which are suffering the effects of acid rain, birch woods will be much preferable to conifers, because they develop a mull humus, with increased pH, more exchangeable cations and higher earthworm (Lumbricidae) populations (Miles 1986). Natural or artificial mixtures of conifers with birch or aspen are serious sylvicultural practices in central Europe and Scandinavia (Hagglund & Peterson 1985). These broadleaved mixtures are more difficult to manage in Britain than monocultures of Sitka spruce (*Picea sitchensis*), but there are likely to be areas in the uplands where improved strains of birch and hybrid aspen could be used successfully in mixture with conifers. Such mixtures would be very likely to benefit wildlife.

### 5.3 Energy from non-woody plants

Biofuel production strategies for herbaceous vegetation in the UK were studied in a number of reports commissioned by the Department of Energy (see Lawson & Callaghan 1983). Most options considered, such as energy catch crops or sugar beet production, do not relate to the uplands, but one feasible use of the most productive upland vegetation is as an 'opportunity energy crop', which could be exploited without planting effort.

Bracken provides an example of a productive native species, which, although an unpleasant agricultural weed, has the potential to become a viable energy crop (Lawson *et al.* 1986). It is thought to cover in excess of 300 000 ha in Britain, although one estimate puts the extent as high as 591 000 ha (Taylor 1985). Above-ground yields of 11 t $ha^{-1}$ $yr^{-1}$ have been recorded, and a sustained harvesting trial recorded an average 7 t $ha^{-1}$ $yr^{-1}$ during 4 successive years of cutting.

The pedogenic effect of this much criticized weed is important, although understudied. The high potassium content in bracken fronds has long been recognized, and they were the feedstock for potash-extracting kilns which supplied the soap and glass industries. Nutrient uptake rates in a bracken sward can be higher than in many woodlands, particularly for potassium (Table 4). It has also been shown in experimental leaching studies that bracken has a considerable ability to mobilize organic and inorganic phosphates (Mitchell 1973). It is, therefore, suggested that, rather than being a curse which occupies the best land on many upland hills, bracken is, in fact, the cause of much of this fertility. A lack of available phosphorus can limit tree growth in many upland areas, and there may be an advantage in allowing the bracken cover to remain beneath widely spaced light-demanding trees like pine, larch or ash.

Bracken could be harvested as an energy crop in summer, when its high moisture content would indicate anaerobic digestion as the most favourable energy conversion route. Later in the year, it could be harvested as a crop with a moisture content of 40% or less, requiring less drying before compression into briquettes and pellets, or thermochemical conversion to a variety of flammable gases and liquids such as methanol. These processes are described elsewhere (Lawson *et al.* 1984), and some preliminary calculations of the potential profitability of bracken are given in Table 5. With the given assumptions, a farmer collecting and briquetting his own bracken could produce a convenience fuel for the local market for around £55 $t^{-1}$ (1983 prices). On a

*Table 4.* Annual nutrient uptake (g $m^{-2}$) and percentage returned in the annual litterfall in various ecosystems (source: Sponder 1979)

| | | Nitrogen | Potassium | Phosphorus | Calcium |
|---|---|---|---|---|---|
| Heather | Uptake | 2.32 | 0.10 | 0.61 | 0.75 |
| | Litter | 110 | 130 | 33 | 57 |
| Bracken | Uptake | 13.4 | 1.0 | 21.3 | 1.35 |
| | Litter | 82 | 60 | 11 | 96 |
| Scots pine | Uptake | 13.9 | 1.1 | 5.8 | 5.6 |
| | Litter | 90 | 91 | 98 | 87 |
| Beech | Uptake | 7.2 | 0.5 | 4.6 | 3.3 |
| | Litter | 74 | 88 | 48 | 45 |
| Mixed oak | Uptake | 9.2 | 0.7 | 6.9 | 20.1 |
| (*Quercus* spp.) | Litter | 67 | 68 | 77 | 63 |
| Oak/birch | Uptake | 8.4 | 0.7 | 2.6 | 2.9 |
| | Litter | 83 | 75 | 75 | 72 |

*Table 5.* Costings per tonne of bracken (20 GJ or 3.4 barrels equivalent), assuming yields of 6 t $ha^{-1}$ $yr^{-1}$ for direct burning and gasification, or 8 t $ha^{-1}$ $yr^{-1}$ for anaerobic digestion (1983 prices) (source: Lawson *et al.* 1986)

| | Direct burning | Gasification to methanol | Anaerobic digestion to methane |
|---|---|---|---|
| Cutting and collection | £13.00 | £13.00 | £12.80 |
| Crop drying | £9.00 | £9.00 | NA |
| Densification | £26.20 | £8.00 | NA |
| Storage (1 year) | £2.00 | £6.00 | £32.00 |
| Transport (20 km) | £3.00 | £3.00 | £12.00 |
| Conversion costs | NA | £54.00 | £30.00 |
| Total cost | £53.20 | £93.20 | £76.80 |
| Conversion efficiency | 70% | 50% | 45% |
| Total cost per GJ | £3.80 | £9.32 | £8.53 |
| Cost per GJ of conventional fuels | £1.58[1]<br>£3.43[2] | £4.56[3]<br>£10.02[4] | £2.94–5.50[5]<br>£8.90–9.85[6] |

Conventional fuel costs assume: coal to industrial[1] and domestic[2] users, pre-tax[3] and post-tax[4] motor spirit, natural gas[5] at 80–800 therms $yr^{-1}$ (5), and propane[6] from 15–47 kg cylinders

weight basis, bracken briquettes contain only 60% of the energy in coal, but they will become more competitive as the price of coal and oil rises. A consumer preference may be expressed for biomass because of its low ash and sulphur content. It is difficult to predict the likely market for these solid-fuel briquettes, and no attempt has therefore been made to establish the enterprise gross margin.

The production of methane gas (Table 5) is unattractive because of technical difficulties in using a high-solids feedstock, and because of the high cost of storing fresh materials. Methanol production is much more feasible, both economically and energetically, particularly if some part of the petrol tax can be waived. However, non-woody crops currently have to be densified before they can be converted to the gaseous precursors of methanol. This disadvantage is not applicable to fluidized bed convertors, but these have a large intake requirement of around 60 t $day^{-1}$, and may not be appropriate for small-scale rural applications (Beenackers & van Swaaij 1984).

Ethanol production is not viable from bracken fronds (although it would be viable from the rhizomes), because the fermentation requires sugar or starch crops. Sugar beet, cereal grains, potatoes and Jerusalem artichoke are the most likely candidates in Britain. However, the price of fuel alcohol produced from grain in the EC, per unit of energy, is around 3 times that of petroleum. This figure is considerably in excess of the restitution payments for cereals (Sourie & Killen 1986), and it is not an economic option to allow farmers to produce surpluses for conversion into alcohol. That is not to say that the option will not be pursued by the EC, as it is in the USA and Sweden (Penrose 1985). Conversion technology is continually improving, and new physical and enzymatic techniques are being developed to convert refractory celluloses to sugars prior to fermentation (Overend *et al.* 1985). Success with these technologies would dramatically change the economics, and would certainly favour the use of productive herbaceous weeds.

### 5.4 Energy from shrubs and scrub

Shrub and scrub vegetation can have several advantages, in addition to the rapid production of biomass. Gorse, broom and tree lupin (*Lupinus arboreus*) are all nitrogen fixers, and have been used to reclaim mining wastes. They could become useful energy crops on derelict land. Tree lupin is rather short-lived but has recorded nitrogen fixation rates of up to 185 kg $ha^{-1}$ $yr^{-1}$ on china clay wastes (Palaniappan *et al.* 1979). Broom lives for around 12 years, and has been suggested as an energy crop in France, where it would be harvested on a 7-year rotation. With potassium and phosphorus fertilization, a dry matter yield of 15 t $ha^{-1}$ $yr^{-1}$ has been claimed (Tabard 1985). The soil underlying gorse accumulates nitrogen more rapidly than that beneath broom, and 70 kg $ha^{-1}$ $yr^{-1}$ has been recorded in Cornwall (Dancer *et al.* 1977). Gorse would be risky as an energy crop because of the ease with which it catches fire, but 6/8-year-old stands in Britain and New Zealand have accumulated biomass at rates approaching 10 t $ha^{-1}$ $yr^{-1}$. Interestingly, the annual litterfall from gorse is almost as high as the biomass increment, indicating a considerable potential for soil improvement. Sea buckthorn (*Hippophae rhamnoides*) and Sitka alder (*Alnus sinuata*) are examples of nitrogen-fixing species which could be used in very different habitats as energy understories beneath widely spaced, and light-canopied, timber trees.

Laurel species (*Prunus lucitanica* and *P. laurocerasus*), rhododendron, and even holly (*Ilex aquifolium*) are understories which could be used as evergreen energy crops in conjunction with widely spaced timber trees. Holly has an annual recorded productivity of 12.5 t $ha^{-1}$ $yr^{-1}$ in an unshaded portion of the New Forest (Peterken & Newbould 1966), and rhododendron was found to grow at around 10 t $ha^{-1}$ $yr^{-1}$ on nutrient-poor china clay waste (Dancer *et al.* 1977). There have, however, been very few studies in Britain of the productivity in different habitats of these shrubs, and no information exists on the effects of different harvesting or fertilizing regimes.

Another problem with rhododendron is the distaste with which it is viewed by most of our foresters, farmers and conservationists. There are several reasons for this (Shaw 1984).

i. Rhododendron is an introduced alien, and the conservationists worry if such species are too successful. It was, however, native before the last glaciation.

ii. It contains an andromedo toxin which is highly poisonous if ingested. It is thus largely avoided by animals.

iii. Flowering is prolific and 3-7 thousand seeds can be produced from each flower. They are so light that dispersal of several km may be possible in turbulent conditions.

iv. Cutting has little effect on established bushes, other than encouraging coppice growth and the production of layered shoots.

v. Fire tends to favour rhododendron by creating ideal conditions for seed germination, and eliminating competing vegetation.

vi. The establishment of conventional forestry is difficult and expensive.

Rhododendron has the ideal strategy for an invasive weed, and possesses further advantages of an evergreen habit, longevity, freedom from pests and diseases, and a rather wide tolerance of environmental conditions. Once established, it can produce satisfactory growth under 5-10% of full daylight, and its physiological compensation point is less than 2% of full daylight (Nilsen 1986). These characteristics suggest it is an ideal energy crop companion to widely spaced timber trees. Indeed, only a few fully stocked conifer canopies (western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*), Sitka spruce) are able to generate sufficient shade to eliminate rhododendron. It would also reduce the risk of grazing damage to accompanying trees, and would eliminate the need for fencing.

It is, therefore, suggested that widely spaced trees could be established in existing stands of rhododendron, after an initial harvest using a brush-cutter, and subsequent repeated application of contact herbicides around the transplants. Periodic coppicing would take place at the same time as lower branch pruning on the timber trees. The combined effect of shade and cutting would considerably reduce the problem of flowering and seed dispersal.

A general thesis is illustrated by rhododendron: the most productive and resilient energy crops are also the worst weeds. Bracken, cordgrass (*Spartina anglica*) and Japanese knotweed (*Reynoutria japonica*) are other examples in this country, and the value of weeds as producers of bioenergy is starting to be recognized abroad (Gilreath 1986).

*6 Agrenforestry*

This unfamiliar term places energy cropping in its true position: that of a land use which is intimately integrated with agriculture and forestry.

Short-rotation osier beds in Somerset are defined as agriculture by the Town and Country Planning Act, so it is semantically correct to view the coppice-with-standard system which is advocated here as a genuine mixture of agriculture, energy cropping and timber production (agrenforestry, for short). Furthermore, there is considerable potential to use the coppice, pollards, or the prunings from standard trees as fodder for animals. Several tree species have leaf protein concentrations approaching 20% of dry weight, and poplars and willows have proved to have particularly high production of the essential amino-acids for non-ruminant feed (Carlsson 1976). Indeed, it has been the practice for many years in Russia to market dried leaf meal under the name of 'mukka' (Keays & Barton 1975); 300 000 t are fed annually to cattle, poultry and pigs as a direct replacement for 5% of the standard feed. Another innovation from Russia is the use of nettles (*Urtica* spp.) as a fodder crop under Siberian larches (*Larix sibirica*) (Bogachkov 1977).

There are several possible environmental consequences of agrenforestry, and these are examined elsewhere (Callaghan *et al.* 1986). However, it is worthwhile in this paper to select one example of the advantage to wildlife of creating a diverse structure in a woodland. This

*Table 6.* The effect of rhododendron clearance in 1982 on bird populations in the Dinnet Oakwood, Cairngorms. An adjacent area of mixed oak/aspen/birch/bird-cherry serves as a control between years (source: French *et al.* 1986)

| | Rhododendron | | | Other broadleaves | | |
|---|---|---|---|---|---|---|
| 2-year period | 1980-81 | 1982-83 | 1984-85 | 1980-81 | 1982-83 | 1984-85 |
| No. of birds | 20.5 | 5 | 8 | 20.5 | 23 | 20 |
| No. of species | 12 | 6 | 11 | 11 | 12 | 15 |
| 'Bird species diversity' | 2.43 | 1.71 | 2.18 | 2.54 | 2.23 | 2.39 |

*Table 7.* Environmental and economic comparisons of agrenforestry with intensive agriculture and forestry

| | Environmental | Economic |
|---|---|---|
| Advantages of agrenforestry | Increased species and structural diversity<br>Protection from wind and water erosion<br>Leaching and denitrification reduced<br>Floods and temperature extremes reduced<br>Risk of fire reduced<br>Smaller scale favours organic farming<br>Less risk of disease and enhanced biotic control<br>Better access for recreation and sport | Soil mixture conserved at ground level<br>Frost and drought protection<br>Efficient light capture in time and space<br>Better animal performance through shelter from wind and sun<br>Possible use of N-fixing mixtures<br>Yield of some trees is favoured by soil cultivation<br>Utilization of farm labour more evenly through the year<br>Shared infrastructure costs with other land uses<br>Use of by-products easier (eg foliage for feed and slurry for fertilizer)<br>Preservation of rural employment<br>Greater crop diversity and flexibility than forestry<br>More even income flow than forestry<br>Felling can be delayed till market prices rise |
| Disadvantages of agrenforestry | Uniform rows of trees may be unattractive<br>Possible increase in total water consumption<br>More complete harvesting may reduce soil fertility | Greater management effort and use of unknown methods<br>Dispersed production means higher transport costs<br>Yield of main component (eg grain) reduced<br>Less flexible than conventional farming<br>High fertilizer input can damage timber quality<br>Soil compaction and bark-stripping by grazing animals<br>Inefficient weed and pest control<br>Less regular economic return than pure farming |

example shows the dramatic decline in bird species and numbers following the clearance of rhododendron in a Scottish oak wood (Table 6). Even the partial recovery of the population in 1984-85 has been attributed to an influx of 'canopy' species, whose territories were centred on adjacent areas.

A number of advantages and disadvantages for agroforestry can be conjectured (Table 7). Considerable interdisciplinary investigation is required to verify these assumptions, but it is encouraging that an agroforestry research co-ordination group has been established which spans an increasing number of Government institutions and universities.

Perhaps it may be some time before a grant is introduced with the title suggested in this paper, but there is little doubt that the increasing pressure for 'set-aside' of agricultural land will favour the use of both energy crops and agrenforestry.

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