Forestry Commission

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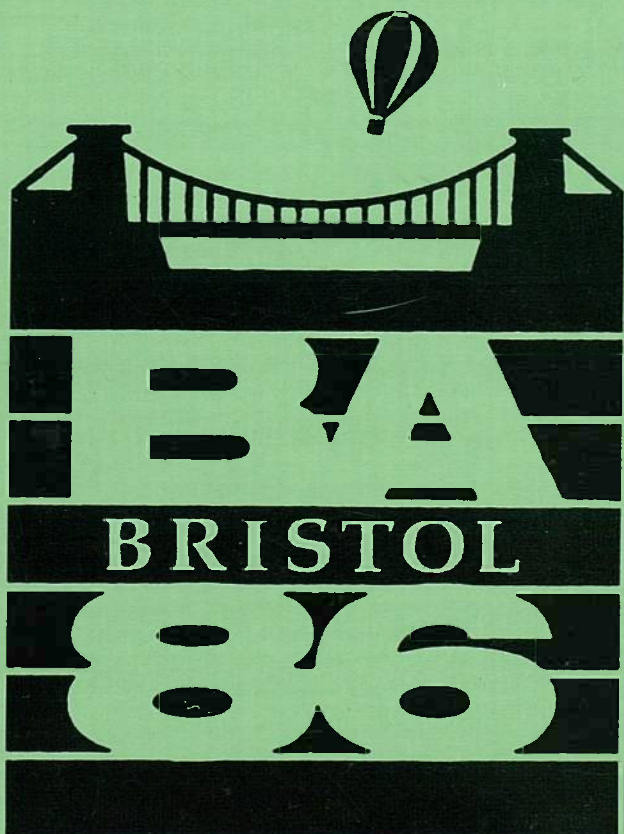
Forestry Section Proceedings

Edited by G C Barnes



British Association for the Advancement of Science

Annual Meeting, Bristol, 1-5 September 1986

FORESTRY COMMISSION
OCCASIONAL PAPER 16

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

ANNUAL MEETING 1986

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Edited by G.C. Barnes
Recorder, Forestry Section

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Enquiries relating to this publication should be addressed to the
Technical Publications Officer, Forestry Commission, Forest Research Station,
Alice Holt Lodge, Wrecclesham, Farnham, Surrey, GU10 4LH.

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Introduction

The British Association for the Advancement of Science was founded in 1831, with the object of strengthening the relationship between science and the public interests. The annual meeting provides a forum where scientists and non-scientists can meet and discuss scientific issues of the day. In September 1986, the annual meeting was held in Bristol, and the Forestry Section organised a varied and topical programme, which attracted considerable interest.

Pressure to reduce the amount of agricultural surpluses seems likely to result in an increase in the planting of new woodland on farmland. This trend comes at a time when many people and organisations have expressed concern over the future of existing small woodlands. It is important that if trees are going to be grown, the objectives of management are clear, and that the trees are grown well. This is as true for the growing of quality oak as it is for the marketing of quality firewood.

The final session was held jointly with agriculture, which is symptomatic of the need for foresters and agriculturalists to work closely together in the coming years.

The meeting was held at the University of Bristol, 2-5 September 1986. The forestry programme was organised by Dr Julian Evans and Gerry Barnes.

Thanks are due to Alan Davies, Ken Stott and staff from the University of Bristol and the British Association for the Advancement of Science for their help in organising the meeting, and to Mr George Holmes for his enthusiasm and help as President.

Gerry Barnes
Recorder for Forestry
British Association for the Advancement of Science

Further details about the British Association for the Advancement of Science can be obtained from:

Dr David Morley
Fortress House
23 Savile Row
London
W1X 1AB

British Forestry — Resources and Resourcefulness

G.D. Holmes, CB, FRSE,
Director General
Forestry Commission

Summary

The paper explores the contribution that science has made to forestry and woodland management and looks at the scientific prospects and limitations for the future.

It explains the reasons why Britain has become so low in self-sufficiency of wood products and charts the steps successive Governments have taken to change this, starting with the creation of the Forestry Commission in 1919. Despite the fact that afforestation in Britain has been deliberately limited to relatively poor and inhospitable sites mainly in the uplands, the paper acknowledges the remarkable achievements of research in solving the practical problems of establishing new forests on such poor types of land. It indicates that in more recent years greater emphasis has been given to research that seeks to improve the quality and yield of timber while at the same time combating pests and diseases, improving manpower productivity and taking account of the increasing awareness of the importance of woods and forests in environmental terms.

In looking at the future of forestry research, the paper addresses the difficult question of assessing the likely priorities bearing in mind the uniqueness of the crop. It suggests that the trend towards more fundamental research will continue and speculates that the fields which are most likely to hold the greatest potential for enhancing forest resources in future will be tree growth — including advances in molecular biology; environmental factors — including research on broadleaves, pests and diseases and soil as well as the effects of afforestation on water, wildlife and the landscape; and research on projects arising from possible land use changes in agriculture — which will hinge on political decisions by Government.

The paper concludes that the overriding prescription for progress is to ensure that people of vision and energy are chosen to lead and conduct research programmes and then given as much freedom as management's accountability will allow.

One of the themes of this BA is 'The Power and Limitations of Science' and I have chosen my title of 'Resources and Resourcefulness' to enable me to tell you something about Britain's forest resources and of the 'resourcefulness' that has and hopefully will continue to be deployed in restoring and improving that resource. In particular, I want to say something about the contribution of science to forest and woodland management and later to speculate on the scientific prospects and limitations for the longer-term future.

Almost the whole of Britain, with the exception of the high mountains and the extreme west and north, has a good forest climate and some 6,000 years ago, before man started to clear land for agriculture, the country was almost totally covered with forest. The process of forest destruction progressed for centuries until by the end of the First World War the area of forest had been reduced to some 4 per cent of the land area and people had become accustomed to upland landscapes that were almost treeless.

The forest area of Britain per head of population is one of the lowest in Europe while the consumption of wood products is one of the highest. There is thus a very low level of self-sufficiency in wood products at about 10 per cent of consumption. A national forestry policy aimed at increasing the production of timber to meet the nation's needs dates only from

1919 when the prime need was to create a forest resource of growing timber for defence reasons. The Forestry Commission was created in 1919 because of the national shortage of timber, and a somewhat delayed recognition of the need to restore at least some of the forest resource decimated in the Middle Ages, the early Industrial Revolution, and finally by World War. The prime purpose of the Commission as the nation's forest authority was to establish and manage forests in the public sector and aid their development in the private sector. Forestry policies have, of course, evolved over the years. So far as wood resources are concerned the objective has shifted from a defence strategy to a commercial strategy, together with increasing stress on the social, recreational and environmental aspects of forests. The latest major review of forestry policy took place in 1980. It concluded that a continuing expansion of forest resources was considered to be in the national interest both to reduce dependence on imported wood in the long term and also to provide continued employment in forestry and the associated industries. Two important ideas underlying this policy are, first the projected rise in demand for timber into the next century coupled with the likely pressures on the world's forests, and second the additions to Britain's forests must preserve an acceptable balance with agriculture, the environment and other land use interests.

The planting achievements since 1920 have been quite remarkable. The area of productive forest has more than doubled from 800 000 hectares to over 2 000 000 hectares, (i.e. from 4-9 per cent of the land area), mostly by planting upland, heathland, moorland and rough hill pastures of very low value to agriculture. The present area of productive woodland is summed up in Table 1.

Compared with almost all the countries in the world our forest area is very small, both in actual and percentage terms. See Table 2.

Table 1. Area of woodland by major forest types - United Kingdom, 1985
Total state and private woodlands

000 hectares

	High forest		Coppice and coppice with standards	Unproductive	Total
	Conifers	Broadleaves			
England	395	422	38	90	945
Wales	395	59	2	10	245
Scotland	871	76	-	70	1017
Northern Ireland	58	9	-	3	70
United Kingdom	1498	566	40	173	2277

Source: Data for Great Britain from *Forestry facts and figures 1984-85*. Forestry Commission, Edinburgh. Data for Northern Ireland from Department of Agriculture, Belfast.

Table 2. Land use - International comparisons

Country	Total area (million ha)	Percentage of total area		
		Forestry	Agriculture	Urban and other
United Kingdom	24.1	9	78	13
Belgium/Luxembourg	3.3	21	48	31
Denmark	4.2	12	68	20
France	54.6	27	58	15
West Germany	24.4	30	50	20
Ireland	6.9	5	84	11
Italy	29.4	22	59	19
Netherlands	3.4	9	59	32
Greece	13.1	20	70	10
USA	912.7	31	47	22
Canada	922.1	35	8	57
USSR	2227.2	41	28	31
Japan	37.1	68	15	17

Sources: GB and UK - CSO *Annual abstract of statistics 1985.*
Other countries - *FAO Production Yearbook* 36 (1982).

The rate of new planting has been fairly steady over the last three decades, with the Forestry Commission carrying out the major part of the programme during the 1950s and 1960s and the private sector accounting for an increasing proportion in more recent years. The area of productive woodland is now 1.15 million hectares or over 50 per cent of the Great Britain total. Throughout the post-war period the encouragement of private planting has been a major aim of Government forestry policy. In the 1980 review of forestry policy the Government decided there was scope for new planting to continue at about the rate achieved in the previous 25 years, that is some 30 000 hectares per annum, with the private sector taking the larger role.

Looking to the future wood production from this expanding resource, new planting now will not affect wood production until the beginning of the next century; until that time wood output will be determined by the cutting plans for the existing forest area. Hardwood production is expected to remain at a level of about 1 million cubic metres per annum over the remainder of this century although active steps are now being taken to supplement our broadleaved woodland resource under the new tres overbark policy to encourage broadleaved woodland announced last October. Our latest softwood production forecasts, on the other hand, show an overall increase of x 2.1 by the turn of the century, see Table 3.

Table 3. Softwood production in UK

Year	Thousands of cubic metres overbark		
	Forest ownership		Total
	Public	Private	
1985	3063	1225	4288
2000	5812	3190	9002

In addition there is a substantial volume that arises in the form of residues on felled sites of which only a very small proportion is currently harvested.

Although these increases in production are substantial by any measure, they still only amount in total to some 10 per cent of the total wood consumption in the United Kingdom, so that there is no question of wood surpluses being produced. The wood-processing industry in Britain is very favourably situated because we are now one of the few major wood consuming countries with an increasing domestic supply of wood. It is, however, important that this growing resource be used wisely and that we should remain in the forefront of technology to enable our wood-processing industries to compete. This will require knowledge, imagination, and the courage to innovate, and I shall return to that theme later.

The original defence strategic reasons for establishing a reserve of growing timber in Britain have, of course, changed and forestry policy is now aimed at economic and social objectives, including supply of raw material to industry and provision of employment in rural areas.

However the type of land being made available for planting has changed very little. This is because until very recently the nation regarded the production of food as an overriding priority, and accordingly limited afforestation to relatively poor and inhospitable sites in the uplands. It is important to recognise this deliberate policy, which directly moulded the type of forests we have today, dictating that the species planted must be both hardy and productive so as to thrive on the infertile and exposed sites available. Conifers best met these criteria, but because of the way in which Britain became separated from the Continent after the last ice age it had very few coniferous species. Introduced species from the similar climatic zone of north west America have proved the most suitable, and the relatively small number of suitable species is typical of the situation found in natural conifer forests in northern latitudes.

Apart from the increasing value of our forest resource as a source of wood and of rural employment, there is increasing recognition of the crucial importance of woods and forests in environmental terms including landscape, wildlife conservation and opportunities for public recreation of all kinds. I have been much impressed, particularly over the last 5 years, by the rapidly-developing awareness in the world of two questions of great importance to forestry in Britain:

1. the finite nature of the world's natural resources and the recognition of wood as a renewable and versatile material; and
2. the environment and its bearing on people's quality of life.

As usual, extremists have vociferous views on both questions. On resources, it is said that oil will run dry in 20 years and even that world wood shortages are just around the corner. On environment, there is criticism on the one hand of the disastrous consequences of forest clearances and on the other of forest planting on landscape, wildlife and water supplies. There is no doubt that the effects of forests on the environment, and in turn, on the quality of life of people, are now much more sharply perceived although many of the values involved are highly subjective and defy precise definition. It is clear that our job as land managers is to help from a balanced view on these questions, a view which recognises both the benefits and costs in both environmental and economic forms.

Forests have to be managed positively with a background of knowledge and understanding if the desired aims are to be met in a way that is sound in the financial, social and environmental senses. In this connection, good research always has and always will have a crucial role to play in providing a sound basis of knowledge on which to base decisions. This is particularly the case in times of uncertainty such as now when so much depends on anticipation and well-informed forecasting of future needs.

The Past Contribution of Research to Forest Management

In the last century there was little managed forest in the modern sense of the word to be found anywhere in Britain. Most of our natural woodland had been destroyed and apart from a number of enlightened landowners who, through their personal interest, had planted forests and experimented with exotic species from different parts of the world, there was no organised forestry in Britain. These few landowners contributed a great deal to our knowledge of what species grow well here and provided a very useful starting point for the organised forest research programmes that began in the 1920s with the formation of the Forestry Commission.

Much of this early research was occupied with solving the practical problems of establishing new forests on the poor types of land that were available, i.e. the land that could be spared from agriculture, mostly heather moorlands and peatlands. The achievements of the research on afforestation techniques has been remarkable. By the 1950s, land in the uplands formerly regarded as useless for forestry was being cultivated and planted as a matter of course, with potential wood yields considerably greater than elsewhere in western Europe and two to three times as great as the yields in Scandinavia.

Since the last war there has been a great acceleration in the tempo of forest research. The Commission established its two main research stations at Alice Holt near Farnham and at the Bush Estate near Edinburgh to conduct and sponsor research primarily to meet the practical needs of forest management. The NERC, mainly through its

Institute of Terrestrial Ecology, but also through support of University workers, embarked on programmes of more basic research in forestry and woodlands. Other organisations who have developed a strong interest in forest research include the Department of the Environment and its Building Research Establishment for work on wood, and the Nature Conservancy Council with its major interest in conservation of forests and woodlands.

In recent years, the problems of afforestation have largely been replaced by those of improving timber quality and yield and managing forests to meet both wood demands and environmental requirements, of protecting the forests against pests and diseases, and of improving manpower productivity by work study and mechanisation. Once again, the impact on practice has been immense. Let me quote some examples.

Compared with agriculture, tree breeding is in its infancy. Nonetheless, large gains in tree quality and vigour have been achieved as a result of research leading to the choice of better provenances or sources of tree seed. Intensification of selection and breeding from superior individual trees holds some prospect for further improvement of tree form, wood yield and quality and reduced susceptibility to some kinds of damage. Research developments in the 1970s have permitted the introduction of vegetative propagation techniques, enabling the breeder to produce improved trees in quantity more quickly. This too is now having an important practical impact.

In the fields of forest protection and wildlife management, research has contributed greatly to the better understanding of the biology of such organisms as red and roe deer, which is crucial if appropriate systems of management are to be adopted. For example, we can now predict with some assurance the population development of red deer in response to various culling practices and changes in forest structure.

Problems can arise not only with indigenous pests but also from new pests, notably those brought in with imported timber. The virulent strain of Dutch elm disease from North America and the European great spruce bark beetle (*Dendroctonus micans*) were introduced to Britain by such means. Britain has led in the development of biological methods of pest control in the forest. An early example was the common fungal disease (*Heterobasidion annosum*) causing stem rot in conifers which can now be controlled in pine by treatment of stands with an antagonistic fungus which is harmless to pine. Other examples include the development of naturally occurring virus diseases specific to particular insect pests. In another field, research analysis has enabled silviculturists to predict the age and height at which forests on certain sites become a windthrow risk and such knowledge has been put to good effect in planning and harvesting programmes.

I have mentioned just these few examples by way of illustration; the fact is that research has influenced practice on a very wide front embracing silviculture, biotic damage and wildlife management, harvesting techniques, wood science and processing etc. Broadly speaking, the main gains have been through increased operational efficiency, increased yield of better quality wood, reduced losses through pests and disease problems and through better understanding of the environmental implications of current forest practices.

In the field of applied research, which has constituted the bulk of the work of the agencies I have mentioned, it is not too difficult to put monetary values on the impact of research. A recent overview assessment of current projects by our Research Division indicated that, excluding environmental gain, a ratio of expected financial benefits, calculated using a 5 per cent discount rate, to costs of the order of 2:1 was being achieved.

It is generally accepted that much of British forestry practice and many of the forests now existing are the direct extension of research activities, the results of which have been applied over the last 65 years or so. I think it is fair to say that the development and the speed of application of new techniques and ideas in forestry have been both rapid and successful. There have been several reasons for this, not least of which has been the absence of long-established forestry traditions and pre-conceived ideas with a consequent willingness to learn and to adopt new practices by management in all sectors. More specifically, the following seem to be the key reasons:

1. the pressing demands for information by those charged with the planting and management of forests on unfamiliar and new ground, which had the effect of focusing rescarch on defined practical problems;
2. the close links between research personnel and forest managers, both in planning research and application of findings;
3. special attention to the form and presentation of published information, including information series designed specifically for users.

The only constant feature in the management of any business today is change. That is an inevitable feature of the times and *demands* a continuous process of innovation by management if it is to cope. This means relevant research with a speedy and efficient process of technology transfer taking the results of the research into practice. So far the track record in British forestry in applying research results is quite good but this will not always be so unless managers retain their drive and willingness to innovate.

The Impact of Research in the Future

What are the likely priorities and practical impact of forestry research in the future? This is not an easy question to answer for forestry because of some of its special features. The first feature is its diversity and range. In essence forestry is a business activity and most of the research has, at its most basic, the strategic purpose of furthering forestry's goals and at its most applied, the role of developing tools and techniques required to serve the operational goals of forest owners. These may be wide ranging from the establishment and maintenance of arboreta and pleasure gardens at one end of the range to the supply of pulpwood to industry at the other. The fact that such activity is largely utilitarian in its purpose does not mean that the pursuit of its goals and the research needed to achieve them is not as intellectually testing as that called for in other branches of research. Forestry calls on the skills of a wide range of disciplines and indeed it is possible to find examples of application of most of the natural sciences and social sciences in forestry research.

The second feature stems from the longevity of trees. The long interval between sowing and reaping in forestry has an effect on man's attitude to growing trees. The peculiar feature of investment in ventures with such long gestation periods made forestry the natural case for the Nineteenth Century German tax collector, Faustman, to base his theory of optimum investment period. Modern investment analysts have exploited methods adopted by foresters a 100 years before. The demands on forestry researchers to anticipate events are peculiarly difficult in an activity where the rate of turnover of the capital stock is typically only a few per cent per annum, so that a manager's errors live with him for decades. The need is clearly for good forecasting so that manager's requirements can be foreseen so well ahead as to enable practitioners to carry out the required action and to deliver the goods and services society will demand many decades into the future. The peculiar features of forestry place premia on two goals; first, shortening the maturation period of trees; and second, development of systems which can, because of their flexibility, meet a variety of demands satisfactorily rather than meet only a limited number with success.

Consideration of the future direction of forestry research cannot be divorced from its application. In so far as forest policy provides a demand, research in forestry is demand led. On some major issues it has to be admitted that the ability of policy makers to give guidance to researchers is, I regret to say, poor. In extenuation of this position one must note that our ability to predict changes in public tastes strikingly is poor, too. The growth of vegetarianism, the nature conservation movement and drug taking illustrate the point. The need for forecasts in these socio-economic fields is pressing. Although some may doubt the validity of a forecast in such difficult areas the need remains to assess the nature and reasons for shifts in taste which have so influenced land use and are capable of continuing to influence it so much in future years. Of all the policy questions now relevant to forestry research, that of the type, scale and distribution of farmland available for tree growing, as opposed to other farm crops, nature conservation or recreation, is the most immediate.

Another area in which attitudes have come to play a significant role is that of relations between water and land use, notably grassland management and afforestation, in the uplands. This matter has become combined with the issue of acid deposition due to air pollution. The responsibilities that such discussions and the surrounding uncertainties place on researchers are considerable. Their speed of reaction and the confidence they engender in the public may determine major investment decisions on new planting of trees, stream management, emission control and drainage practice in the hills.

The Kind of Research Required in Future

Most of the advances in forestry techniques referred to earlier were achieved by applied research and development. Some of the most obvious developments have been made by adoption of this form of enquiry which has followed the classical lines of well-designed field experiments first exploited by agricultural experimenters at Rothamsted and taken up strongly by the Forestry Commission in its experimental programmes on silviculture and forest protection over the past 40 years. This exploitation of variation in responses of different species, provenances and origins of trees to different sites and modifications to sites has, as has already been noted, proved a most rewarding one.

There is now a move towards more fundamental research. Empirical research has served us extraordinarily well during the formation of the new forests but as in any field of enquiry this approach can begin to show diminishing returns and a tendency to elaboration of old ideas and information. There is now a need to understand the growth processes in forests more completely by encouraging more basic research which will in turn stimulate more applied research. To the extent that today's fundamental research delivers novel ideas on which to base tomorrow's applied work then all novel approaches become part of an applied research programme. In 1979, the House of Lords Select Committee on Science and Technology under Lord Sherfield examined the scientific aspects of forestry in some detail and made recommendations which, in brief, were for an increase in fundamental research in forestry and closer co-ordination through the Forestry Commission of the research of different institutions. As a result of this report, the Forestry Research Co-ordination Committee (FRCC) was formed under Forestry Commission chairmanship for the exchange and co-ordination of ideas on research needs and opportunities. The membership was drawn from the Natural Environment Research Council, the Agriculture and Food Research Council, the Nature Conservancy Council, the Agriculture Departments of Government, the Department of the Environment and the Universities.

This Committee has now operated for 5 years and has done some very effective work in helping identify research priorities for the future mainly through a series of sector review groups conducted by selected leading scientists able to take a well-informed long-term view of affairs. So far there have been review groups concerned with research in wood science, farming and forestry integration, broadleaved woodland management, forestry and the environment, and tree physiology. One group is currently looking at research on the effects of biotic factors on trees.

It is against the background of the work of this Committee that I embark on my main purpose today which is to indulge in a forward look to try and indicate some of the fields of science which are most likely to hold the greatest potential for enhancing our forest resources in the future. Despite the fact that this is a highly subjective matter I believe it important and necessary that we exchange views from time to time both on potentials and the prospects of their achievement. This also helps create a climate of informed opinion which can influence decision making in an important way.

It is not difficult to identify spheres in forestry where new techniques are urgently required — techniques of timber harvesting are having to change rapidly to increase output and reduce costs; forests are now larger in area, volume and financial value and are coming under increasing threat from the greater international mobility of insect pests and diseases, which justifies more research into protection techniques; endemic windthrow has become a major cause of lost revenue and we must continue to adjust forest management techniques to minimise losses; deer are as impressed by the new forests as we are, and better control techniques are urgently needed; it is also now an important requirement to enhance the value of forests as habitats for wildlife, as places of public recreation and as more attractive elements of the landscape.

I propose to speculate on the potential for research in three broad fields.

1. Tree growth — considering genetic routes to enhancing the growth and yield of tree species; tree/site interactions and the potential and limitations for site improvement; and the restrictions imposed on growth by pests and diseases.
2. Environmental influences of trees and forests — including the shifting priorities in public opinion on what is considered important.
3. Research on projects arising from land use changes as a result of possible shifts in agricultural policy.

Tree growth

Viewed across our whole range of species and conditions the potential is immense for improving tree vigour, and form, and wood quality, and resistance to pests and disease, as well as improving growing conditions through site treatments of various kinds.

One of the most exciting prospects is tree improvement through developing the genotype. In agriculture, conventional plant breeding has been dramatically successful in increasing and stabilising crop yields over several decades. In forestry on the other hand tree breeding is at an early stage and the potential gains are very high. Much plant breeding has been technology concerned with discovering new knowledge so much as exploiting present knowledge to improve plant performance in a chosen way. The route chosen may be by selection and breeding, by creating hybrid varieties, by inducing mutations — and possibly in the future by employing genetic engineering.

The third quarter of this century has been referred to as the 'electronics revolution'. Many now see the remainder of the century as a 'biotechnology revolution' of similar magnitude and impact on society. The basis of this forecast is the rapid advance in molecular biology and its contribution to our understanding of genetics. As this science develops the prospect and ability to transfer genes directly from cell to cell, from one tree species to another, and even from some other organisms to a tree species could have an important impact on forestry through accelerated tree improvement and possibly improved resistance to pests and pathogens. This could happen by reducing the time required to breed new lines, including resistance to pests, or adverse environmental factors such as drought, overcoming barriers to hybridisation, including inter-specific hybrids with the prospects of rapidly multiplying superior trees by cloning from cell culture. A current example in this field is in the work of Skilling and Ostry in the USA using plant tissue culture techniques to obtain disease resistant forest trees by identifying genetic variation in cultures.

These developments apart, I think it is essential to stress the enormously valuable resource that we possess in the existing wide range of variation within our tree species in all their characteristics of form, vigour, adaptation to site and biotic influences and so on.

At another level, our knowledge of tree physiology is still rudimentary compared with what is known about many crops in agriculture and horticulture and it is almost certain that fundamental work on trees will yield important surprises and offer new prospects for solving practical problems.

We need to know much more about root growth and the physiological processes involved as a key to improved silviculture. Equally our understanding of nutrient cycling and effects of tree crops on soils is thin in the extreme. Only when the processes and their directions and rates under various conditions have been ascertained will we truly be able to say we know what silvicultural treatment — which is after all applied physiology — will yield what consequences. This field is important not only for the production of wood but also for my other subject of environmental influences. One other aspect, wood quality in terms of strength, density, uniformity and so on, is so important to the industry that it is remarkable so little work has been done on the physiology of cambium activity and work on this could open up new fields for early selection criteria for tree improvement. This is well recognised by Professor J.P. Cooper who led one of the FRCC review groups recently. Incidentally, he also stressed the importance of studies of the physiology of ageing in trees. This is largely associated with the difficulty of vegetative propagation from older trees which are demonstrably of higher quality. Indeed, he has pointed out that a better understanding of the factors that control the ageing process is essential if specific trees are to be multiplied by seed or vegetative propagation.

Protecting the forest against loss and damage due to attacks by pests and diseases will continue to be of great importance as can be exemplified by the experience with epidemics over recent years, notably Dutch elm disease, the pine beauty moth and more recently the great spruce bark beetle. These epidemics have emphasised a number of points of principle, including the significance of alien pests on native hosts and vice versa, and the need for the effective monitoring of imports to keep out new pests or variants of them. In practice, high priority has to be given to anticipating problems by monitoring or 'watchdog' activities and to studying life histories of actual or potential pests to ensure that the effects of management practices are properly understood. The field of enquiry is large and complex but one aspect of great potential benefit, both in terms of the environment and crop protection, lies in the use of selective biological pesticides rather than non-selective chemicals. We can expect new research based on the existing excellent work on virus control of forest insect pests at the NERC's Institute of Virology at Oxford — both on the effectiveness of biological control agencies and its environmental implications. I am happy to say that UK research is in the forefront in both aspects. Such developments of course may carry their own dangers and stringent testing of the new techniques is necessary both on grounds of effectiveness and because the long-term consequences of large-scale releases of organisms always require careful consideration. There are many other aspects of protection from biotic factors which I have not time to explore other than to make a passing reference to the importance of behavioural studies in mammals, particularly deer and grey squirrel, to offer keys to better tree protection in future.

However, while considering forest protection I cannot omit reference to environmental factors, notably wind and air pollution. For decades the afforestation programme has been concentrated on the poorer upland soils frequently exposed and poorly drained with the result that wind is a dominant factor in forest management. Research on how to control and minimise damage by windthrow must continue to have a high priority, although of course any shift of new planting to lower ground and better soils will greatly reduce this problem.

Concerning air pollution, public concern has led to a major cause both in survey and experimental research in Britain in the last 3 years. We still have no direct evidence of important effects of air pollution on tree growth in Britain but continuing vigilance is necessary.

Forests and the environment

In Britain, as in most developed countries, the prospect is likely to be one of slow rates of population growth, increasing affluence and leisure and a continuing high demand for industrial wood which is and will continue to be accompanied by increased public and political values attached to environmental outputs of the forest, particularly landscape, wildlife conservation and recreation value. The future prospect is undoubtedly one of a long period of shifting priorities as ideas develop about what society wants from its countryside. In general in forestry these trends are likely to mean much greater emphasis on the forest providing various goods and services at the same time, i.e. 'multiple use management'.

Pursuit of the 'right mix' of objectives is an important requirement and strenuous efforts to achieve it and adjust it if necessary are essential if the support of the general public for forestry development is to be retained. There are two broad requirements each of which involves support from research programmes if these aims are to be achieved:

1. good silviculture to ensure healthy growth of trees at an economic level of production and quality in a way that is suitable in terms of conserving soil productivity;
2. good environmental management in terms of the visual landscape, conservation of nature, soil and water.

These management aims often conflict: pursuit of efficiency favours large-scale simple and uniform methods of work, while pursuit of environmental quality favours small-scale complex and diverse methods. In practice compromises have to be struck and getting it right demands increasing professional skill and sensitivity on the part of managers and more research, particularly on environmental influences. A recent FRCC review group under Dr F.C. Hummel on forestry and the environment recognised very clearly that highly subjective value judgements are involved in assessing what constitutes quality in the environment. Some of the underlying questions are unanswerable except in political terms, and Hummel recognised the need and value of injecting a little more science into the decision making process by two steps namely:

1. by more research on the social and economic relationship of forestry and the environment — including studies on thee changes and trends in social attitudes to help better understand what people want (such analyses, independent of sectional bias, could help in many ways including research planning); and
2. by presenting land use data in a digestible form so that present uses and the likely effect of optional changes in use can be more readily seen.

Concerning specific aspects of the environment, there are several critical fields in which more research is needed.

1. We must know what our forest management is doing to our soils and what are the likely effects of our choice of species, fertilising treatments, choice of harvesting methods and so on, in conserving soil productivity for future rotations. In particular we need to know more about nutrient cycling in trees (especially of nitrogen), and the basic processes of mineralisation and mobilsation of nitrogen, including the role of micro-organisms, which hold the key to fertility of many soils.
2. We need to know more precisely what are the effects of afforestation and forest operations on the quantity and quality of water, and how much any effects matter in practice and what can be done to minimise any adverse effects. The sheer size of water catchment studies in time and space presents great difficulties, but progress has been made in miniaturising the work to help speed it up and fill in gaps in knowledge relating to

different combinations of trees and climate, etc. A special aspect of this important field relates to recent awareness of the effectiveness with which trees 'filter out' atmospheric pollutants, both gaseous and soild — observations which have led to an upsurge in interest in the interactions between forests and air pollution. This subject deserves study, as a factor in tree nutrition, but the immediate concern is that in some circumstances trees may concentrate pollutants to the detriment of the quality of water derived from such forests. The topic is highly complex and work is proceeding to clarify the process of concentration of pollutants in tree crowns and the micro-biological and chemical processes in forest soils.

3. We need to know more of the effects of afforestation and individual forest practices on wildlife and how best to go about the process of its conservation. Volumes have been written on this subject in recent months and in research terms the problem is to know where to draw the line in planning research in such an open-ended subject. All I would do today is to add a plea for a positive and 'experimental' approach to work on these matters, in particular:

a. by devising means of describing the wildlife resource of whole localities or districts so that the effects of land use changes can be quantified and put into better perspective; and

b. by research on the steps that can be taken to enhance the diversity and quality of wildlife in the course of forest management.

It would be wrong for me to omit reference to the effect of forests on landscape as it is a major factor influencing public attitudes. I believe this is well recognised by foresters today and the 'state of the art' in terms of awareness and application of good design principles has improved greatly. I consider the needs of the next decade or so lie primarily in communication of these principles to all concerned, including the farming community who may become increasingly involved in forestry.

Much of the concentration of forestry research in the past 30 years has been on conifers and a recent review group of the FRCC under John Workman has indicated a number of topics in which there is a weakness in our understanding of broadleaved species. In particular, their protection against mammals, notably deer and grey squirrel, and the high potential for clonal selection of trees yielding timber with special properties of grain or colour as well as for improved strains of oak, beech, cherry and birch. Broadleaved trees are of immense importance to the environment in both rural and urban situations. In urban situations there are special problems of managing trees where they are frequently planted on 'man-made' sites, such as motorways, building sites, rubbish tips and so on, and enquiries into questions of long-term stability, detection and prevention of decay and hence tree safety, are important. In such urban situations, the aesthetic values of trees can be extremely high and justify research on special measures including intensive manipulation of growth either physically or chemically.

Changes of land use strategy

The problem of surplus agricultural production is a central issue now and fundamental questions about future land use have to be addressed. One possibility is that some farmland could be converted to woodland. However, so long as afforestation is confined as is currently the case to extensive sheepwalks carrying few sheep per hectare, the of such impact a change on agricultural production would be minimal. However, were it to become acceptable policy to plant better quality land, the effect in reducing agricultural output could be much greater and a whole range of new possibilities of combinations of outputs of food, wood, environmental and social values would open out. This sort of prospect raises new questions, many of which will require research to answer satisfactorily. While it is too early to assess just what the impact would be of such a change of policy, it would be surprising if one result was not that site factors become less dominant, allowing for greater species diversity and productivity of tree growth.

In this connection much depends on political decisions by Government on land use. A positive decision to reduce agricultural production would shift the emphasis in research in forestry into new pesticides, possibly giving a renewed emphasis to work on broadleaves and into the cultivation and management of small woods, and the special problems that apply to them. There would also be greater focus than now on the prospects of agroforestry systems both in the lowlands and the uplands to study the possibilities of gains in farm incomes by growing widely-spaced timber trees combined with sheep or cattle grazings on land suitable for both. There are many questions of species, spacing, pruning, and crop/stock combinations which arise. Similarly, short rotation coppice could be an attractive alternative.

One of the questions that comes to the fore as a result of possible major changes in land use is the question of growing special purpose energy or fuelwood crops, perhaps involving coppicing systems of management. As Melvin Cannell points out in a paper to this meeting, forests like all crops capture only a minute fraction of the solar energy received by the earth. Nevertheless, wood serves as a valuable and often convenient source of energy for domestic heating as fuelwood. This could have special appeal to the farmer and his farm woodland management.

Conclusions

This discourse all started with the concept of saying something about the powers and limitations of science, a major theme of this BA conference. I could go on speculating for a long time about the potential and possible future impact of scientific developments in forestry, and the further into the future one goes the easier it is to speculate. When we get away from the debate some hard-headed research managers have to make their minds up about priorities and selection of research projects for the future. Research project evaluation is a notoriously difficult and famous field for the concoction of bureaucratic and useless procedures. In extremes I have known research workers spend almost as much time in evaluation as in research. The costs of research can be measured fairly readily but the assessment of benefits is difficult. Nevertheless a disciplined effort needs to be made to do this preferably under the four heads of cost reductions, wood production, environmental effects, and scientific merit. However, none of this can detract from the overriding prescription for progress — which is to ensure that people of vision and energy are chosen to lead and conduct research programmes and then give as much freedom as management's accountability to Parliament or the shareholders will allow.

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Harnessing Solar Energy

M.G.R. Cannell
Institute of Terrestrial Ecology (NERC), Penicuik, Midlothian

Summary

Forests (like all crops) harness only a tiny fraction of the solar energy received by the earth. The 'losses' of energy can be traced to the earth's geometry, its atmosphere, the restricted waveband absorbed by chlorophyll, the quantum efficiency of photosynthesis, finite CO_2 diffusion rates into leaves, incomplete light interception, respiration, and partitioning of photosynthates to unharvested plant parts. When all of these losses are estimated, it becomes clear that the range of dry wood yields to be expected is 5—15 t ha^{-1} yr^{-1}.

The measured yields of dry wood produced by productive forests in Britain do, indeed, lie in the range of 5—15 t ha^{-1} yr^{-1}, with surprisingly little difference between conifer stands in the uplands and fast-growing broadleaved trees growing in the lowlands.

With wood yields of 5—15 t ha^{-1} yr^{-1}, fuelwood can provide only a tiny fraction of the energy requirement of the UK. Even if our total area of productive forests produced nothing but fuelwood, this would provide only 2—6 per cent of the UK annual energy requirement.

Trees transform solar energy into chemical potential energy by the process of photosynthesis. The great disadvantage of that transformation is that it is inefficient compared, for instance, with photovoltaic cells; only a tiny fraction of the solar energy reaching the earth per unit area is stored in wood even in the fastest growing forest. The great advantage of wood as an energy source is that the energy is already stored, and can be used at some future time when needed.

In this review I shall, first, trace the path of energy from the sun in space to wood in British forests, and see where the losses of energy occur; from this analysis we can estimate the order of magnitude of energy capture in wood that might be expected. Second, I shall examine the actual measurements of wood production per hectare in Britain for different sorts of trees and forests. Third, I shall use these estimates of wood production to see what proportion of the UK energy requirement could be met from our forests.

Energy from the Sun to Wood — Where do the Losses Occur?

Outside the earth's atmosphere, a surface kept at right angles to the sun's rays receives energy at an average rate of 117.5×10^9 J m^{-2} day^{-1} (1.36×10^3 J m^{-2} s^{-1}) — a figure known as the solar constant. The energy store in wood is about 20×10^9 J t^{-1} dry matter, so the solar constant is equivalent to the production of about 26000 t ha^{-1} yr^{-1}

Clearly, forests produce much less wood than that! So we must explain where all the energy is lost.

In the following analysis I shall follow the approach of Monteith (1972) and estimate the energy losses in six steps: from the sun to the earth's surface, to the energy available for photosynthesis, to a 'theoretical', then a 'potential' and 'actual' production of carbohydrate, and finally to wood itself.

Sun to the earth's surface

A surface outside the earth's atmosphere, that is parallel to the atmosphere above Britain, and rotating with the earth, receives much less than the solar constant, because it is not at right angles to the sun's rays, and because it spends much of its time on the dark side of the earth. At the equator, such a surface receives about 30 per cent of the solar constant all year round, whereas at the latitude of the UK it receives an amount varying from about 5 per cent of the solar constant on 21 December to 36 per cent on 21 June. For the UK we may assume an annual average of 20 per cent.

Solar radiation penetrating the earth's atmosphere is absorbed by:

1. gases in the air itself, particularly water vapour;
2. aerosol particles of soil, salt, smoke, spores, etc; and
3. cloud droplets.

The gases alone absorb about 20 per cent of the solar radiation, and aerosol and cloud take up a further 40 per cent (Figure 1). As a result, only about 40 per cent of the solar radiation at the top of the atmosphere gets through to the earth's surface.

We may summarise the losses in the solar constant due to the earth's geometry and atmosphere in southern Britain (at 50°N) as follows.

Solar constant in space 117.5 MJ m^{-2} d^{-1} ≡ 26 000 t ha^{-1} yr^{-1}
↓
Reduced by earth's geometry (0.20) and atmosphere (0.40)
↓
Incoming radiation at earth's surface 9.4 MJ m^{-2} d^{-1} ≡ 2080 t ha^{-1} yr^{-1}

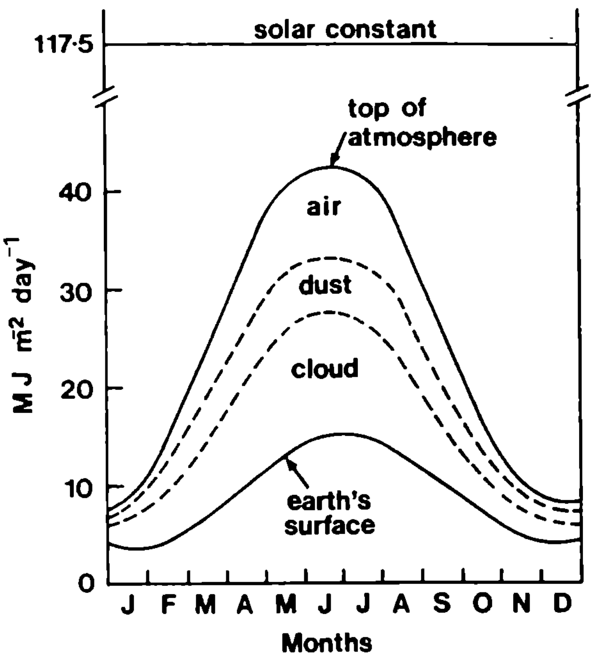

Figure 1. Annual variation at 50°N in the amount of solar energy received at the top and bottom of the earth's atmosphere, showing the losses due to absorption and scattering in the air and by aerosols and cloud.

That is, the average daily receipt of solar radiation at the earth's surface at 50°N is about 9.4 MJ m^{-2} d^{-1} (117.5 x 0.2 x 0.4), which is equivalent to 2080 t ha^{-1} yr^{-1} of wood.

Incoming radiation and amount available for photosynthesis

The process of photosynthesis in green leaves uses radiant energy only in the waveband 0.4 to 0.7 μm, referred to as photosynthetically active radiation (PAR). PAR contains only half the energy of the total spectrum of solar radiation. Furthermore, only about 85 per cent of PAR is absorbed by green leaves; the rest is reflected or transmitted. Thus, we must reduce the amount of whole spectrum solar radiation received at the earth's surface as shown in the box below.

That is, the maximum amount of solar radiation that can be absorbed by chlorophyll in Britain averages about 4.0 MJ m^{-2} d^{-1} (9.4 x 0.5 x 0.85), which is equivalent to 884 t ha^{-1} yr^{-1} of wood.

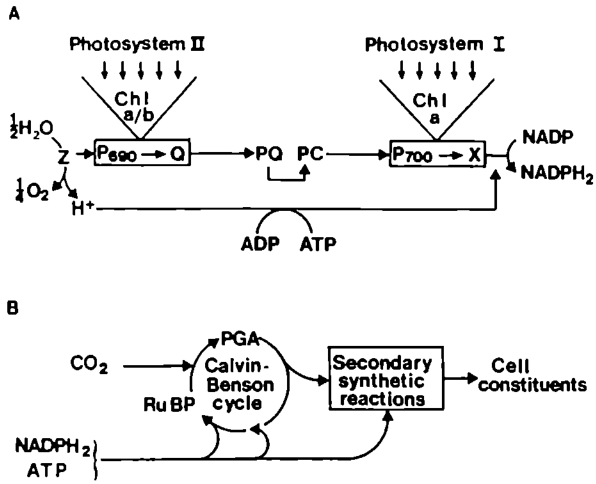

Figure 2. The partial processes of photosynthesis.
A. The light-trapping and electron transport system. Electrons move from left to right, and are released on the left by splitting water.
B. The carbon fixation and reduction system.

PAR and 'theoretical' carbohydrate production set by the photochemical efficiency of photosynthesis

Only a proportion of the PAR energy absorbed by chlorophyll can be converted to chemical potential energy because of inherent limitations in the processes of photosynthesis.

Photosynthesis occurs in two separate processes, illustrated in Figure 2. In the first process, light is trapped by chlorophyll and is used to produce chemical reducing power ($NADPH_2$) and chemical energy (ATP). In the second process, CO_2 is fixed to form carbohydrates in the Calvin—Benson cycle which is driven by ATP and $NADPH_2$.

In so-called C_4 species, CO_2 is first fixed in 4-carbon organic acids before being released into the Calvin—Benson reactions, which occur in 'bundle-sheath' cells where there is a low oxygen concentration.

This 'C_4 shuttle' is of benefit because it increases the concentration of CO_2 at the carboxylation site and because the carboxylating enzymes are protected from atmospheric oxygen so that very little photorespiration occurs. Unfortunately, the C_4 system has not evolved in any tree species (except perhaps for mangrove) and, in any case, the enzyme in the C_4 shuttle has an optimum temperature which is well above the average summer temperature in the UK. Consequently, we must ignore the high efficiencies of tropical C_4 species when considering wood production in the UK.

The maximum photochemical efficiency of the C_3 system illustrated in Figure 2 has been estimated by measuring the rate of photosynthesis of leaves in very weak light. Their photosynthetic rate is then limited by the supply of light quanta to photosystems I and II, and is not limited by the supply of CO_2. In that condition, it takes at least 10 light quanta (sometimes 20) to convert one molecule of CO_2 to one molecule of carbohydrate. The average energy content of one quantum of PAR is 3.6×10^{-19} J, and the energy stored in one molecule of carbohydrate is 7.7×10^{-19} J, so the efficiency of a 10-quantum process is $(7.7 \times 10^{-19}) / 10 \times (3.6 \times 10^{-19}) = 0.215$.

Thus, the flow of PAR energy to a 'theoretical' production of carbohydrate set by the quantum efficiency of C_3 photosynthesis is as shown in the box on page 20.

Incoming radiation at earth's surface 9.4 MJ m^{-2} d^{-1} ≡ 2080 t ha^{-1} yr^{-1}

↓

Reduced by the proportion of PAR (0.5) and leaf reflectance and transmittance (0.85)

↓

Radiation available for photosynthesis 4.0 MJ m^{-2} d^{-1} ≡ 884 t ha^{-1} yr^{-1}

Radiation available for photosynthesis 4.0 MJ m^{-2} d^{-1} $\equiv$ 884 t ha^{-1} yr^{-1}

↓

Reduced by quantum efficiency of photosynthesis (0.215)

↓

'Theoretical' carbohydrate production 0.86 MJ m^{-2} d^{-1} $\equiv$ 190 t ha^{-1} yr^{-1}

That is, if all the PAR received at the earth's surface in southern Britain were absorbed by chlorophyll in tree leaves, and photosynthesis was not limited by the supply of CO_2, then a maximum of 0.86 MJ m^{-2} would be used in photosynthesis per day, equivalent to 190 t ha^{-1} yr^{-1} of wood.

'Potential' carbohydrate production set by the rate of diffusion of CO_2 to chloroplasts

The 'theoretical' photosynthetic efficiency described above can be achieved only in dim light when the absolute rate of photosynthesis is very small. When the light intensity is increased to the levels received on normal summer days, the intercellular concentration of CO_2 must decrease because of the finite rate at which the CO_2 molecules can diffuse to the chloroplasts from the external air and from the sites of respiration within leaves. This decrease in the availability of intercellular CO_2 is responsible for the characteristic shape of the photosynthesis—light response curves shown in Figure 3.

That is, the shape of the photosynthesis—light response curve largely describes the extent to which CO_2 diffusion limits photosynthesis and carbohydrate production. The numerous factors which affect the shape of the curve can be divided into:

1. single leaf or shoot properties, such as the stomatal and internal conductances for CO_2 transfer to the chloroplasts, and the mutual shading of needles on conifer shoots; and
2. canopy properties, such as the numbers of layers of leaves (the leaf area index) and their arrangement in space, which determines how light penetrates the canopy and the light intensity received by each leaf.

Differences in these properties are responsible for the differences in the photosynthesis—light response curves shown in Figure 3. Note that canopies of leaves are light-saturated only on bright summer days, if at all.

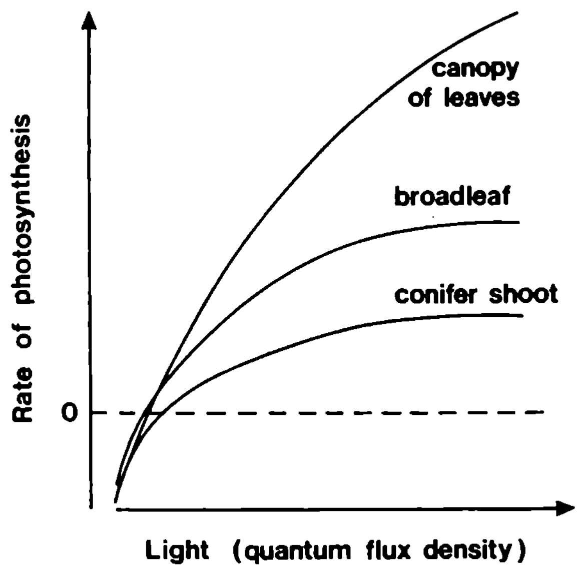

Figure 3. Relationship between light intensity (quantum flux density) and the rate of photosynthesis of conifer shoots, broadleaves of trees, and tree canopies.

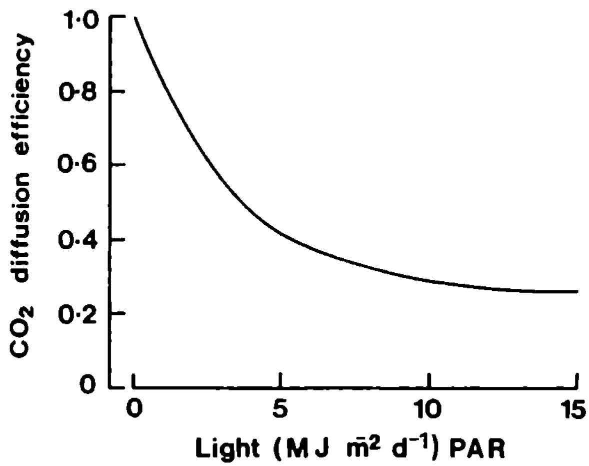

Figure 4. The CO_2 'diffusion efficiency' of tree canopies that intercept solar radiation completely.

The photosynthesis—light response curves can be expressed in an inverted form, showing the decrease in 'efficiency of CO_2 diffusion' to the chloroplasts with increase in light intensity. Figure 4 shows a typical curve for tree canopies. With an average solar energy receipt of 4 to 5 MJ m^{-2} d^{-1} of PAR, a typical 'CO_2 diffusion efficiency' value is about 0.4.

We can now summarise the flow of PAR energy from a 'theoretical' carbohydrate production, limited only by the quantum efficiency of the light reactions of photosynthesis, to a 'potential' carbohydrate production, limited also by the rate at which CO_2 is supplied to the C-fixation reactions of photosynthesis as shown in the box below.

Thus, if all PAR were intercepted and photosynthesis was limited only by light and CO_2 supply, about 76 t ha^{-1} of carbohydrate would be produced per year.

'Actual' carbohydrate production, limited by light interception and winter temperatures

In the real world, photosynthesis is limited by low temperatures in the winter months, deciduous trees intercept light (with green leaves) only in the summer months, and all trees intercept only a fraction of the light while they are young — before canopy closure.

The optimum temperature for C_3 photosynthesis is about 20°C in the summer. This optimum can fall to 10°C in the winter — and some photosynthesis can occur in conifer needles down to -4°C — but, even so, in Britain much of the light intercepted by evergreen trees between October and April cannot be fully used because of low temperatures.

Closed evergreen forests of Sitka spruce intercept almost all PAR all the year round. Pines, however, intercept an average of only about 70 per cent, with some seasonal variation (Figure 5). Deciduous woodlands intercept about 30 per cent during the winter months (by stems and branches) and 75—85 per cent for a short period in summer (Figure 5).

The differences in light interception at full canopy cover between species are due to differences in leaf area index and canopy architecture.

The proportion of light intercepted by *green leaves* (as opposed to leaves and stems) is about 30 per cent less than the values given in Figure 5.

Losses due to:

1. poor light interception;
2. interception by woody tissues rather than by leaves; and
3. low temperatures, are highly variable.

An average figure for the 'interception efficiency' of annual agricultural crops in Britain is about 0.3. For trees, we may assume an average value over a rotation of about 0.4, to give the next step in our analysis as shown in the box on page 22.

'Theoretical' carbohydrate production 0.86 MJ m^{-2} d^{-1} ≡ 190 t ha^{-1} yr^{-1}

↓

Reduced by the rate of diffusion of CO_2 to chloroplasts (0.4)

↓

'Potential' carbohydrate production 0.34 MJ m^{-2} d^{-1} ≡ 76 t ha^{-1} yr^{-1}

'Potential' carbohydrate production 0.34 MJ m^{-2} $d^{-1} \equiv 76$ t ha^{-1} yr^{-1}

↓

Reduced because only a proportion of light is intercepted (0.4)

↓

'Actual' carbohydrate production 0.137 MJ m^{-2} $d^{-1} \equiv 30$ t ha^{-1} yr^{-1}

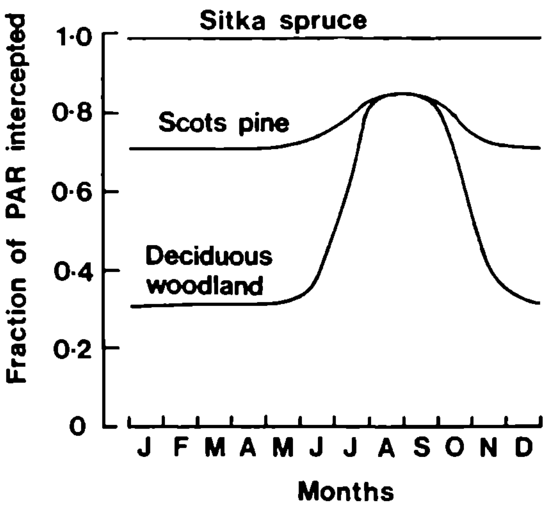

Figure 5. Seasonal changes in the fraction of total solar radiation intercepted by closed canopies of Sitka spruce, Scots pine and deciduous woodland in Britain.

'Losses' due to respiration and partitioning to non-woody parts of the tree

Some of the 30 t ha^{-1} yr^{-1} of carbohydrate is used in respiration associated with the maintenance of existing tissues, some is used in respiration associated with the growth of new tissues, and some is built into new cells and tissues. Losses due to maintenance respiration in trees are more a function of the surface areas of stems and branches, rather than of their mass, and, in the relatively cool British climate, the average loss of carbohydrate is only about 15 per cent (i.e. the efficiency is 0.85). Losses due to 'growth respiration' are quite high for trees, because woody tissues are costly to build; a reasonable estimate for the so-called 'growth efficiency' of trees is 0.7. Thus, the total fraction of carbohydrate not used in respiration is $0.85 \times 0.7 = 0.6$.

The remaining carbohydrate which is built into new cells and tissues is shared among the shoot, cambial and root meristems, and among the sites of storage. A substantial proportion is used to maintain the turnover of both leaves and fine roots, and there are inevitable losses from predation and mortality. On infertile sites, about 60 per cent of the carbohydrate may be used in fine root turnover, whereas on fertile sites only 15 per cent may be so used. Foliage production is also variable, and for each unit of foliage, a unit of branchwood has to be produced to support it. A reasonable, but arbitrary, figure for the proportion of net carbohydrate partitioned to wood (stems and branches) in a well-managed fuelwood plantation is 0.6.

Thus, we may complete our analysis as shown in the box on page 23.

In conclusion, we see that only 0.05 MJ m^{-2} d^{-1} of solar energy is likely to be fixed and stored as chemical energy in wood in Britain, equivalent to about 11 t ha^{-1} yr^{-1} of dry wood. Note that 0.05 MJ m^{-2} d^{-1} is only 0.04 per cent of the solar constant (117.5 MJ m^{-2} d^{-1}) and only 0.5 per cent of the average incoming total solar radiation received at the earth's surface in Britain (about 9.4 MJ m^{-2} d^{-1}). There are, clearly, opportunities to increase this efficiency by increasing and improving light interception, and by increasing partitioning to wood, as well as by changing the basic photosynthetic properties of leaves, but we are certainly dealing with an inherently inefficient light harvesting system. Yields of dry wood of only 5—15 t ha^{-1} yr^{-1} are to be expected. Let us now examine the range of yields that have been measured.

Measured Wood Production in Britain

There are three sources of data which will give us estimates of the range of wood production values measured in Britain.

First, regional and national average rates of harvestable stemwood production can be derived from Forestry Commission yield tables. If we

Actual carbohydrate production 0.137 MJ m^{-2} d^{-1} ≡ 30 t ha^{-1} yr^{-1}

↓

Reduced by respiration (0.6) and the proportion partitioned to wood (0.6)

↓

Wood production 0.0495 MJ m^{-2} d^{-1} ≡ 11 t ha^{-1} yr^{-1}

consider Sitka spruce, with an average annual yield of 10—15 m^3 ha^{-1} yr^{-1} of stemwood, and a basic wood density of 0.4 kg m^3, the mean production of dry harvestable stemwood is 4—6 t ha^{-1} yr^{-1}. If we add branches, total above-ground wood production is about 5—7 t ha^{-1} yr^{-1}, averaged over a rotation. A very productive stand in 'yield class' 25 m^3 ha^{-1} yr^{-1} might produce 10—12 t ha^{-1} yr^{-1} (bearing in mind a probable decrease in wood density). Very few long-rotation broadleaved woodlands, including poplars, are likely to exceed this average production.

Second, there have been several studies in which the woody biomass production of mature forests and woodlands have been measured directly. The data from those studies are given in Figure 6. For most species the average production over the rotation has been 5—10 t ha^{-1} yr^{-1} of stems plus branches. The high value for Sitka spruce was obtained for probably the peak year of production, and the average production of that stand was probably 10—15 t ha^{-1} yr^{-1}.

Third, there have been a few studies to investigate the production of intensively managed short rotation stands of willow, poplar and other trees with rapid juvenile growth. The maximum yields of wood from poplars (established from cuttings) growing at close spacing in fertile agricultural soil was about 50 t ha^{-1} over 5 years. Willow grown in fertile compost with trickle irrigation and nutrition produced 9 t ha^{-1} in its first year. It should be noted that these yields, of 9—10 t ha^{-1} yr^{-1} are *not* greater than those achieved by Sitka spruce stands growing in the uplands in much less favourable conditions.

In the willow study, dry matter production was linearly related to the amount of solar radiation intercepted by the canopy. About 2.0 g of woody dry matter was produced per MJ of PAR intercepted. In a normal year in southern Britain it is conceivable that 1000 MJ m^2 of PAR could be intercepted in ideal conditions, giving 20 t ha^{-1} yr^{-1}, but there are very few reliable measurements of such high yields, and they are unlikely to be achieved in operational conditions.

In conclusion, the average wood production of the more productive coniferous and broadleaved forests in Britain is about 10—15 t ha^{-1} yr^{-1}, which is the same order of magnitude expected from the analyses of energy capture given above.

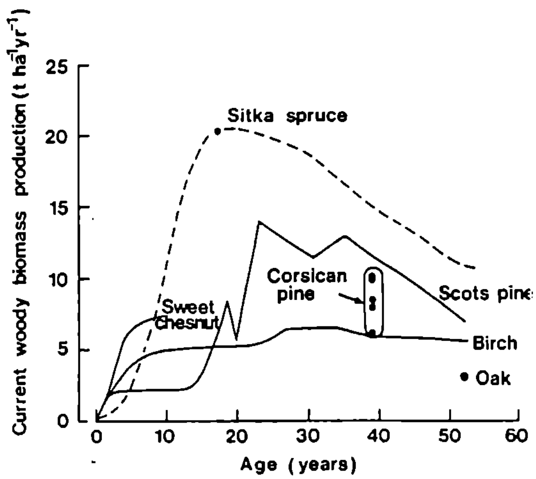

Figure 6. The measured current annual production of dry stem and branch wood of forest and woodland stands in Britain.

Fuelwood — What Proportion of the UK Requirement?

If we accept that, in operational, 'real-world' conditions, the annual yields of wood in the UK are no greater than 15 t ha^{-1} yr^{-1}, what proportion of our energy requirement could be met from our forests?

As mentioned, the energy content of wood is about 20 x 10^9 J t^{-1}, so forests producing 5—15 t ha^{-1} yr^{-1} harness 100—300 x 10^9 J ha^{-1} yr^{-1}.

The total energy contained in 'primary' fuels (i.e. coal, oil, etc. before conversion to electricity, petrol, etc.) that are consumed in the UK each year is about

9×10^{18} J yr^{-1}. Figure 7 shows what proportion of this annual consumption would be met by up to 4 million hectares of forests yielding 5—15 t ha^{-1} yr^{-1} of wood.

If our total existing area of productive forest of nearly 2 million hectares was devoted to fuelwood production, this would represent only 2—6 per cent of our annual energy requirement. The actual area available for fuelwood production is likely to be less than 0.5 million hectares, providing less than one per cent of our annual energy requirement.

This reality is not always appreciated by those who focus on the limited energy needs of households or small enterprises. Also, the picture is quite different from country to country, depending on the land area available and total energy requirement. For instance, Ireland consumes only 3.5 per cent as much energy as the UK, but has about 30 per cent as much land area; thus Ireland could supply about 10 per cent of its energy needs from fuelwood plantations on only 2—3 per cent of its land. The Netherlands, on the other hand, would need to devote about 40 per cent of its land to forests to meet 10 per cent of its energy requirement.

Reference

MONTEITH, J.L. (1972). Solar radiation and productivity in tropical ecosystems. *Journal of Applied Ecology* **9**, 747-766.

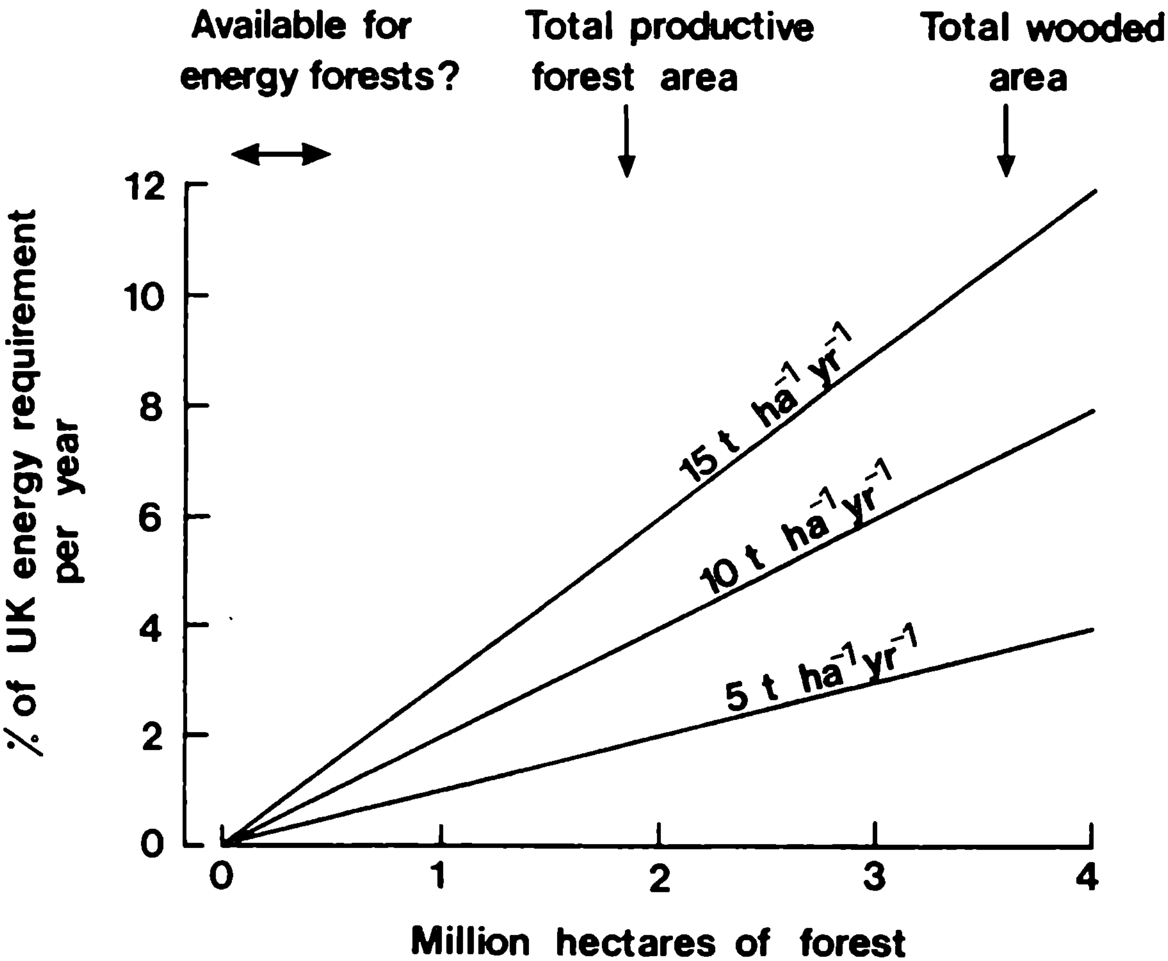

Figure 7. Percentage of the total UK primary energy requirement that would be met by up to 4 million hectares of forest yielding 5, 10 or 15 t ha^{-1} yr^{-1} of dry wood.

Wood as Fuel for the Home

G.D. Keighley
Fuelwood Consultant

Summary

Dry wood, burnt efficiently, produces little smoke and no acid rain. It is a valuable source of renewable energy for users and growers at a price that is competitive with other fuels.

Wood and peat were the main fuels in Britain until increasing population and industrialisation made coal the major fuel followed by gas, electricity and oil. The woodland area is limited but, by efficient management, a substantial quantity of fuel is available from parts of trees which are not suitable for saw timber.

All domestic fuels burnt in efficient stoves or boilers provide adequate heat but there is a significant range of capital outlay and running costs. Mains gas is cheapest; oil, bottled gas and electricity require similar capital outlay to mains gas but have higher annual costs. Wood and coal stoves have higher capital outlay, but lower annual costs recoup the extra outlay in 3—5 years.

Fresh felled wood contains 45 per cent of its weight as water for broadleaves and 60 per cent for conifers; air dry wood has lost the water in the cells reducing the moisture content to 26 per cent for all species. This is achieved at low cost by felling in the previous winter, stacking on a sunny site, splitting and storing under cover in the autumn. Wood burns by driving off the 26 per cent moisture to become oven dry and with primary air to hydrocarbon gases and charcoal; with hot secondary air gases burn to carbon dioxide and steam. The charcoal burns with primary air to carbon dioxide and ash. If the hydrocarbon gases do not all burn due to lack of air and the chimney is not hot enough, then steam and gases condense as tar. This is avoided with an efficiently operated stove and an insulated chimney.

A reliable fuelwood industry depends on good co-operation between grower, user and merchant in each locality. Wood burning stove centres are willing to act as clearing houses for information on supply and users are encouraged to order 6 months ahead. A *Code of practice for fuelwood merchants* is being adopted which includes definition of a 'solid' cubic metre and guidance to users to check the quantity delivered. The Forestry Commission leaflet *Wood as fuel* and the *Code* are available for growers, users and merchants; they have been widely distributed by merchants and stove centres to users in south England, where lists of suppliers have been compiled for each county. Extension to the rest of Britain is planned.

Larger houses, farms and business premises usually require automatic stoking of furnaces and this can be provided with wood chips/chunks from material, which is too small for logs from felling sites. Many firms have mobile chippers and can deliver or can contract to produce chips for growers.

Wood sold for fuel as logs or chips can make a positive contribution to the net income from woodland and trees, especially in those localities which are remote from coalfields or pulp and chip mills.

Reference

KEIGHLEY, G.D. (1987). *Wood as fuel – a guide to burning wood efficiently,* third edition (4 pp.). Forestry Commission, Edinburgh.

The Potential for Wood as Fuel in the UK

L. Martindale
Energy Technology Support Unit,
AERE, Harwell, Oxfordshire

Summary

The potential for wood as fuel in the UK is discussed, with particular reference to two desk studies commissioned by the Department of Energy under its Biofuels R&D Programme. The implications for changes in land use from agriculture to new types of energy forestry, including modified conventional forestry and short rotation coppice, are considered. Current R&D programmes concerning growth, production, harvesting, processing and combustion are reviewed. Emphasis is given to the industrial and commercial markets for fuelwood.

Introduction

During the last decade the Energy Technology Support Unit (ETSU) has been conducting research on behalf of the Department of Energy to determine the technical and economic potential for a range of renewable energy sources in the UK. Of these bioenergy has consistently appeared attractive, both in the short term and in the longer term, as a potential source of heat and fuel.[1]

The bioenergy resource comprises organic wastes and energy crops. In the short term the use of wastes (such as residues from forestry) as fuel could contribute around 5 Mt cepa (million tonnes of coal equivalent per annum) nationally, and a strong programme of demonstration projects and supporting RD has been instigated to develop and promote this area. In the longer term, however, it is energy crops (specifically short rotation forestry) which show the greatest potential. Moreover the increasing problem of food surpluses within the EEC may create opportunities for land to be used for forestry.

In normal forestry practice residues in the form of tops, branches, roots and stumps are generated during harvesting and are usually left in the forest. These can be recovered following and during harvesting. In the UK, however, except in exceptional circumstances it will not be possible to recover roots and stumps, as to do so would lead to unacceptable damage to the soil.

Residues are also generated in the sawmilling and secondary wood processing industries. Much of this residue already finds a ready market in chip and particleboard manufacture.

As well as taking the opportunity of recovering forest residues, forests can be planted and managed specifically with the aim of producing an energy product as well as a more conventional forest product such as sawlogs. In this fashion early thinnings and residues from later thinnings and clear fell could all be recovered for energy (modified conventional forestry); the actual proportion removed would be determined by market forces.

Forest biomass can be grown under short rotation intensive culture and the whole crop harvested for energy. Coppice, which relies on the ability of many broadleaved trees to regrow from cut stumps, requires fertile lowland sites. These can be grown on cutting cycles (intervals between harvests) of 2—5 years. Single stem energy plantations, however, are more suited to less fertile and upland sites and are grown on longer rotations (up to 20 years) than coppice.

[1] *Prospects for exploitation of the renewable energy technologies in the United Kingdom.* ETSU R30, 1985.

The potential supply of wood for fuel therefore comes from two main sources:

1. existing forests and industries; and
2. from new purpose-grown forests.

In order to try and establish a realistic estimate of the potential supply of wood for fuel two studies were commissioned. The first, *Wood utilisation systems – combustion strategies*,[2] examined the short-term (up to the year 2000) potential supply of wood from energy from existing woodland and attempted to match this with demand. The second, *Growing wood for energy in Great Britain*,[3] examined the potential availability of land for growing trees for energy and its resultant supply of wood for energy and traditional uses. The two reports are discussed below.

Wood Utilisation Systems — Combustion Strategies

This study examined the potential of using existing wood resources for energy purposes in the UK

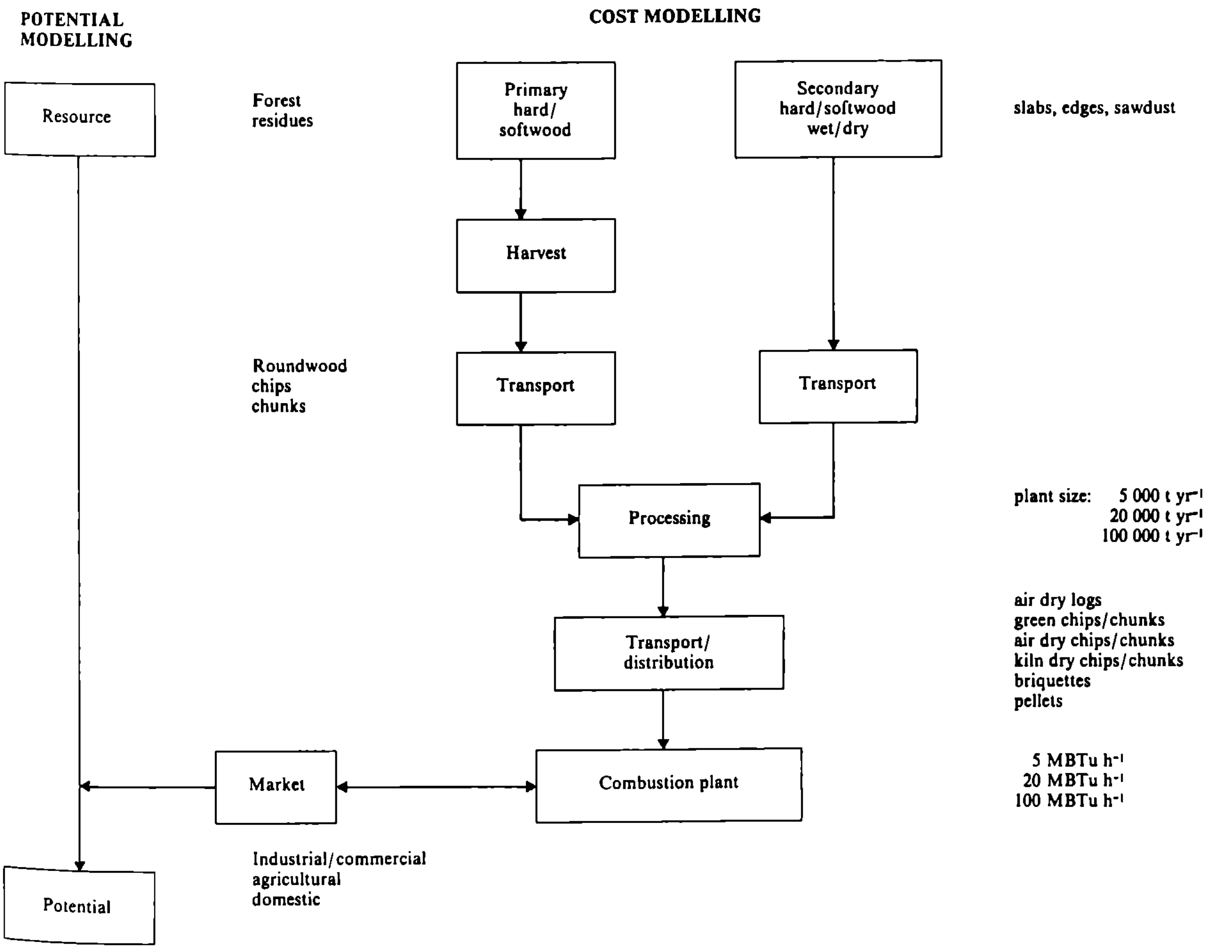

Figure 1. Schematic diagram showing stages in determining potential.

[2] *Wood utilisation systems – combustion strategies.* A study carried out on behalf of ETSU by W.S. Atkins and Partners and IFSC. ETSU B1122, 1986.

[3] *Growing wood for energy in Great Britain.* A study carried out on behalf of ETSU by ITE, Forestry Commission, Aberdeen University, Centre for Agricultural Strategy and Dartington Amenity Research Trust. Due for publication shortly.

(including Northern Ireland which was not covered in *Growing wood for energy*). Two classes of resource were identified: those arising in the forest and woods themselves, i.e. from scrub woodland, thinnings, tops and branches, for which there is no current commercial outlet (primary arisings): and those residues arising in the wood processing industries (secondary arisings). The quantity and distribution of wood suitable for use as fuel was estimated, using Forestry Commission data supplemented with field survey and questionnaire-derived (secondary arisings) data.

It was concluded that of the total growing stock of 334 M m^3, 111 M m^3 is unsuitable for industrial manufacturing use and represents a potential supply of wood for fuel. Consuming 90 per cent over 20 years would provide an annual yield of 1.3 Mt ce and this together with 0.6 Mt cepa arising from the timber processing industries gives a total yield of about 1.9 Mt cepa. Over two-thirds of this total is produced in just four areas of the UK - south and west England, central England, Highland Region and the Borders Region.

It was concluded that some 385 000 t cepa of wood fuel is used currently and that the major potential for expansion lies with the utilisation of primary arisings. Secondary arisings already find a ready market.

The main concern of this report was the development of a series of strategies to supply combustion plants of three sizes: 5, 20, 100 MBtu h^{-1} (1.5, 6, 30 MW respectively) boilers. These would either be supplied direct from the forest or via a processing plant (again of three sizes: 5, 20, 100 thousand tonnes per year) producing a range of products from wet chips to pellets. Separate strategies were developed for hardwoods and softwoods, hardwoods having a slightly higher calorific value. Elements in the strategies included harvesting, transport to the processing plant, processing and storage, transport to the user and finally the 'burning penalty' of using wood instead of coal (Figure 1). The strategies were costed in both money and energy terms. Comparisons between the use of wood and coal were calculated in pence per gigajoule.

Supply of green and air-dried hardwood forest chips into the 5 and 20 MBtu h^{-1} combustion plant was considered economic. Use of softwood green and air-dried chips in the same size boiler was under some circumstances marginally economic but use in the 100 MBtu h^{-1} boiler was not economic at all. (The hardwood resource is not sufficiently large to supply such a facility.) Production of the more heavily processed wood fuels such as kiln-dried chips, briquettes and pellets appeared not to be economic at the scale of operation envisaged and the costings used.

Using these findings and the relationships developed in the report concerning population and woodland density (for which a series of zones were defined) the number of combustion plants that could be accommodated in each of the zones was estimated. Three market sectors were considered:

1. industrial and commercial;
2. agricultural; and
3. domestic.

For the short-term potential from both primary and secondary arisings the following factors were considered: overall resource available; resource distortion and accessibility; user distribution; regional wood fuel cost variations and regional coal cost variation. Hence the overall national potential for use of wood fuel could be estimated (Figure 1). On the basis of these cost estimates and 1981/82 energy prices some 651 000 t cepa could be used by the year 2000. This consists of a domestic consumption of 310 000 t cepa, industrial and commercial 251 000 t cepa and agriculture 90 000 t cepa. The supply would come from non-commercial woods (210 000 t cepa), commercial plantations (256 000 t cepa) and secondary arisings (185 000 t cepa) — shown in Table 1.

The major factor limiting the potential for wood as fuel in these markets is their geographic mismatch with the wood supplies. Hardwood primary arisings and all secondary arisings offer most significant potential, since much of the softwood primary arisings are sited in areas of low population density (and hence low industrial and commercial activity). This is illustrated in Table 2, which describes the potential future industrial and commercial use of wood as fuel by zones and by primary and secondary arisings.

The most significant costs affecting the potential for wood as fuel are harvesting, transporting and processing costs. Changes in woodland management, e.g. by integrating the harvesting of timber and fuelwood, could lead to reduced overall costs and hence an improved potential.

The longer-term potential was examined in relation to:

1. improvements in the technology of silviculture, harvesting, preparation and combustion;
2. expansion of wood processing industries increasing the availability of both primary and secondary arisings; and
3. changes in the cost relations between competing fuels.

The analysis suggested that in general, developments will lead to increases in the economically available fuelwood. However, it was considered that the greatest potential lay with the establishment of coppice energy crops on marginal land.

Table 1. Estimated annual wood fuel consumption by year 2000

(1000 t ce yr^{-1})

Market		Primary arisings		Secondary arisings	Total
		Non-commercial	Commercial		
Current	Industrial	-	-	55	55
	Domestic	120	45	85	250
	Agricultural	80	-	-	80
	Total	200	45	140	385
Future	Industrial	-	101	150	251
	Domestic	120	155	35	310
	Agricultural	90	-	-	90
	Total	210	256	185	651

Table 2. Potential future industrial and commercial use of wood for fuel

(1000 t ce yr^{-1})

Zone	Primary Arisings	Secondary Arisings	Totals
Urban England	3	20	23
Central England	10	10	20
Central Scotland	24	0	24
E Anglia	10	0	10
S & W England	14	40	54
N Ireland	2	5	7
N & E England	6	0	6
Borders	2	10	12
Highland	25	10	35
W Wales	5	0	5
Total	101	95	196

Growing Wood for Energy in Great Britain

The purpose of this study was to determine whether sufficient land would be available for growing trees for energy and whether enough wood could be produced to make a significant contribution to the national energy budget. Rather than being concerned with the use of existing woodland, attention was paid to the potential of new forests, managed specifically to supply wood for fuel. These 'new' forestry systems included modified conventional forestry in which early thinnings and residues are used for energy (timber also being produce), in addition to forest energy plantations (coppice and single stem), the whole above-ground production of which is used for energy.

A modelling technique was developed, using the ITE Land Classification System as a framework, which allowed comparison of the economic return (in terms of Net Present Value) from existing land use with that of a series of forestry systems designed to supply wood for energy. That land use that showed the greater financial performance was deemed to be the one which would be implemented in practice. In this way it was possible to estimate the areas of land economically suitable for producing wood for energy and timber.

This study was mainly concerned with the potential supply of wood and was not directly concerned with matching that to potential demand. However, in developing the benefits stream for the forestry energy systems, values had to be placed on the use of wood as fuel. These were estimated at current energy prices in a similar but not as detailed fashion as the wood combustion study.

The values calculated were those meeting the requirement for the market concerned. Domestic, institutional and industrial scale systems were evaluated and account taken of land factor; type of fuel currently being used; the lower efficiency of wood combustion; transport and storage of the wood. However, no attempt was made to 'place' these combustion plants in relation to supply and demand as was done in the *Combustion strategies study*.

On the production side, the full costs of growing and harvesting the crops were considered. Costs of harvesting were estimated on the assumption that systems would be used which had been developed and optimised specifically to harvest wood for energy rather than using existing methods which had been modified sub-optimally.

Change in land use was not considered purely in financial terms. The concern of the public and Government agencies regarding changes in the landscape, and damage to sites of special scientific interest were all considered in a systematic examination of the constraints on change in land use. Indeed, the changes predicted were expressed as 'before' and 'after' constraints have been applied.

For the 'exploratory case' with wood at the forest edge valued at £20 dt^{-1} (dry tonne) (£36 dt^{-1} in 1983 terms), a 5 per cent discount rate applied and all constraints taken into consideration, the model predicts that some 0.8 million hectares of land would change use from agriculture to forestry, i.e. 3.4 per cent of the total area of Great Britain. The production association with this new land use when it is completely afforested and in full production would comprise 2.9 Mt cepa of wood for energy and 8.8 million cubic metres of timber per year. Of the energy wood, 2.1 Mt cepa would be derived from thinnings and residues produced from modified conventional forestry and 0.8 Mt cepa from coppice energy plantations.

If, however, wood at the forest edge had a value of £25 dt^{-1} (£45 dt^{-1} in 1983 prices) then some 1.83 million hectares predicted to change use yielding some 10.4 Mt cepa, of which 78 per cent would arise from coppice plantations.

As indicated earlier, these predictions take no account of the geographical distribution of the supply in relation to the distribution of potential users. In addition, the study assumes that there would always be a demand for wood fuel, even though in practice there is no fuel supply chain to industry and a lack of confidence in the industrial use of wood as fuel. An additional interpretation is therefore necessary.

The results of the two interpretations are shown in Figures 2 and 3; all costs are expressed in 1983 terms.

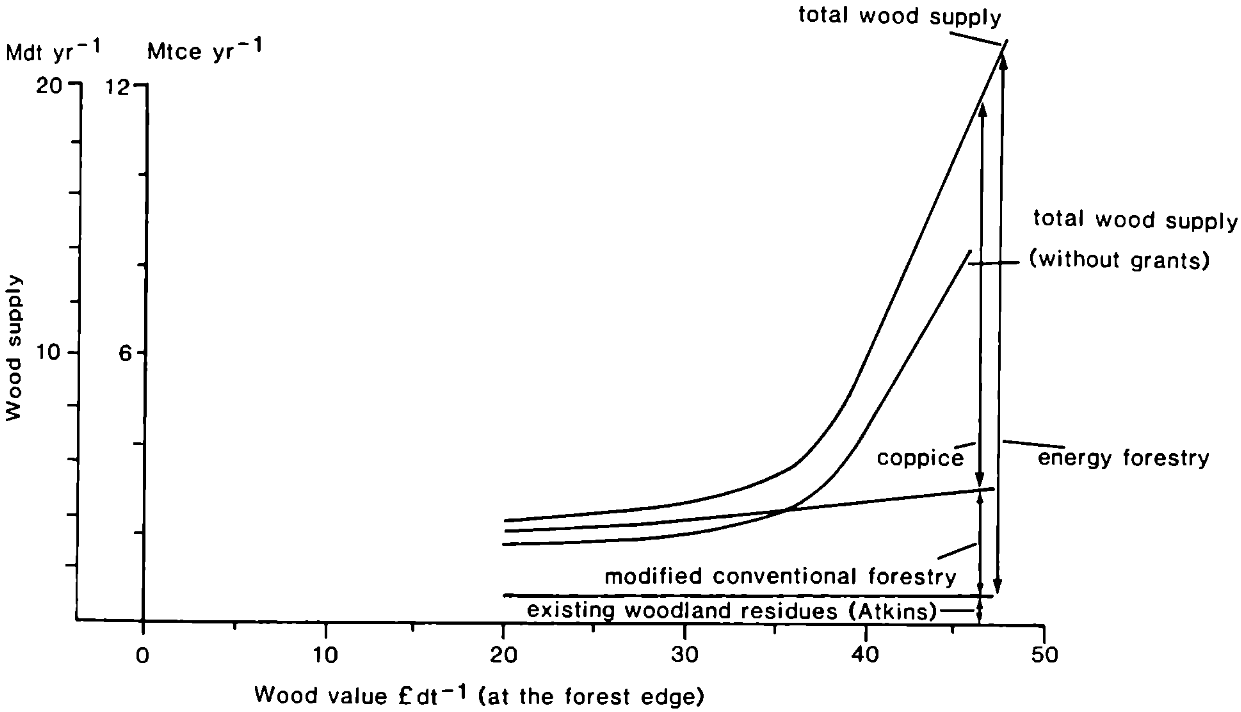

Figure 2. Wood supply as a function of its value at the forest edge.

Assumptions for the upper curve:
- — 5% discount rate
- — with constraints on land availability
- — with agricultural and forestry grants
- — neglecting effects of tax relief
- — no market restrictions

The lower curve shows the level of economic supply without grants.

Figure 2 is a supply curve which was derived from the study on growing wood for energy and shows how much wood could be grown economically as a function of the value of that wood at the forest edge. It also illustrates the potential for residues from existing woodland as estimated in the *Combustion strategies* study. The upper curve shows the total wood supply taking into account constraints on the availability of land, assuming a 5 per cent discount rate and that both upland livestock and forestry planting grants are available, but makes no allowance for the benefits of tax relief to the landowner. The lower curve shows the effect of removing capital grants, reflecting more closely the economics of switching land use as seen by the UK Government. The result is to reduce the economic potential for growing wood as fuel by about one-third. (Strictly, to obtain this Governmental view would require a detailed assessment of the impact of UK Government and EEC grants, price support and tax relief on both agricultural and forestry operations, but this was not possible as part of these studies, although it has been looked at since.)

This supply would be provided by thinnings and residues from modified conventional forestry, and also by coppice, with the latter becoming more important at higher energy prices. No single stem short rotation forestry would appear to be economic below a price of about £46 dt^{-1} (£75 t ce^{-1}) for wood at the forest edge.

However, a major problem is that the modified conventional forestry would be practised in regions relatively remote from potential markets whereas coppice would be comparatively nearer to potential markets. (It will be recalled that geographical mismatch between supply and demand areas, coupled with high transport costs, has been identified in the

Combustion strategies study as the main factor limiting the potential for using residues from existing woodland.) The supply/demand interface has not been examined in detail but as a first approximation it is estimated that only about 40 per cent of the produce of modified conventional forestry and 70 per cent of the coppice would be close enough to a market to have access to it.

Figure 3 is analogous to the 'with grants' data in Figure 2 but the supply curves have been modified to take these correction factors into account, and thus represents the *accessible* supply.

It is unlikely that all of this potential supply could be realised (even if the demand were there), so we shall assume that the *realistic* potential is about half of the *accessible* supply. This shown by the heavy lower curve in Figure 3.

In addition, Figure 3 shows the ranges of wood values, at the forest edge, for a variety of markets. Small roundwood for pulping is currently worth about £22—28 dt^{-1}. Selling to industrial and institutional energy consumers would value the wood at £21 dt^{-1} for firing of wet wood as an alternative to gas-firing for a 15 MBtu h^{-1} industrial boiler, £27 dt^{-1} where wood can be burned directly on a coal boiler without any modification, rising to £30 dt^{-1} where wood-firing substitutes for firing with light fuel oil in a 5 MBtu h^{-1} boiler. These prices allow for transport costs of around £8 dt^{-1} for a 50 mile round trip. If energy prices should double

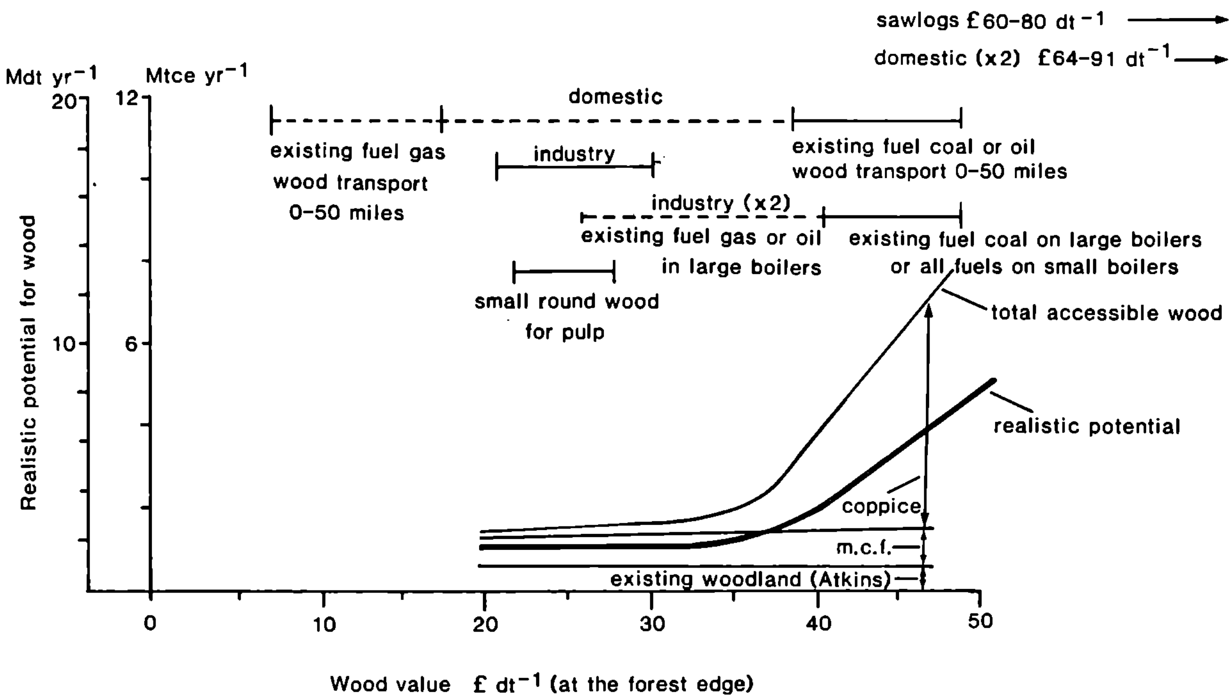

Figure 3. Realistic potential for wood as a function of its value at the forest edge.

Assumptions for the upper curve:
- — 5% discount rate
- — with constraints on land availability
- — with agricultural and forestry grants
- — neglecting effects of tax relief
- — modified for restricted market access (m.c.f. x 0.4, coppice x 0.7)

Heavy line shows realistic potential (+ 0.5 x accessible potential)

Dotted line on demand bars show where no market penetration by wood is expected.

these values would move up to a range of £28—48 dt^{-1}, although if industry has by this stage largely switched out of gas and oil into coal for large boilers (15 MBtu h^{-1} and upwards) this range would narrow to £41—48 dt^{-1}.

For the domestic market at current energy prices wood cannot compete with gas. However, in competition with coal and oil, wood is worth £38—49 dt^{-1}, depending on the transport distance. The lower figure would correspond to a 100 mile round trip to a depot, plus local distribution, while the higher figure would be for local supply only. None of these estimated wood values is high enough to affect supplies of sawlogs, since on a dry weight basis these are worth £60—80 dt^{-1}. However, doubling of domestic fuel prices would boost fuel wood values to £64—98 dt^{-1}, suggesting that the supply would expand rapidly.

In addition to its sensitivity to selling price, the potential supply of wood depends markedly upon the discount rate and the degree to which land could not be used because of environmental pressures. The most easily realised supplies would come from land where forestry is the better bet at 5 per cent and for which there are no environmental constraints; this is the central case on which predictions are based. It has in the past been argued that some potential calculated using a 3 per cent discount rate should be added, for, although the returns on this land are not very exciting, nevertheless forestry shows itself to be a better bet than the existing land use. However, it is now felt that this additional potential could be more than balanced by the loss of potential from these farmers for whom a 5 per cent return on investment would not be considered adequate. It has also in the past been suggested that some of the environmental restrictions identified might not inhibit free planting on 'constrained' land. However, it is now felt that this is less likely to be the case in view of growing public awareness of the visual, recreational and amenity value of land and uncertainty of the ecological impact of change in land use. Indeed, it is possible that planting of energy forests (e.g. coppice) on some nominally 'unconstrained' land might not be acceptable, even if there are no formal barriers to the land operator. In short, the best central view of the economic supply potential is probably given by the 5 per cent discount rate case on 'constrained' land.

Thus, the main findings of the study of growing wood for energy are that for 1983 fuel prices:

1. supply of wood for the industrial and institutional markets could be about 1.6 Mdt yr^{-1} (1.0 Mt cepa);
2. in the domestic market, wood from energy forestry could not compete with gas. For prices which wood could attract in competition with oil or coal the supply could be in the range of 3.0-6.7 Mdt yr^{-1} (1.8-4.0 Mt cepa), with 4.7 Mdt yr^{-1} (2.8 Mt cepa) as a central estimate.

At approximately doubled energy prices:

the wood supply to industry could rise to around 5.7 Mdt yr^{-1} (3.4 Mt cepa), whereas the supply to the domestic sector could reach 16 Mdt yr^{-1} (10 Mt cepa).

The effect of even a modest increase in the value of wood fuel beyond about £35 dt^{-1} at the forest edge could have a dramatic effect on the level of economic as a supply, due to the non-linear shape of the supply curve. For example, Figure 3 indicates that an increase in value of one-quarter could yield a doubling in the level of economic supply at the forest edge. Few other renewable energy sources are in this advantageous position. However, the successful marketing of this supply would require development and demonstration of adequate fuel supply chains and combustion trials on a range of appropriate equipment, in order to increase the confidence of potential users.

Summary of reports

In the short term, i.e. up to the year 2000, and assuming energy prices remain constant in real terms, some 651 000 t cepa of fuelwood could be realised from existing sources; if this were to be supplemented by wood grown specifically for fuel then supplies of wood for industrial and institutional markets could reach about 1.0 Mt cepa and for the domestic market some 2.8 Mt cepa.

In the longer term, if energy prices were to approximately double, then the fuelwood supply to industry could amount to around 3.4 Mt cepa, while the supply to the domestic sector could reach 10 Mt cepa.

The Department of Energy's R&D Programme on Wood as Fuel

The Department of Energy's current R&D Programme on wood as fuel has largely been developed as a result of the conclusions and recommendations of the desk studies considered above. Details are shown in Table 3. As will be clear from the table this significant programme has mostly been implemented and work is still in progress on individual projects. It is too early to present detailed results, but the structure of the programme is described below.

Projects are underway or planned to develop and demonstrate industrial and commercial scale use of wood as fuel (C5/2, C5/3). Projects are planned to develop and demonstrate supply chains for wood from existing forestry sources (BR4/4). Regional market surveys are underway to identify where supply and demand best coincide geographically (C5/1). Together, these projects should increase the confidence of potential suppliers and users, and thereby aid the successful short term exploitation of the fuelwood potential.

The development of woodland management regimes is under investigation (BR4/1), designed to establish the optimum balance between fuelwood and timber products from existing forestry and from unmanaged and undermanaged woodlands (after introduction of adequate management). This may be followed up by demonstrations in a commercial situation (BR4/5). Improved systems for harvesting, processing, storage and transport are also under investigation, the aim being to reduce supply costs (BR4/3).

For energy forestry, studies are in progress to develop and optimise the choice of species and establishment, management and harvesting operations, especially for short rotation coppice techniques, with the aim of maximising the yield of product harvested per unit cost (BR5/2, BR5/3, BR5/4, BR5/5, BR5/7). This includes, most recently, the establishment of large-scale plantation trials, and the development of a coppice harvester. The practical and financial barriers to integration of forestry on farms is under investigation (BR5/1), as are the possible visual, amenity and environmental impacts of energy forestry (BR5/6).

The UK activity contributes to collaborative research undertaken under the auspices of the International Energy Agency's Biomass Implementation Agreement — in exchange, first-hand information on work in other countries is obtained. The EEC also makes substantial financial contributions to UK R&D on wood as fuel. Such international involvement is very important in focusing the UK programme and maximising its impact.

Acknowledgements

The enormous contribution of Dr C.P. Mitchell of the Department of Forestry, Aberdeen University, to both this paper and the development and implementation of the R&D programme on wood as fuel is acknowledged.

The studies summarised in this paper were carried out under contract to ETSU. The views expressed are not necessarily those of either ETSU, UKAEA, or the Department of Energy.

Table 3. The current portfolio of R&D projects on wood as fuel supported under the Department of Energy's Biofuels Programme.

Contractor	Project title	Status
	PROJECT AREA C5 — USE OF WOOD AS FUEL	
	Aim — To help exploit the potential for industrial use of wood as fuel	
PE Consulting Group	C5/1 — Market Assessment for Wood as Fuel	Work in progress
FEC Consultants	C5/2 — Wood Combustion Trials	Work in progress
	C5/3 — Demonstrations of the Industrial Use of Wood as a Fuel	Proposals in pipeline
	PROJECT AREA BR4 — STIMULATING THE SUPPLY OF FUELWOOD FROM EXISTING AND MODIFIED CONVENTIONAL FORESTRY	
	Aim — To encourage the production of wood as fuel by developing management techniques, harvesting and processing systems, and by stimulating the growth of robust supply chains	
Oxford University	BR4/1 — Management of Woodland for Fuel and Non-Fuel Markets	Work in progress
Aberdeen University	BR4/3 — Trials on Equipment for Harvesting, Processing, Storing and Transporting Wood	Work in progress
	BR4/4 — Demonstrations to Produce, Supply and Distribute Wood as Fuel	Proposals in pipeline
	BR4/5 — Management of Existing Woodland for Energy	Proposals to be brought forward in due course.
	PROJECT AREA BR5 — DEVELOPMENT OF 'SHORT ROTATION ENERGY FORESTRY'	
	Aim — To generate information on: short rotation energy forestry management, for growers; harvesting equipment designs, for manufacturers	
Centre for Agricultural Strategy (University of Reading)	BR5/1 — Integration of Forestry for Energy with Agriculture	Work in progress
Forestry Commission	BR5/2 — Coppice Energy Forestry — Initial Field Trials	Work in progress
Aberdeen University	BR5/3 — Single Stem Short Rotation Forestry — Initial Field Trials	Work in progress
Aberdeen University	BR5/4 — Large Scale Coppice Energy Forestry Trials	Work in progress
Loughry College/ Aberdeen University	BR5/5 — Development of a Coppice Harvester	Work in progress
Environmental Resource Ltd	BR5/6 — Environmental Impact of Energy Forestry	Work in progress
Long Ashton Research Station	BR5/7 — Weed Control in Poplar and Willow Coppice Plantations	Work in progress

Willows on Farms for Amenity and Profit

G. Stott and R. Parfitt
Long Ashton Research Station, Bristol

Long Ashton Research Station, and its National Willows collection of 500 types has, for over 50 years, provided a centre for research on all aspects of willow culture, directed by the National Willows Officer. Our expertise has shown that willows can be used for a wide range of purposes on the farm and in the countryside, and this note discusses some of the more important aspects and indicates which willows are best suited for the different uses.

Amenity Willows

Amenity plantings to enhance the environment or provide a wildlife haven, can be selected from particularly decorative willows. The attractive habit of the common golden weeping willow (*Salix* x *chrysocoma*) is well known, but many other willows exhibit different forms, and are equally attractive. *Salix matsudana* Tortuosa has unusually twisted stems, *S. rigida* Rouge d'Orléans an attractive feather, drooping habit. To many the amenity value of willows is typified by the spring burst of the catkins on our indigenous sallows *S. caprea* and *S. cinerea*. However, these are surpassed in size, earliness and general 'showiness' by a number of selected cultivars or hybrids of *S. caprea, S. daphnoides, S. purpurea,* and *S. aegyptiaca,* some of which may flower as early as January.

Summer foliage ranges from the glossy dark green of *S. pentandra* through the lavender-like *S. incana,* silvery white *S. alba* Argentea and the shimmering whitish-blue foliage of cricket bat willow, *S. alba* Caerulea. Leaf shape ranges from short, broad leaves of *S. caprea* goat willow, and some of the dwarf and alpine willows to the long narrow leaves of the osiers (*S. viminalis*). There is even one with tightly curled leaves, *S. babylonica* Annularis.

The young stems of willows can add a splash of colour to the drabbest corner in winter and early spring. There are the red, orange, yellow or grey barks of some *albas* and *fragilis,* black of *S. nigricans,* or the white bloom over a purple or blue-green bark of *S. daphnoides* Continental Purple and Oxford Violet. Willows, in their manifold variety provide a range of habit, form and colour rivalled by few other genera.

Many of the above — and their allies — have a more practical amenity value, as protective plantings to aid establishment of commercial crops on exposed salt-laden coastal sites, wet peats, heathland and cold high altitude sites. They also act as pioneer species whose leaf litter and root action can improve the chemical and physical structure of the poorest soils.

Basket Willows

As a commercial crop, willows have for centuries been grown for basketry. Baskets are best fashioned from the one-year shoots of *S. triandra.* They may be untreated or the bark may be removed by boiling, leaving a pinkish-buff stem, or by a special technique of early spring stripping giving white rods. Heavy work often needs osier stems (*S. viminalis*). The most slender rods are produced from *S. purpurea* and are traditionally woven into fancy, decorative baskets. The specialist knowledge, techniques and equipment of basket willow growing probably places it outside the province of most farmers, but there could be profit in an acre of osiers to produce material for agricultural baskets, log baskets, wattle hurdles and fencing, either for home use or local sale.

Cricket Bat Willows

Some willow uses fortuitously combine aspects of both amenity and commerce. Mature cricket bat trees for example, are currently worth about £50 after 15 years growth, but during those years they provide shade and shelter for stock, and add immeasurably to the beauty of the landscape. Only the basal 10—12½ feet of trunk are usually bought for bats, so that the surplus branches, the lop and top can provide up to half a tonne of firewood. Firewood is also a self renewing product of the pollard willows, so much a feature of our lowland landscape. Throughout their lives they give valuable shade and shelter to stock, but they also stabilise the banks of waterways and by shading out aquatic weeds, reduce the amount of maintenance required.

Windbreak Willows

Shelter is an area where willows (and the other genus of Salicacae, poplars) can be particularly effective, either as shelterbelts for farm buildings or stock or single lines to protect crops from cold spring easterly winds or from westerly autumn gales.

Around farm perimeters, where eventual height is not critical, tree willows are a good choice. Native cricket bat willow, or continental selection of *alba, fragilis* or their hybrids, can be used. Planted at 1 m centres, they grow 1 m per year, and provide full protection from early May. Note that a windbreak is fully effective when leaves produce 50 per cent porosity, giving a reduction in windspeed downwind for about 10 times the tree height, with minimum turbulence. For earlier protection, the earlier leafing balsam hybrid poplars are more effective.

For windbreaks within the farm, where height and hence competition for light, water and nutrients are important, alders and birch are often recommended. As alternatives the shrub willows, *S. viminalis* Bowles Hybrid or *S. purpurea* Helix make effective cheap wind-breaks. Planted as close as 30 cm, their vigorous early growth rapidly produces an effective windbreak. Many fruit growers have found that 10 m high windbreaks at 100 m intervals appreciably reduce windspeed, and increase crop yield. When it comes to maintenance, willows are more easily trimmed than poplars and they do not produce troublesome root suckers, though the roots of either can block non-plastic drains. When windbreaks are grubbed the timber makes useful fuelwood. A farm could be self-sufficient from 3500 metres of single line willow windbreaks if portions were felled and replanted each year.

Biomass Willows

Finally a look to the future. Drawing on the traditions of coppicing basket willows and pollarding for stakes, fuel and so on, and adding our expertise on the growth and productivity of many willow types, we are working on a new concept of agroforestry; short rotation coppice biomass for energy.

Ten years research has shown that willow coppice can produce 12 tonnes of dry wood per hectare per year if cut every 3 or 4 years. This is equivalent in energy content to 6 tonnes of coal or 4 tonnes of oil. Though poplar, alder and eucalyptus are also possibilities, willow is likely to be the best choice for very wet sites.

There is real potential for farmers to utilise odd corners of land disadvantaged by virtue of poor drainage or access, or adverse slope, producing their own self renewing source of domestic heat.

Most widely planted for biomass is *S. Aquatica Gigantea Korso,* but *S. viminalis* Bowles Hybrid or the hybrid *S.* x *dasyclados* may have advantages on some sites.

In parallel experiments in Northern Ireland made by the Horticultural Centre, Loughall, Armagh these willows have been grown, processed and burned as chips to heat 200 m^2 of tomato glasshouse, at a cost of little more than a third of oil. As the underlying trend of energy prices continues to rise, and much disadvantage land can be farmed economically only by virtue of EEC subsidies, (now under threat), planting your own energy may be a viable alternative to the mountains and lakes of surpluses which currently bedevil us.

Willows have much to offer farmers in hard cash and in the beauty and variety they bring to the landscape.

Broadleaves in Britain — Policy, Practice and Potential

J.R. Aldhous
Forestry Commission, Edinburgh

Policy

1985 was a landmark in the history of British woodlands. In July of that year the Government announced a new policy for broadleaved woodlands in Britain. This aimed at encouraging positive and sympathetic management of the country's broadleaved woodlands, to arrest further depletion, to improve the quality of growing timber and to manage this valuable national resource to meet the various complementary objectives of enhancing the landscape, providing recreation and conserving wildlife.

Britain has over half a million hectares of broadleaved woodland out of a total of 1.8 million hectares. Table 1 illustrates its composition, and shows that oak is the predominant species followed by beech, birch and ash.

In addition, there are a further 78 million broadleaved trees occurring as isolated trees in groups or in hedgerows and belts. Ash is the dominant species, followed by oak, sycamore and alder (see Table 2).

Table 1. Areas of broadleaved woodland

000 hectares (minimum area 0.25 ha)

	Ownership and management			Total	% of Broadleaves
	Forestry Commission	Private			
		Under management plan	Other		
Oak	18.5	27.6	125.9	172.0	31%
Beech	19.6	17.1	37.2	73.9	13%
Sycamore	2.3	8.4	38.7	49.4	9%
Ash	2.9	8.3	58.3	69.6	12%
Birch	4.2	2.6	61.3	68.1	12%
Poplar	1.5	4.5	7.6	13.8	2%
Sweet chestnut	0.6	1.7	7.5	9.9	2%
Elm	0.2	0.9	8.3	9.5	2%
Other broadleaves	2.1	1.5	25.5	29.1	5%
Mixed broadleaves	3.3	28.6	33.2	65.1	12%
Total broadleaves	55.2	101.4	403.7*	560.2	100%
Total conifer	818.2	377.6	125.1	1321.0	
Combined total	873.4	479.0	528.8	1881.2	
Broadleaves as % of total	6%	21%	76%	29.7%	

* Includes approx. 100 hectares of woodland of coppice origin.

Source: Forestry Commission Census of Woodlands and Trees 1979-82.

Table 2. Number of broadleaved trees not in woodlands

	million trees (over 7 cm diameter at breast height)				
	Isolated trees	Clumps	Linear features	Total	% of Broadleaves
Oak	3.6	3.4	5.3	12.3	16%
Beech	0.6	1.4	2.5	4.3	5%
Sycamore	1.6	3.6	4.1	9.3	12%
Ash	3.7	6.0	5.9	15.6	20%
Birch	1.1	4.6	2.4	8.1	10%
Poplar	0.5	0.6	0.9	2.0	3%
Sweet chestnut	-	0.1	0.3	0.5	1%
Horse chestnut	0.3	0.2	0.2	0.8	1%
Alder	0.4	2.8	6.6	9.8	12%
Lime	0.4	0.4	0.5	1.3	1%
Elm	0.4	1.1	1.7	3.1	4%
Willow	0.7	1.4	1.5	3.6	5%
Other broadleaves	2.0	3.1	1.8	7.8	10%
Total broadleaves	16.2	28.6	33.9	78.6	100%
Total conifer	1.9	4.0	3.3	9.3	
Combined total	18.1	32.6	37.2	87.9	
Broadleaves as % of total	89%	88%	91%	89%	

While the total woodland area is similar now to that under broadleaves 40 years ago, there has been a reduction in the area of 'ancient woodland' i.e. ground that has been woodland continuously for several centuries. The area of ancient woodland lost has been offset in the same period by colonisation or planting of broadleaved trees on open land. Registers of ancient woodland sites, compiled by the Nature Conservancy Council on a provisional basis have been prepared for 37 counties in England and Wales and four regions in Scotland (Kirby, 1986). Such registers show where positive management in the interests of wildlife conservation are particularly required.

It is the Forestry Commission's responsibility to ensure that the new Government policy is fully understood and is translated into practice quickly and effectively. Because most of Britain's broadleaved woodland is privately owned by people for whom woodland management is subsidiary to their main occupation, particular efforts are being made to make advice readily available to woodland owners who consider they may now benefit from advice and from encouragement to seize opportunities for improved management. Such advice is being channelled not only through the Forestry Commission's private woodlands staff but also through the national advisory services to farmers (MAFF/ADAS in England and Wales and DAFS/Agricultural Colleges in Scotland), and through voluntary bodies such as the Farming and Wildlife Advisory Groups (FWAGs).

Practice

The silviculture of broadleaved woodlands has not been the main focus of attention in 20th century British forestry. The loss of traditional markets, the relatively slow rates of growth of native broadleaved species, the depletion of broadleaf and conifer woodland during the 1914—18 and 1939—45 wars and the emphasis on food production from British farms resulted in the bulk of forestry research effort in Britain being directed (with considerable success) to the silviculture of introduced conifer species on the poorer land types of the uplands.

Nevertheless, recent experience in growing broad leaves both in the best types of woodland, e.g. beech in the Cotswolds, oak in Herefordshire, sycamore in Yorkshire, and also from the old historic Crown forests of the Forest of Dean and the New Forest, where provision of recreation and conservation of wildlife have long been part of the management of objectives, all provide a basis for contemporary practice.

Guidelines for the management of broadleaved woodlands was published by the Forestry Commission in 1985 after consultation with the Countryside Commission, the Countryside Commission for Scotland, the Nature Conservancy Council, Timber Growers United Kingdom, and the Institute of Chartered Foresters.

The guidelines set out:

- Management principles
- Woodland types in relation to conservation value
- Management for particular objectives
  - Wood production
  - Landscape
  - Recreation
  - Nature conservation
  - Game management
- Other management considerations
  - Herbicides
  - Fertilisers
  - Ride and glade management
  - Wetlands
- Sources of advice
- References

Applying the guidelines

Trees can grow in Britain from sea level to over 600 m elevation above sea level. However, soil and climate dictate the distribution of different species and it is important to recognise in applying the Guidelines that in Britain below the tree line, two main climatic zones exist, one where appreciable summer moisture deficits occur and which is mostly capable of supporting a wide range of broadleaved species; the other where moisture is largely in excess for most of the year, so that peat accummulates to a greater or lesser extent and where the range of broadleaved species able to survive and grow is drastically reduced. At the risk of over simplification, these can be called 'lowland' and 'upland' zones respectively.

Good silviculture, incorporating drainage and improved nutrient status can extend the range of species and enhance rates of early growth on upland sites (Low, 1985). It is unrealistic however to expect that the broadleaves typical of the warm more fertile lowlands of the south and east of England can be made to grow well every where in the uplands.

Nor must it be forgotten that beech and the two native British oaks are at the northern limit of their range. They are species which reach their optimum in Western Central, Southern Central and South Eastern Europe. Their natural distribution contrasts with the more northerly occurrence of the British native birches, alder and aspen for example.

Remnant oak woods in Scotland and in the higher rainfall areas of Wales are most frequently found on warm, well-drained south-facing slopes the north-facing slopes in the range of native Scots pine, being occupied by that species and birch (Steven and Carlisle, 1959).

Beech, while widely planted and a particularly successful woodland tree on calcareous soils over limestone and chalk, is not truly native to those parts of Britain north of Oxford or west of Bristol.

A more detailed guide to good practice is Forestry Commission Bulletin 62 *Silviculture of broadleaved woodland* while adaptations of practice to favour wildlife conservation are described in the RSPB handbook *Birds and broadleaves* and in the NCC publication *Forest operations and broadleaf woodland conservation.* For guidelines on landscape, see Forestry Commission Booklet 44 *The landscape of forests and woods.*

Native species dominate British broadleaved woodland and rural landscape (Tables 1 and 2). While it is fashionable in some circles to decry introduced broadleaves, they have a major contribution to make to the British scene. Sycamore in particular regularly makes a telling and substantial contribution to many landscapes, both lowland and upland. FC Bulletin 62 describes the growth and potential of many other species. It is only at the wider use of the hardy eucalyptus species that it might be necessary to draw a line. Their form and colour are so dissimilar from any European broadleaved species that they should perhaps be thought of as 'honorary conifers' just as larch is sometimes recommended as a nurse in mixture with oak and beech and is proposed for 'honorary broadleaf' status.

Motivation for practice

The nub of 'practice' is to plant and to tend in a way that embodies the objectives in the policy guidelines. It is the landowner controlling actual or potential woodland who must be motivated to take appropriate action.

Financial encouragement is provided by a higher level of grant for planting pure broadleaves under the Forestry Commission Broadleaved Woodland Grant Scheme (BWGS) than is available for conifer or mixed broadleaf/conifer woodland planting schemes. Grants under the BWGS are available for natural regeneration and for improvement work in young previously neglected woodland.

It is vital that the general public and amenity and conservation bodies in particular, generously acknowledge that owners embarking on broadleaved woodland planting are acting with altruism. With new planting, there is a prospect of continuing expenditure annually for 30—50 years with no major return from timber sales until at least at the end of the 21st Century. Any serious thought about conditions in the year 2100 for example brings realisation that any hopes of particular timber revenue then are speculations of a high order.

Farm woodland practice

Farmers between them own a very substantial proportion of the older semi-mature woodland. Such woodland is often on narrow strips of the steepest land on the farm and in small blocks, often associated with coppice working for former farm needs. Farm stock often is let into the woods for shelter and for supplementary grazing. Heavy grazing in woodland usually reduces drastically the range of flowering plants together with any young seedling natural regeneration of the woodland trees. Experience in the New Forest and the Forest of Dean shows that livestock grazing and timber production can be integrated by formation of enclosures excluding stock until trees are 60 feet or more tall and able to withstand the effects of browsing, gnawing and rubbing. However, such a practice is not always easily integrated into the small scale of most farm woods.

Prospects

The responses in the first year to the new Government policy offer the prospect of a much greater scale of positive management of existing woodlands. Advisory services being offered are being welcomed and widely used.

The number of applications for grants under the BWGS has substantially exceeded initial expectation.

Number of BWGS applications
as at 30 June 1986

2373

Area to be planted
under proposed schemes

15 612 ha

It should be noted that a number of schemes now propose pure broadleaves as amendments for previous proposals to plant broadleaves and conifer in mixture.

In the longer-term, other prospects can be identified.

Prospects for better quality trees

Normal silvicultural practice of dense planting and thinning out periodically malformed or slowly growing trees has only a small beneficial effect on the genetic quality of the remaining trees. While the best stands of oak and beech in Britain are used, where possible, as sources of seed for future woodlands, this also achieves only a small improvement in quality of the growing stock. It is from intensive systems of vegetative propagation of the very best trees that substantial improvements may be achieved. For broadleaves, work on micropropagation of oak offers best prospects. While present work is aimed towards propagation of ornamental varieties, it should be relatively easy to extend the technique to trees for woodland planting.

Prospects for silvicultural changes

Many pedunculate oaks have the undesirable habit of producing epicormic branches, to the detriment of the quality of the timber in the log. Vegetative propagation of oak, so as to grow only clean stemmed oak has been attempted for many years. However, current work on ornamental varieties of oak at East Malling Research Station offers some promise.

Work on improved strains of other forest broadleaved trees has been sporadic and so far to little effect. Nevertheless, selection and vegetative propagation offer the best prospect of achieving better quality of trees.

Fears are from time to time expressed that the genetic base of British trees is limited and might be more restricted if current EEC rules about using phenotypically superior 'registered' stands are applied vigorously for oak and beech. However, there has been no positive selection of any British tree species in any way compar able to the selection and rapid breeding cycles found in cereals and similar farm crops. Most British woodlands have been repeatedly creamed of their best trees. To perpetuate them indiscriminantly in many instances will perpetuate second class strains.

The tree shelter developed by G. Tuley has been one of the outstanding and unexpected innovations of the last decade, and one which generally has benefited broadleaves and especially oak, more than conifers.

Small scale regeneration systems based on felling coupes of 0.5—1.0 hectare are currently being encouraged in order to bring more variety into the age and structure of woodlands nearing maturity. The success of this technique depends partly on the number and speed of growth of young planted or natural regeneration and partly on the successful control of potential predators, especially deer. Currently deer populations are slowly spreading, roe into the south-west and Wales and sika in the Scottish Borders for example. While groups are being actively encouraged to control grey squirrels where these are perceived to be a problem, greater use of broadleaves may also generate a need for more stringent control of deer, where the broadleaves are specially threatened.

Prospects for change of land use

The consequences of the present concern about food surpluses as a result of the EEC Common Agricultural Policy are not yet clear. While some commentators are forecasting turnover of substantial areas of marginal hill land to forestry, others are reviewing agroforestry and the extension of woodland pasture systems. For the latter to succeed, trees that are fast growing and not specially palatable to livestock are needed. While New Zealand farmers may be able to combine sheep grazing with growth of *Pinus radiata*, there is unfortunately no obvious equivalent among the British broadleaved range.

Prospects — continuing achievement

British woodland owners have responded to the Broadleaved Woodland Grant Scheme in a very positive way. The prospect is, with continued support from other countryside interests, that woodland owners will continue to be attracted to manage and extend broadleaved woodland and that as a consequence the 1985 Broadleaves Policy will be seen to be a notable and far-sighted success.

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Growing Broadleaves Successfully*

J. Evans
International Institute for Environment and Development, London

Few products are enjoyed so much as trees when both living and dead (and I don't mean the elm of one's coffin!). Mature oak trees and natural woodland are appreciated for what they are in themselves but equally as the sources of beautiful furniture and fine cabinet work. Resolving this dilemma presents an unequalled challenge to foresters today. Neither should conservation deny enjoyment of finely crafted timber nor should the search for quality lay waste much of the very resource which provides it. We can have our cake and eat it and see the wood and the trees.

Growing high quality timber efficiently for furniture grades and veneer has these ingredients:

1. growing a quality product;
2. maximising the quantity of good timber; and
3. perpetuating the best trees and forest.

When in sympathy with conservation of landscape and wildlife, achieving these three aims for broadleaves is the silviculture of success.

Quality begins with species which in Britain means concentrating on oak, cherry, and sweet chestnut and the white woods of ash, beech and sycamore. Their absence from the large plantations on the peats and gleys of the uplands is not some grand conspiracy but a silvicultural requirement for reasonable shelter and moderately fertile soil. The broadleaved silviculturist competes with the lowland farmer for land, once largely unsuccessfully, but today with more a spirit of co-operation. Broadleaves also possess another disadvantage compared with conifers, their stems are rarely very straight, a defect which lowers outturn and distorts grain. Straightness is helped by dense stands giving greater selection and mutual shelter and better suppression of side branches which reduces knots. For broadleaves there is, without doubt, 'safety in numbers', but there is a penalty — slower individual tree growth.

Maximising quantity must not be at the expense of quality. There is plenty of low grade hardwood in Britain but little of top quality. But to depress further the naturally slow growth of broadleaves with high stand densities to achieve more stems of good quality, is prohibitively expensive. The solution is early selection of well-formed trees and favouring these in thinning. Indeed, in every thinning in broadleaved stands the primary focus must be on quality — leaving and encouraging the growth of every straight defect-free tree. Happily, today, in many parts of the country the poorly shaped trees thinned out are readily saleable for firewood. Without doubt thinning is the forester's most powerful tool. It ensures only the best grow on and, when carried out regularly and sensitively, that they grow as rapidly as possible. For broadleaves, rapid growth does not impair timber quality.

Thinning always to favour the best trees satisfies the third ingredient for success. And, if a stand is naturally regenerated, at least the best trees of the former crop are the parents of the next. Most regeneration, however, is by planting. This permits the once per lifetime opportunity to improve the genetic quality of the crop. Thus use of the best available provenance or even selected material must rank as a high priority but so must, equally, the question of species itself and especially with oak. Many woodlands of this species will never produce much good quality timber, not because straight even vigorous trees cannot be grown, but because the site, especially light textured, sandy and very freely draining soils, predisposes trees to shake. This serious internal flaw of longitudinal cracks is revealed only at felling but downgrades timber value by an order of magnitude. Even though oak may grow well on the site it is undesirable to perpetuate a crop which will be inherently defective; other broadleaved species should be chosen.

All this silviculture is expensive and when compounded by the risks to which young broadleaves are prone — browsing, barking, smothering by weeds, overtopping, herbicide spray and, later on, squirrel damage — it is not surprising that broadleaved planting in Britain has been ticking over at only 1500 or so hectares per year. But change is in the air encouraged by the unlikely partnership of policy and plastics! The Government recognises the expense in growing broadleaves and now offers favourable rates of grant support of up to 1200 per hectare. As for plastic, tubes called tree shelters, which are like vertical cloches, not only overcome

* This short paper is a summary of a more extensive contribution presented orally at the meeting.

all the main protection problems in the early years but enhance growth. Since their discovery in 1979 they have become the main establishment technique for small plantings of broadleaves; over 2 million are now used each year.

Successful broadleaved silviculture is nothing more than laying a sound foundation of the right species on the right site established in sufficient numbers and with good protection from weeds and biotic damage, followed by regular application of the rule of always thinning to quality. There is nothing mystical or mysterious about growing broadleaves successfully, just commitment but, like all genuinely good things, it cannot be done on the cheap.

Growing Sound Timber — Shivers and Shakes

G.S. Henman
Department of Forestry and Wood Science, UNCW, Bangor

Summary

'Shake' is the name given to extensive longitudinal splits in the wood which can develop inside a living tree; they are not apparent until the tree is felled. There is no known disadvantage to the tree, but the loss in value of the timber is great. The discovery of shake in a promising timber tree is likely to elicit stronger language from the forester than 'Shiver my timbers!'.

Much effort is required by the forester to produce oak timber of the desired quality — in tree form, wood texture, density and appearance. If a tree is shaken however, all these refinements are lost; the oak timber which was expected to enter high value markets for sawn and veneer wood will be fit only for low value mining timber and firewood.

Shake is found in several tree species, and in Britain affects oak (*Quercus robur* and *Q. petraea*) and sweet chestnut (*Castanea sativa*) particularly. Shakes either run outwards from the pith, parallel to the rays ('star shake'), or follow individual growth rings ('ring shake'). When a shaken log is sawn, the planks can fall into pieces along the shakes. The defect has been recognised for centuries — John Evelyn refers to it in his writings in the 18th Century; and 19th Century works on timber for the Navy describe the nuisance of shake. Only recently has the cause been researched — and oak has been the species studied.

Field surveys confirmed the foresters' 'lore' that shake is associated with certain soil types. It was found that oaks on sandy, gravelly and stony ground — or any site subject to a fluctuating water table and seasonal droughtiness — were more prone to ring and star shake. Such sites can however produce occasional top quality timber trees, more usually found on deep, moist clay soils.

It seems that a two-stage mechanism operates to cause shake in oak. Firstly, some weak zone in the structure of the wood makes trees shake-prone. Then, probably much later, a combination of internal and external mechanical stress triggers these weak zones to split. The triggering effect appears to be site-related, affecting any shake-prone trees on that site. Weak zones in the wood may develop as inherited wood structure patterns or may be due to some traumatic influence on the cambium such as wounding, drought or defoliation. As shakes do not generally appear in oaks under 40 cm diameter, it would seem that natural growth stresses (which increase as the tree grows) act as an aggravation to site-induced triggers. Such growth stresses are under both genetic and silvicultural control.

At present, the only means of controlling ring and star shake in oak are:

1. to avoid planting for timber production on shake prone sites; and
2. to minimise wounding and other damage to the cambium.

Current work aims to discover whether any of the wood structure patterns predisposing a tree to shakes are heritable characteristics. Selection of less susceptible trees could allow oak to be grown for timber on shake prone sites, thus increasing the number of areas suitable for oak woodland in Great Britain. The British oak is valuable both in conservation and as an amenity tree. Its beautiful and valuable timber can make it financially self-supporting in such roles - *if* it is of good quality.

The quality of timber can be judged in a variety of ways. It depends upon the desired end-use — thus tree form, wood density, strength, texture and appearance are the usual considerations. However, if the major defect of 'shake' affects the tree, the time and effort expended by the forester in achieving these ends, will be wasted.

The term 'shake' refers to longitudinal splits which can form within the wood of a living tree. It can cause a reduction in value per m^3 of timber, to about one-fifth of that expected for a sound sawlog. Shake may affect the majority of trees in a woodland, or only a few — but it is not visible until the tree is felled. Hardwoods in this country are usually sold standing, so the discovery of shake after felling can at least be very disappointing and at the worst, be financially ruinous to the unsuspecting buyer. Timber merchants look for external indications of shake in oak, such as long ribs or channels in the bark, but these are not reliable because their absence is no guarantee of a sound tree.

There are two types of shake, described by their appearance in the cross-section of a log. Star shakes run radially from the pith towards, but not into, the sapwood and bark. Ring shake is a separation of the wood within one annual ring. Several rings may be affected, and ring and star shake may occur together. In oak, a dark or a milky-white staining is characteristic of shake. The extent and severity of shake can be seen when the log is put on the saw. The boards can fall apart along the lines of severe ring shakes, which extend for the length of the tree.

Supplies of saw and veneer quality hardwoods in this country are very low; and in shake-prone woodlands up to 60 per cent of the trees can be badly affected by the defect. Top grades of log found shaken may be downgraded to mining timber or even firewood, so shake is economically important.

Shake occurs in several species of tree, and in this country is a problem in oak, sweet chestnut and yew. The nature of the defect is variable. In sweet chestnut, multiple ring shakes generally develop after about 60 years of growth, virtually prohibiting its cultivation for large dimension timber. In oak, shake incidence is site-related, thus limiting the sites on which the tree can be grown for timber. This is particularly important now, with increasing areas of oak being grown for conservation and amenity purposes. There can be no choice in the matter of soil type, yet these plantations need to produce good quality timber in order to support the roles which bring no financial return.

Shake has been recognised for centuries, but its cause never understood. John Evelyn in the early 18th Century frequently refers to 'rifts', 'frow' and 'shivers' in oak. Gilbert White writes of oaks on the 'freestone' (greensand), they "..... grow large, but are what workmen call 'shakey' and so brittle as to fall to pieces in sawing". Nineteenth Century works on timber for ships also warn against the defect. More recently, American work in the 1970s studied the structure of shakes within trees. Now, our own work looks at the problem of shake in the British oak species *Quercus robur* and *Q. petraea.*

Many factors are reputedly associated with the incidence of shake. Preliminary studies confirmed some of these — and also showed up many anomalies. These factors are divisible into two groups:

1. those intrinsic in the shaken tree, but not due to constant site conditions; and
2. those which are constant characteristics of the site on which the shaken trees grow.

The most clear association within trees is that of wound tissue and ring shake in oak. Associated site characteristics are reflected in the foresters' lore concerning shake, much of which was quoted by Evelyn over 250 years ago. The action of wind is often blamed, but the most certain association is that of soil type. Oaks are more prone to shake if grown on gravels, soils containing broken stone, certain sands or any substrate which exhibits a fluctuating water table or seasonal droughtiness. Oak crops off such sites will always be affected, so estates and even counties tend to gain permanent reputations for the quality of their oak, depending on the predominant soil type.

There is no individual cause of shake however. Not every wounded tree contains shakes; and not every tree on a shake-prone site succumbs — figures can be as low as 20 per cent badly affected. We suggested that the development of shake is a 2-stage process influenced by a variety of silvicultural and environmental conditions. First, a predisposition to shake develops in the wood structure: a zone of weak tissue or stressed wood. This can happen at any time, from the earliest formed wood onwards. Then, probably many years later, external and internal mechanical forces trigger a separation of the wood along the predisposed zones. These triggers are site related and appear to operate only after the tree reaches larger dimensions — usually over 40 cm diameter.

Influences predisposing oak to ring shake are those which upset the cambium and result in the formation of a ring of weak-walled cells. Several events can be a cause of this:

1. Wounding: Shigo in America and Pearce in Britain have shown that wounding leads to the formation of a 'barrier zone' in the next formed layer of wood. The cells of this zone are chemically strong against the spread of fungal infection — but the cell walls are thin or even collapsed.
2. Frost damage may also be implicated.
3. Observations of ring shake in the same year-rings of all shaken oaks in a woodland, suggest drought and defoliation as predisposing factors. The shaken rings are frequently very narrow, in a series of wider ones. Drought causes reduced growth and weaker cell walls; in addition, sudden changes in ring width may build up stresses in that zone of wood. In one woodland though, where conifers showed no growth reduction in the year which was narrow and ring shaken in oak, defoliation by caterpillars could have affected the oak alone.

The predispositions leading to star shake remain unexplained; we are examining the possibility of some genetic predisposition in wood structure patterns.

The material used for this study of oak, comes from three sources. First, 30-year-old oak from a seed origin trial; tissue proportions, cell sizes and growth patterns were quantified to discover which characteristics are most strongly influenced by genetic type. Second, young oak trees treated experimentally, to demonstrate the effect on wood structure patterns, of known amounts of frosting and defoliation. The third category is material collected from shaken and sound mature oaks, from several sites in England and Wales. The results of all these studies are being combined, to try to confirm which factors cause wood structure patterns predisposing oaks to shake. If the predispositions can be controlled by genetic or silvicultural manipulation, we may be able to grow more shake-free oak for timber on shake prone sites.

If the factors which trigger shake could also be reduced, we should have an even better chance of growing sound oak. We know that certain sites provide the triggers to shake (the mechanism is not understood, perhaps water-stress may induce internal, mechanical stresses), but changing the soil type of an area is not feasible! Currently the only possible controls are to avoid such sites or reduce the predispositions. However, we believe that the trigger effect may be aggravated by natural growth stresses within the tree. 'Growth stresses' are the longitudinal and transverse mechanical stresses which develop in a tree trunk as it grows. The transverse stresses are tensions in the centre of the tree and compressions at the periphery — a pattern which matches the area in which star shakes develop. Amounts of growth stress depend on tree species, growing conditions and tree diameter, and there is a clear association between shake and tree diameter in oak and sweet chestnut. Our future work includes study of growth stress in oak. Perhaps control of growth stress represents another opportunity for control of shake, by reduction of forces which supplement site-induced triggers.

In conclusion: shake is an important problem in British oak. Management of oak is expensive in time and money — so in woodlands where timber production is the primary objective, growing oak is only worthwhile if the product is of high quality and shake-free. Currently this precludes such woodlands from many sites in this country. Site studies and comparative wood structure studies are being used to try and discover the cause of shake. It is hoped that its prevention may come through reducing the intrinsic susceptibility to shake, by genetic selection or by silvicultural manipulation of growing stock, thus increasing the number of sites on which oak can be grown shake-free.

Growing Sound Timber — Knots and Nonsense

T.A. Wignall
East Malling Research Station, Kent

Summary

A major problem in growing oak is the large number of epicormic shoots which sprout from the trunk. These cause small knots in the wood which severely reduce timber quality. Plant hormones and tree water relations may underlie this knotty problem.

Introduction

Epicormic shoots sprout from the lower parts of trunks of oak trees (often seen as 'cat's paws') leaving knots in the wood which downgrade the sawn timber, particularly in veneer quality butts. The rise in demand for good oak timber, and increased interest in amenity and conservation tree planting, has prompted a Forestry Commission sponsored investigation into the possibilities of controlling epicormic production.

Seed propagated oaks are extremely variable and have traditionally been planted at high density to allow for later removal (thinning) of weak ('suppressed' or 'non-dominant') trees. It may take as long as 150 years for an oak tree to reach the size needed for veneer production when conventional methods of thinning the plantation or stand are used. However, the required girths can be achieved in half this time by resort to 'free-growth', in which only 60—80 trees are planted per hectare, each with complete crown freedom (Evans, 1982). This affords the 'dominant' trees more light, water and space, so they can compete more efficiently for the resources needed for growth. However, a deleterious side-effect both of thinning and of planting at initially lower densities is increased production of epicormic shoots, which increase in number as stand density is decreased (Wahlenberg, 1950; Sonderman, 1985).

At present the economic return on epicormic-prone oak as a timber crop may be less than 3.0 per cent over 100 years (Smith, 1972), so it is hardly surprising that it is still seen as an economically marginal use of land.

Financial gain aside, there are other good reasons why oak should be planted. It is an important tree ecologically, supporting more species of insect than any other native tree, as well as providing a habitat for wildlife. During its life span, a stand of oak can be used for sporting and recreational purposes, and for interplanting with coppice tree crops. Finally, there are apparently those who are prepared to plant British oak also for sentimental reasons, not wishing to see future generations deprived of good quality timber or of the traditional contribution of oak to the English countryside. Indeed, there are in the UK precious few stands of high quality oak left. In 1974, only nine stands were considered good enough for their acorns to be used for establishing new plantings (Penistan, 1974). Clearly, if the quality of oak timber could be better assured, then the prospects for oak as a future crop might be secured.

Genetic Variation

The propensity to generate epicormic branches varies considerably between tree species, being found on many broadleaves and even on some conifers. Their greatest abundance in the UK is on oak, but they also occur in significant numbers on elm and poplar, and to a lesser extent on beech, ash and sycamore. Spruce and larch are notable amongst the conifers in producing epicormics, particularly when subject to physiological stress.

Within the genus *Quercus* there is also variation between species. In the UK, the exotic oaks such as *Q. cerris* and *Q. borealis* have less epicormic branching than the native *Q. robur*. Furthermore, the frequency of epicormic production varies between trees of the same species and, to some extent, independently of environmental variation. In any stand of oak this genetic variation is quite apparent. Trees with many epicormic sprouts are often to be found growing close to individuals with clear boles.

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The production of epicormic branches also varies with tree age, degree of exposure and crown class. Young suppressed oaks in dense stands are more likely to have epicormicc branches than dominant trees, a possible result both of genotype and location. Of greater practical concern is the stimulation of epicormic branch emergence which often occurs on the dominant trees left when stands are thinned to encourage faster stem growth.

Epicormic Control

In the past, research on epicormic control has concentrated on removing the epicormics rather than preventing their appearance. The traditional method has been to remove new epicormic shoots by pruning chisel, or by mechanical methods. These methods are expensive, require frequent repetition and do not avoid the undesirable effects on wood quality of initial sprouting. Treatments such as maleic hydrazide and herbicide sprays have been applied to the shoots, or wrapping the trunks in black polythene, or painting them with bitumastic paint. None of these treatments have been particularly effective in preventing epicormic emergence, especially in the second or third year after the treatment. In contrast, as an experimental treatment, trees have been exposed in the field to continuous fluorescent light to see if this encouraged epicormic growth, but again to no effect.

The most impressive control of epicormics I have seen is the labour-intensive method of rubbing off the buds, by hand, each year (Blewitt, 1985). After about 6 years, no more buds emerge, presumably because no more are left dormant within the bark. Needless to say, this is not likely to be an economically viable practice for the forester.

Consequently, with the wider adoption of the modern forestry practices of wide spacings, free growth and heavy thinnings, greater need exists for a cheap, effective method of control. However, we first need to understand more about the physiology of epicormic production and it is towards that end that our research has been aimed.

The problem of epicormic control can be considered in two stages corresponding to the development of the buds:

1. origin of the buds — related to the growth and development of the trees; and
2. release of the buds from dormancy — through physiological processes in response to external stimuli.

Both these stages of epicormic development are affected by genetic variation between trees.

Origin of Epicormic Buds

Considerable discussion has surrounded the origins of epicormic buds, not only in oak, but in other species. How they originate in oak thus remains finally to be resolved, although it is clear that the buds from which the shoots develop are embedded in the bark. Whether these embedded buds arise from earlier developed structures or develop 'adventitiously' in the bark is a question central to their control.

If they arise from pre-existing 'axillary' structures, their presence at the outset can never be eliminated entirely, being an integral and original part of the pattern of growth of the tree. At the end of each flush of growth, of which the oak has several in a season, a ring of terminal resting buds is formed at each growing shoot tip. On subsequent re-growth the leading bud expands and grows but most of the others remain in a state of rest. As the sapling increases in girth these buds can become embedded in the bark, remaining dormant until they receive the required signal to develop, though this may never necessarily occur. Such buds will have a continuous vascular trace to the pith of the tree and, to remain viable, they require functional connections to be developed with the new vascular tissue created each year. This can only be achieved if the bud extends outwards by the width of each annual ring as the ring is formed. As they undergo this small amount of growth, the buds form new scales and possibly lay down new 'secondary axillary' buds in the axils of these scales. This might be how a single bud apparently gives rise simultaneously to four or five green epicormic shoots.

Alternatively, epicormic buds may arise adventitiously as newly-developed structures within the bark tissues. Most often this 'adventitious' type of bud regenerates from the callus tissue which forms after a tree is wounded, such as after the pruning of branches and possibly epicormic branches.

If at least some proportion of epicormics are of such adventitious origin, then the possibilities for their control become more remote, as they would occur adventitiously in a random manner on the trunk and the potential for their production will increase as the surface area of the tree increases.

In our research on the anatomical development of epicormics we have seen no evidence to suggest that epicormic buds do arise adventitiously in oak, the original bud apparently being of axillary origin developed at an early stage in the growth of the tree. Subsequent proliferation of epicormics seems to arise via secondary axillaries rather than adventitious buds. Observation suggests that epicormic shoots occur in whorls around the trunk, probably associated with the ring of terminal buds formed after each flush of growth.

The Breaking of Dormancy

Epicormic emergence in other species has been reported to be stimulated, for example, by exposure to light and injury (yellow poplar: Wahlenbergh, 1950), direct sunlight, rapid growth rate, small trunk diameter, and pruning of the crown (white fir: Cosens, 1952).

That light, either directly or indirectly, is not the sole factor is indicated by the presence of epicormic 'agony shoots' on many suppressed and shaded trees. However, exposure to light does appear to be, in oak, a major factor in stimulating the later growth of epicormics once they have emerged from the bark. Other suggested stimuli for epicormic production include physiological imbalance (Wahlenberg, 1950) and a disruption in the equilibrium of the shoot-to-root ratio caused by pruning and thinning (Geete, 1946). A further possibility is that competition for nutrients exists between the cambium and the resting buds (Bachelard, 1969). If cambial activity is reduced, then the nearby epicormic buds may be given a chance to develop. This situation could arise during the winter, or on suppressed trees in low light intensities. An increased supply of the factors needed for cambial activity might therefore indirectly reduce epicormic production. Such factors are warm temperatures, plant hormones (especially auxin), carbohydrates and nitrogen, mineral nutrients and sufficient supply of water to maintain cellular turgidity.

With this range of external stimuli in mind, how might they all produce the same effect on the tree, namely the emergence of epicormic shoots? It seems likely that they all have some influence on a common physiological process; possibly the production or transport of auxins synthesised in the crown, or the balance of auxin to cytokinin around the bud initials. Bowersox and Ward (1968) showed that auxins at concentrations from 0.25 to 1.0 per cent inhibited epicormic bud emergence when applied to white oak stem segments *in vitro* and our studies with synthetic auxins and auxin transport inhibitors have indicated that in oak, epicormic bud emergence is under the control of such plant growth regulators. If oak trees are partially 'girdled' with a semicircular saw cut in the trunk, epicormic buds are stimulated to emerge below the cut.

This response might be due to the interruption of the supply of factors from above, a build-up of factors from below, or a combination of both. With two cuts, one above the other separated by 0.5 m, there is greater emergence from below the lower cut. This suggests that root-related, possibly osmotic factors are important. If NAA, a synthetic auxin, is applied to the girdles then epicormic emergence below is suppressed, while introduction of the auxin transport inhibitor, TIBA, to the cambium, stimulates bud emergence.

When solutions containing cytokinins and gibberellins was injected into oaks there was massive proliferation of ray and axial parenchyma by the cambium, but no significant effects on epicormic production, suggesting that perhaps cambial competition is not important. The results obtained are consistent with a mechanism in which an edogenous, downwardly-transported inhibitor, probably an auxin, interacts with an upwardly-mobile promoter to control epicormic bud emergence.

Presently, there are two schools of thought on how thinning might influence the level of auxin around the dormant buds. One proposes that light falling on the stem penetrates the bark and causes the destruction of the auxin IAA in the cambial tissues, while the other envisages modulation of auxin through changes in tree water status.

The first hypothesis fails to account for the existence of free-standing trees with clear boles, although clearly, genetic factors, including differences in bark thickness may play some important part here. Certainly, light is able to accelerate the oxidation of IAA in the laboratory, but apart from the measurements of light penetration though the bark, there appears no substantive evidence to support this theory of epicormic control. Further, the occurrence of epicormics as 'agony shoots' on suppressed and over-topped trees in heavy shade seems difficult to explain if light is the only stimulus. Certainly, light is of importance for growth and vigorous development of epicormic branches after their initial emergence. Often trees next to rides and clearings have larger, although fewer, epicormic branches.

Traditionally, stands of oak have been thinned in the autumn for reasons of management; there is less waste if trees are felled when dormant, extraction is easier as there is less ground foliage, and foresters are not then involved with other work, such as planting. However, we have found that trees thinned during the summer are less likely to produce epicormic branches. When trees are thinned in the spring, there follows a rapid emergence and growth of epicormic buds, which arrests once the leaves of the crown have unfolded. If the crown is already present before the thinning occurs, then there is some shading between trees, and the crown is presumably already producing a supply of auxins capable of inhibiting epicormic emergence. This beneficial effect of summer thinning is carried over into the second year after thinning, suggesting that summer thinning produces a less severe disturbance to the equilibrium of the tree than autumn thinning.

After the canopy is fully developed, the inhibition by auxin might be sufficient to prevent bud emergence despite any stimulation of root growth by thinning. Equally, shading by the canopy might also be an important factor suppressing bud emergence during the summer, even though exposure to light cannot be the factor solely responsible for bud emergence stimulated by early thinning. The role of light might thus be a 'permissive' one, both exposure to light and the specific thinning stimulus being required for bud emergence.

The second hypothesis proposed to account for the occurrence of epicormic shoots on oak suggests that they are associated with an increase in water available to the trunk. Thus, thinned trees are free of root competition while suppressed or pruned trees have reduced crowns and hence reduced transpiration. Another possibility is that in dense stands the root systems of individual trees may have 'joined up' or anastomosed. When the stand is thinned, the trees remaining will benefit from the increased volume of roots serving them. When trees are thinned, an anastomosed root network beneath the soil need not initially be affected.

Our measurements of the levels of auxin IAA in the cambium of thinned trees have shown that IAA levels are lower than in unthinned trees during the summer after thinning. Also, this difference was associated in the thinned trees with a reduction in the water content of the cambial tissues. Possibly thinning increases water stress, thereby reducing IAA levels, leading to the subsequent removal of epicormic bud inhibition. Water stress might be increased by the increased exposure of the canopy after thinning, but experiments where trees were injected with water under pressure have shown no effect on the emergence of buds in either thinned or unthinned trees. Therefore it is premature to judge whether the difference in auxin levels is the result of changes in the water status of the trees. More detailed measurements of tree water relations are under way this year.

Account needs to be taken also of the occurrence of epicormic shoots on suppressed trees in unthinned stands. Such trees clearly cannot be water stressed by exposure. However, their crowns are much reduced when compared to dominant trees and might be unable to produce auxin in sufficient quantities to maintain suppression of the buds lower down the stem.

Conclusion

Epicormic bud emergence would appear to be controlled both by factors linked to crown development, possibly mediated via auxins and/or light, and by factors linked with root activity. If the crown is reduced then upwardly-mobile promoters originating in the roots might stimulate epicormic growth. The stimulation of epicormic bud emergence by thinning might result from an increase in canopy exposure and mediated via reduced IAA production, or by an increase in root-produced factors supplied from a network of anastomosed root systems previously serving a denser stand of trees. If light should also fall on the stem, its role, rather than being a stimulus for emergence, might solely by a 'permissive' one of providing energy to enable the young shoot to emerge and develop.

The use of clonally-propagated, or mass-selected seed-propagated elite genetic stock with a low tendency to produce epicormics would appear theoretically to be the best long-term solution for epicormic control. Such elite trees could be planted initially at, or closer to, the finally required density, which would obviate or reduce the need for thinning. Some benefits for epicormic control would then accrue, even if elite clonally-propagated stock was not pre-selected for low epicormic production. However, selection for epicormic-free trees may be difficult as dormant buds are not always visible until they emerge as shoots and there is considerable variation in the appearance of trees at different ages.

To make meaningful genetic selections, a thorough knowledge of bud formation and development and the mechanism of bud suppression in different species will be required.

Summer thinning, when the crown is fully developed, is a promising means of reducing the emergence of epicormics. After summer thinning, a chemical treatment such as maleic hydrazide to inhibit the reduced amount of epicormic growth still evident might beneficially be used.

Without summer thinning, control of epicormic growth by treatments with herbicides would require yearly, if not more frequent, applications and may result in knot holes where the dead branches were attached. Similarly, other types of hormonal applications to maintain suppression would require repitition of the treatments during the years of the thinning response and then would only be practical on an amenity scale.

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Broadleaved Woodland Conservation — The Search for Balance

G.F. Peterken
Nature Conservancy Council, Peterborough

The Nature Conservancy Council's contribution to the development of the 1985 policy was part of a continuing search for a reasonable balance between timber production, nature conservation, landscape conservation and many other sometimes conflicting requirements.

Although there has not been a great change in the area of broadleaf woodland over the last 40 years — as classified by Forestry Commission censuses — the NCC has been concerned because:

1. mature broadleaf stands have been felled rapidly;
2. semi-natural stands have been replaced with plantations;
3. conifers have partially or wholly replaced broadleaves in many woods;
4. native species have been reduced, especially oak;
5. many woods have been cleared to arable, especially semi-natural woods;
6. there has been a general reduction of ancient and semi-natural woods by clearance, felling and planting;
7. grazing continues heavily in upland woods;
8. many semi-natural woods are unmanaged, thus becoming impoverished as rides are shaded.

Entering the discussions leading to the 1985 policy, the NCC was especially concerned to:

1. stop woodland clearance;
2. promote new woodland of broadleaves on surplus arable;
3. ensure that most broadleaf woods are managed;
4. ensure that the management is based wherever possible on locally native tree species, traditional systems, natural regeneration rather than planting, and a diverse age structure; and
5. ensure that these features are especially promoted in ancient, semi-natural woods.

Essentially, this would increase the broadleaf resource; be conservative in retaining existing woods, revitalise management, and generally work with the ecosystem, not imposing our current concepts of the proper order.

In the late 1960s, forestry was emphasising timber production, conifers and return on investment, and was essentially separate from nature conservation. Correspondingly, nature conservation sought reserves, and was only beginning to be interested in management. Since then much has changed. Public support for nature conservation has increased, while it has decreased for forestry and agriculture. Nature conservation has recognised the need for management, and the legitimacy of taking a timber crop. Forestry has recognised the need for hardwoods and the developing gap in the supply from home woods. An 'alternative forestry' has developed — based on coppicing, conservation work, amenity management, unemployment relief and local small wood enterprises — which is virtually outside the ambit of the Forestry Commission.

Will the policy work, in the sense that we all agree that a reasonable balance has been struck? At present we do not know, and the great need now is to have an acceptable monitoring process. Nature conservationists still have many misgivings, but remain hopeful of a co-operative relationship.

Forestry and Famine — Arguments Against Growth Without Development

L. Roche
Department of Forestry and Wood Science, UCNW, Bangor

"A direct attack on rural poverty through a widespread revolution, green or red, is improbable, and would as in the past have mixed effects. A better life for disadvantaged rural people may be more feasibly sought through a different sort of change: through quiet personal revolutions in the perceptions, values and choices of professionals concerned with research technology and action for rural development" (Chambers, 1984).

Introduction

In 1974 during the time I was living in Ibadan, Nigeria, a small book was published entitled *Can Africa survive?: arguments against growth without development* (Davidson, 1974). The book made little impact and I have never seen it on anybody else's shelf. Nevertheless, the title and thesis of this paper are in part taken from that book, for almost everything I have seen and heard during the past 13 years of work and extensive travel in many African nations confirms the rightness of Basil Davidson's assessment of that continent's troubles. His proposals for their resolution are, however, open to question; but more of that later.

Why is there so much political instability, injustice and hunger in so many African nations at the present time? Why is there such massive destruction of natural resources, such as forests, upon which so many people depend for their very survival? Why is traditional husbandry, both of soil and water, almost everywhere neglected? Why is it that what has been done by the international community so far has had little or no effect in arresting the general impoverishment of people and the land and water resources that sustain them? Why is drought, or as it is more rightly described, deviations below the mean rainfall, identified as the cause of famine in African states when foresters and others have long forecast catestrophic decline in food production as a consequence of massive deforestation?

More than 40 years ago a distinguished French forester with profound experience of African conditions wrote:

"We are witnessing the death struggle of a plant world, slow stages in the drying up and degeneration of tropical Africa ... it is probable that the wholesale destruction of inland forests will accelerate deterioration of vegetation and soil in Africa and bring about acute desert conditions. The insidious thing about it is that, generally speaking, nobody seems to realise it. In much the same way that the friends of a very sick man, who has been an invalid for years, get so used to seeing him in an ailing condition that they forget that once he was in perfect health. They cease to perceive the slow encroachment of the disease until one day the sick man dies." (Aubréville, 1947).

Why have these prophetic words by a man of such experience and distinction as Aubréville had such little effect on the funding policies for African states of international and national agencies including the World Bank?

Unprecedented media treatment of drought, famine and the compassionate response of nations, has resulted in large sums of money being collected for the relief of famine. But the multitude of words and images generated has, perhaps not surprisingly, pushed aside for the time being at least, searching and deeper analysis of the causes of famine in our time which might provide answers to at least some of these questions.

What follows is a contribution to this analysis, and, given the great complexity of the subject, I am well aware that it is offered at the risk of appearing both simplistic and dogmatic. My remarks relate primarily, though not exclusively, to the highly populated and semi-arid lands south of the Sahara.

Deforestation and Rural Impoverishment

The prosperity of traditional African husbandry in times past has been vividly described by early explorers. Travelling across Africa between 1795—1797 from Gambia though the territory of the present-day states of Senegal and Mali, Mungo Park, the British explorer, was repeatedly struck by the prosperity of agriculture and the ecological richness and diversity of the landscape. One of his observations is worth quoting:

> "We passed a large town called Kabba, situated in the midst of a beautiful and highly cultivated country; bearing a greater resemblance to the centre of England than to what I should have supposed had been the middle of Africa. The people were everywhere employed in collecting the fruit of the shea butter tree from which they prepare the vegetable butter mentioned in former parts of this work. The kernel is enveloped in a sweet pulp, under a thin green rind; and the butter produced from it, besides the advantage of its keeping the whole year without salt, is whiter, firmer, and, to my palate, of a richer flavour than the best butter I have ever tasted from cows' milk. The growth and the preparation of this commodity seem to be among the first objects of African industry in this and neighbouring States, and it constitutes a main article of their inland commerce."

This report on the commercial importance of the shea butter tree in African States was written more than 180 years ago. The States through which Park travelled are now two of the most ecologically impoverished and poorest nations in Africa. The shea butter tree, what is left of it as a species, is still in its wild state, endangered, unselected and unknown to the world's planners of green revolution technology.

This tree is a symbol of the decline and destruction of traditional husbandry over much of the tropics. Its history can be multiplied many times over for other woody species throughout the region. Such species have received the attention of neither agriculturists nor foresters and it must be said that despite some small improvement in recent years, education and training, together with research and development in agriculture in the tropics, are still locked in conventional attitudes and policies that have been determined by historical accident rather than the needs of rural people. Most aid programmes in agriculture reinforce these policies.

The leviathan of western agricultural science, technology and commerce has historically concentrated on an extraordinary small number of plant species. In colonial times, and since, this same leviathan, without change of direction or modification of any significance, extended its power to tropical environments here it forged the green revolution, a high energy, essentially urban, mass production technology not easily transferable to most small scale peasant farming systems in sub-Saharan Africa.

The shea butter was without significance in the world markets in colonial times and was, with many other comparable food and fodder trees, ignored. All effort then and since has been concentrated on commodities familiar in world trade such as wheat, rice, maize, coffee and tea, and well-known to western science. In the meantime, the ecological bases of small-scale, traditional farming systems, and related sustainable natural resources husbandry such as that described by Mungo Park, have been and are being destroyed over much of the tropics.

Traditional forms of land husbandry were not assisted or given the opportunity to evolve to higher technological levels. They are now an over-taxed impoverished and neglected sector, albeit involving millions of rural people. The resulting exodus to cities and its political consequences inaugurate the familiar pattern of increased emphasis on green revolutionary technology, often with direct involvement of the public sector (state farms, etc.) and artificially maintained low food prices through government marketing boards. Over much of the tropics, because of these policies, the small farmer does not obtain the market price for his products. A vicious circle of increased penury and increased social and political instability in the rural areas is established without any improvement in the quality of life in the urban.

Scientists, planners and politicians have simply not grasped the fact that the economic and ecological bases of small-scale peasant farming systems depended on the continued existence of natural forest vegetation. For this reason the appalling consequences of deforestation, in terms of human deprivation, have not been foreseen. In Tigre and Wollo, regions of endemic famine in Ethiopia, whole mountain catchment areas and huge areas of farmlands on the lower slopes are denuded of forest vegetation and massively eroded. Low rainfall has merely exposed both the underlying collapse of the ecological bases of peasant agriculture in countries such as Ethiopia and the inadequacies of an urban/industrially based green revolution technology with its limited options in crop production.

The number of plants currently being used in modern agriculture is less than a fraction of one per cent of the flora of the earth. For example, fewer than 10 of the higher plant species of the earth's estimated 250 000 account for more than 70 per cent of the total cash receipts from crops from member States of the Organisation for Economic Co-operation and Development (OECD).

Man has hardly begun to explore, conserve and manage for his own benefit the genetic resources of tropical and sub-tropical forests, though these forests provide habitats for the richest plant genetic resources on earth including many of the centres of origin of major food crops. Ironically, famine-striken Ethiopia is one such centre.

Despite the adverse changes that have taken place in the ecology of African nations since Mungo Park's time, rural communities in the tropics still depend for a multiple of products on what is left of natural forest vegetation.

Two thousand million people, that is roughly three-quarters of the population of developing countries, depend on fuelwood and other traditional fuels for their daily domestic energy needs. Of these, 100 million are unable to satisfy their minimum energy requirements. A further 1050 million meet their needs by depleting the existing resource. By the year 2000 at least 500 million people will be unable to satisfy their minimum energy requirements (FAO, 1981).

Traditional forestry practice has not been concerned with fuelwood production and plantations established since the Second World War are large-scale industrial plantations for pulp and paper. The green revolution in agriculture is not concerned with fuelwood production. Yet it is certain that for the foreseeable future peasant farmers in the tropics must grow their own fuelwood supplies.

There are at least 300 million people practising shifting cultivation in the tropics, sustained by the continued existence of primary, secondary and degraded forests. Many more millions practise some form of sedentary agriculture but also continue to depend on the remnants of natural forest vegetation for food, fodder, fuelwood, building poles and other forest products. In India alone it is estimated that 60 million tribal people are sustained in their traditional way of life by the continued presence of natural forest ecosystems.

Over 1500 species of wild uncultivated plants, many of them woody species, are used by local people in the tropics as leafy vegetables. In Nigeria, field assessment has shown that there are 150 species of woody plants used by local people for a variety of nutritional purposes.

Time and again one reads that the forestry sector contributes one to three per cent of the gross domestic product of particular developing nations. Such statistics, which appear even in documents concerned with fuelwood supplies, invariably refer only to the quantified and monitored industrial sector, and more often than not, do not include values of other forest products including fuelwood. Yet it is certain that for the well-being of millions of rural people, the industrial forestry sector is often the least important fraction of the overall contribution of forests, woodlands and trees. The value of these in the provision of fuelwood, building poles, food and fodder; in the ecological underpinning of traditional agriculture and in the conservation and management of water resources, is rarely, if ever, properly quantified in national planning.

At a time when per capita agricultural production is decreasing over much of the tropics, and when chronic famine prevails in Africa from Senegal to Somalia, it is time to question these statistics and the basic assumptions of development which lie behind them.

Growth at all Costs

Following independence, most African nations abetted aided and by the international funding system have gone whole-heartedly for growth, and in an age of heroic materialism in the West, that is during the past 25 years, who could blame them? But growth without development is one definition of cancer. It can occur in nations as in individuals, and anyone who has visited Lagos and similar cities in the Third World will know what I mean.

> "Duly encouraged by foreign advice, the essential idea of African nations about national development has been to draw up a list of desirable projects of things that modern countries were thought to need, and call this a plan. The task then was and is to tout it around the world till the necessary 'aid' was raised. Usually the total that was raised fell a long way short of what was asked. But even what was raised then flowed into a system which belonged in all essentials to the colonial period. Such money flowed, that is, into an elitist structure concerned with its own enlargement, rather than with overall development for the mass of the population." (Davidson 1974).

In many African countries a miscellany of growth projects, often lacking any form of logical integration with each other and with the rural economy, has taken the place of carefully thought our strategies of national development. The beneficiaries of this have been primarily the industrialised nations.

The industrialised nations of the West pointed the way, and the post-independence growth boom, fuelled by cheap energy and massive imports, was launched. Cities grew grotesquely, and burgeoning urban elites achieved Rostow's fifth dimension of growth (Rostow, 1960), defined as mass consumption, while the vast bulk of the people remained almost untouched within traditional societies and subsistence agriculture.

The entreprenurial trading power of industrial nations, geared to the interests of urban governing elites in the essentially agrarian countries of Africa, is in my view by far the most important factor influencing urban growth and rural impoverishment in the Third World generally but particularly in African countries.

In comparison with the effects of this trading power, frequently given impetus by international funding agencies, bilateral aid programmes of the major powers are at best very small but real palliatives of human suffering and at worst mere public relations exercises facilitating the real business of selling everything from powdered milk to gigantic, ecologically and socially destructive dams and canals, not to mention armaments of every kind.

During this period of growth at all costs the small farmer and his family were deemed a hopeless case. You could not sell him anything since he had no money to buy, and he was and is ignorant, conservative and unteachable. Let him disappear and let large, mechanised farms, either state or private, feed the cities and his disinherited children. If this view was not always stated it was certainly always implicit in the policies followed. Research and development in agriculture were directed not to small farming systems but increasingly to cash crops and high yielding cultivars of rice and maize, which needed high inputs of water and fertiliser, and were beyond the use of the small farmer.

Examples of Internationally Funded Growth

The drive to enlarge and mechanise had the blessing of such agencies as the World Bank, the representatives of which in recent years have been referring to the Sudan as the Bread Basket of the World. With western advice and money the Sudan has ventured into one gigantic growth project after another — often in the teeth of contrary advice from Sudanese scholars in the University of Khartoum.

Its mechanised farming project, encouraged and funded by the World Bank, repeated all the ecological errors of the Tanganyika groundnut scheme. Seven million acres of natural acacia forest were bulldozed and replaced by a mechanised sorghum monoculture. Net discounted revenue had been finely calculated and expatriate experts gave freely of their advice. Within 3 years this scheme was abandoned and the World Bank is now seeking to rehabilitate the bulldozed and ravaged land by alternative schemes of agroforestry.

Irrigated farming along the Nile has been progressively mechanised. Pumps have replaced traditional manual and animal power with the consequence that probably 50 per cent of the land is lying idle because there is no fuel to work the pumps and because there are no spare parts. But, perhaps, no matter, since in the south the 300 km long, Jonglei Canal is being built at enormous cost, and in addition the Sudan has the distinction of building, with the encouragement and support of a well known multinational company, the largest and most sophisticated sugar processing factory in the world, designed to produce sugar at a cost vastly inflated above world prices.

The question surely must be asked; had the millions of borrowed money that have gone into these vast grandiose schemes of western influenced projects been channelled toward improving output of established farming systems, would there be famine in the Sudan today?

Unfortunately, there are many similar examples of western inspired and funded growth projects for countries other than the Sudan. The Manantali Dam, designed amongst other things to make the River Senegal navigable from Mali to the sea is costing millions of dollars. In addition to making the Senegal navigable it is proposed to establish on irrigated land, farms of 1000 ha minimum in size for the cultivation of wheat, rice and barley, crops alien to the region, in place of the traditional crops of sorghum and millet. The new crops are to feed the people of the cities of Dakar and Bamako now accustomed to the taste of imported cereals. Mali, with one of the most impoverished peasantries in Africa, has been provided with the encouragement loans, goods and services to proceed with this enterprise. Almost certainly the traditional husbandry and culture of a vast number of small farmers, and associated savanna woodlands, in the basin of the Senegal will be destroyed as a consequence of this project.

This is but one of the many examples where complex mosaics of traditional C4 food crops and tree legumes are being replaced by mono-cropped systems of comparatively less efficient C3 cash crops such as rice and wheat. One result is that a much narrower range of food and other plant products is available for local use, with a corresponding reduction in the self-reliance of the rural population, particularly during periods of low rainfall. In the absence of leguminous field trees, these crops require heavy applications of costly commercial fertiliser. Fertiliser requirements are further increased as the mineral nutrients contained in the crops are lost to the system with the removal of the crops. It has been estimated that in some areas the shift to mechanised, large-scale monocultures has reduced the human carrying capacity of the land from 25—40 individuals km^{-2} to 10—20 individuals km x 2 (Anon. 1984).

Such projects have many adverse ramifications one of which is the build up of sustained demand for foreign currency to service the debt and pay for massive imports of goods of every kind including, increasingly, food. To earn such currency Ethiopia clears the last of its forest remnants to plant more coffee, and Kenya is clearing another 50 000 ha of what is left of its virgin forest estate to plant more tea. The fact that there is famine in Ethiopia and northern Kenya does not seem to halt the spread of cash crops in both these countries, nor does it halt the continued imposition of grandiose projects as remote as is possible to be from the real needs of local communities. On the edge of Lake Turkana in northern Kenya you can visit the most sophisticated fish processing plant in the world. This is the claim made for it by the representatives of the industrialised nation that built and supplied it. There is unfortunately, one thing wrong about this factory. It has proved wholly unsuitable to the needs of the locality. It is now abandoned and you will find trees growing through its windows. It stands as a bleak monument to the folly and culpability of those representatives of Western nations who appear to have learned nothing from past mistakes or are unaware of them, or who are aware of them but are cynical enough to sell technology however unrelated to the real interests of nations.

The Consequences

The consequences of growth without development are now everywhere apparent in Africa. But it has taken famine on a large scale; famine televised into western sitting rooms to bring home to the western world that something is radically wrong.

Africa is fast losing the ability to feed itself. In 1984, 140 million of its 531 million people were fed with grain from abroad. By the end of 1985, the ranks of those fed from abroad, already nearly half as large as the population of North America, will have increased substantially. A recent assessment by the United Nations reported that some 10 million people had left their villages in search of food, many of them now crowded into relief camps (Brown and Wolf, 1985).

In addition to declining per capita food production and income, Africa's foreign debt is growing rapidly, not least because of rising food imports. The region's cereal import will climbed from 600 million dollars in 1972 to 5.4 billion dollars in 1984, a nine-fold increase. By 1984 food imports claimed 20 per cent of total export earnings. In addition, the cost of servicing the continent's debt is expected to reach 170 billion dollars by the end of 1985 which is an additional 22 per cent of export earnings (Brown and Wolf, 1985). Clearly the way ahead for the industrial nations of the world, if they are serious about eliminating the causes of famine, rather than merely reacting to its effects, cannot, and ought not to be, business as usual.

A Possible Way Forward

There is some hope, that lessons have at last been learned as a consequence of the world-wide publicity given to famine in Ethiopia. Even the World Bank appears to have lost its certainty in the effectiveness of its operations. Its Vice-President has very recently stated: "We along with other donors, I think it is fair to say, among all our achievements, have failed in Africa. We have not fully understood the problem, we have not identified the priorities, we have not always designed our projects to fit both the agroclimatic conditions of Africa and the social cultural and political framework of Africa." (Brown and Wolf, 1985).

I have referred earlier to Basil Davidson's book, and indicated that while I subscribed to his thesis concerning the causes of Africa's troubles, his proposal for their solution is open to question. He concluded that the continent's difficulties can only be resolved within the confines of socialist states. Surely this is as simplistic a solution as the *laissez-faire* capitalist one, and Popes dictum springs to mind:

"For forms of government let fools contest
Whate'er is best administered is best."

There is a way forward, long recognised and articulated (Ward and Dubos, 1972) which though requiring elements of both ideologies is not ideologically motivated. India has tried to follow that way and we are beginning to see Tanzania loosen the shackles of state control of the economy while retaining all that has proved effective of its national priorities in ensuring equity and justice.

Once again we begin to hear what may be called a Gandhian philosophy of development discussed in the corridors of power. The planners do not of course refer to it as such, for these modes of thought are being forced on them by the collapse of former policies and not because of knowledge of this philosophy and conversion to it.

And what is this Gandhian philosophy? I gave what I thought was a very short but reasonable version of it in a paper delivered in Ibadan, Nigeria, in 1973 at a United Nations Symposium on Soil and Shifting Cultivation in Africa (Roche, 1974). This was 12 years ago and before the first widely publicised famine in Ethiopia. Since I believe it still holds good, I will repeat it here.

1. Through agriculture, however primitive, every environment has taught its inhabitants a certain way of life.
2. Attempts at improved agricultural output, to be successful sociologically and not merely in terms of output statistics, must take into account the way of life, customs and needs of the peasant farmer.
3. The technological change that must in time occur in tropical agriculture is best introduced by stages, particularly when the utilisation of available labour is low and the drift from the rural areas to the cities is high.
4. Rapid industrialisation and expansion of agricultural production for market are not synonymous with improving the welfare of peasant peoples in the tropics.
5. Although the traditional structure of subsistence agriculture is unsuitable in the long run for commercial farming, designed to feed large, non-food producing urban populations, output can be considerably improved within familiar traditional patterns of production.
6. Structural change is necessary only when output can no longer be increased within the traditional forms of production. However, when this stage is reached, technological change is likely to be evolutionary and thus less disruptive of the rural welfare of peasant peoples.

Here we have a framework for the opening up of what I have called a 'second front' in agricultural research and development in African states which will complement and not necessarily replace current, large-scale green revolution technology.

This second front will concentrate on small-scale farming systems and community needs, and research and development programmes will include those neglected plants traditionally valued by local communities. It will ensure the conservation of the natural forest estate and the management of rangelands and give greater attention than ever before to the role of trees in sustaining farming systems and providing rural people with fuelwood, food and fodder while protecting vitally important catchment areas and arresting soil erosion. Forestry in all its ramifications must become an integral part of agricultural development in African states in the future.

Conclusion

Until local people are given a say in their own destiny; until it is recognised that growth is not the same as development; until agricultural production by the masses is seen to be more important or at least as important as mass agricultural production; and until Western nations are prepared to forgo some of their selfish interests, there can be no major improvement in the present system despite the incidence and awfulness of famine and the generosity of famine relief.

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Agroforestry — Prospects and Potential in the UK

S.P. Carruthers
Centre for Agricultural Strategy and Department of Agiculture and Horticulture, University of Reading

Summary

Agroforestry is an ancient and widespread practice involving the integration of trees and crop plants or livestock. Worldwide interest in agroforestry has increased considerably in recent years, particularly in the tropics. In the UK the practice of agroforestry is, at present, very limited, but research interest is growing.

There are a number of reasons why agroforestry is worth considering as a more significant land-use for the UK.

1. There is a strong case for forestry on farms as national self-sufficiency in wood products is low (10 per cent), most UK land is farmland and the current problems of overproduction mean new farm enterprises are needed.
2. Agroforestry may be more desirable from the farmer's viewpoint (in terms of cash-flow and flexibility) and the national viewpoint (in relation to conservation interests) than plantation forestry.
3. There is evidence from research and practical experience, notably in New Zealand, that agroforestry is feasible and may be more profitable in some situations than forestry or agriculture alone.

At present the use of trees for shelter and the grazing of livestock in forest plantations appear technically feasible, but limited in potential application; silvopastoral and agrosilvicultural systems could be applied widely, but are less understood or developed; other systems (e.g. chickens under trees, complex multi-storey systems) are both undeveloped and limited in application, but may be important in particular circumstances.

The adoption of agroforestry on farms depends strongly on effective promotion, education, advice and information dissemination, on the development of markets and successful marketing and on suitable financial arrangements. Further research and development, is, therefore, needed on technical, economic and social aspects of the practice of agroforestry.

Introduction

While the practice of agroforestry is ancient and widespread, its scientific study is a relatively new phenomenon. However, interest has been quick to grow and the last few years have seen a mushrooming of agroforestry-related research and development projects and some practical implementations around the world.

Both the practice and the study of agroforestry are, at present, greatest in the tropics. Particularly indicative of this was the formation, in 1979, of the International Council for Research in Agroforestry (ICRAF); this organisation is based in Nairobi and has a mandate to stimulate, initiate and support research in agroforestry throughout the developing world.

In temperate regions agroforestry activity has been less evident — with the notably exception of New Zealand — but is growing. While interest in the UK has been weak even compared with other temperate counties, in the last couple of years serious consideration has been given to the potential of agroforestry in the UK, and a number of research projects are now underway.

In view of the increasing importance of

agroforestry worldwide and the interest beginning to be shown in this country it is timely to review what agroforestry has to offer in the UK; this paper aims to provide such a review.

What is Agroforestry?

According to the definition proposed by ICRAF, agroforestry is a collective name for land use systems and practices in which woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals in some sort of spatial arrangement and/or temporal sequence. This definition is, by no means, universally accepted and there are many others, but is becoming widely used and proves a useful working framework for the discussion of agroforestry.

It is clear from this definition that agroforestry is a generalised approach to land use with a diversity of specific traditional and innovative manifestations, and which may incorporate a number of components and techniques. Possible forestry components include forestry species (grown primarily for wood products) or tree crops (grown primarily for fruit or nuts); agricultural components include arable, horticultural and tree crops, pasture and grazing livestock. Examples of techniques include the use of woody perennials as fences (i.e. hedgerows), as protection for crops or livestock (i.e. shelterbelts, windbreaks, overwintering areas) and to maintain or improve soil conditions or fertility.

Why Agroforestry?

In the tropics agroforestry addresses a number of the pressing problems confronting those regions; in particular, integrating forestry with agriculture offers better environmental protection than agriculture alone, and provides much needed fuelwood.

While these problems are less of an issue in the UK, there are a number of other reasons why agroforestry is worth considering.

1. The present and anticipated future demand[1] for forestry products and levels of national self-sufficiency in the UK are such that there is a strong case for an expansion of the UK forestry resource.
2. The high proportion of UK land that is farmland together with the current problems of agricultural surpluses make a strong case for this expansion of forestry to occur on farms.
3. There is growing evidence from theoretical studies and practical experience in other countries, notably New Zealand, that agroforestry is not only feasible, but also, in some situations, more profitable that forestry or agriculture alone.
4. Agroforestry may be socially, organisationally and financially more acceptable to farmers than plantation forestry, offering interim income from the agricultural component, greater flexibility and scope for gradual adoption of forestry.
5. Agroforestry systems may be more desirable from a conservation viewpoint that plantation forestry or agriculture, providing attractive landscapes, promoting habitat diversity and preventing soil erosion.

Practical Experience

Experience of agroforestry in the UK is limited: the remnants of some traditional systems can be found and some current agroforestry practices can be identified. The latter tend to be informal and do not form a significant part (in economic terms) of individual farm businesses or the national agricultural scene as a whole, and are not well documented.

Past and present applications of agroforestry include: the productive and functional use of hedgerows; the grazing of livestock on parkland type pastures, in orchards and in forestry plantations; the use of pigs in orchards to consume fallen fruit in the autumn; and the rearing of game birds in farm woodlands.

Agrosilviculture[2] (strictly agrosilvopastoralism[3]) based on poplar has also been practised in the UK relatively recently. Poplars for traditional products planted at 8 m spacings were underplanted with wheat barley and oats for the first 6 to 7 years; after this period the trees were no longer sensitive to damage by cattle and the area was sown with mixed grasses and grazed for the remaining period.

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[1] Current UK consumption of wood is about 40 Mm^3 per year; only 10 per cent is from home production. Home production will increase, but at the present rate of expansion, this will only keep pace with demand which is expected to double by 2025; self-sufficiency will, therefore, be much the same.

[2] 'Agrosilviculture' refers to combinations of trees and crops.

[3] 'Agrosilvopastoralism' refers to all systems which include trees, herbaceous crops and pasture or animals.

The most widespread application in the UK is the use of trees to provide shelter for crops, pasture and livestock: shelterbelts and windbreaks are a common occurence around orchards and soft fruit and in exposed grazing areas, and a number of farmers use existing farm woodlands as overwintering areas for livestock.

The most relevant and interesting experience of agroforestry is that of New Zealand. This has centred on silvopastoral systems[4] based on radiata pine and sheep (mostly) or cattle. The initial impetus came from changes in the silvicultural practices advocated (lower densities, early thinning to waste, intensive pruning) which enhanced the grazing potential of forests, and a series of droughts in the early 1970s which resulted in large numbers of cattle being grazed in forests, but the concept quickly gained interest among farmers. Silvopastoral systems now occupy an estimated 30 kha of farmland and 70 kha of forest areas. The practice is still in its infancy, but results are so far promising. Similar systems have also been examined in farm trials in Chile.

Although, for many reasons, these systems cannot be directly transferred to the UK, experiences in New Zealand, Chile and elsewhere provide an important input and impetus to the consideration of agroforestry in the UK — in terms of a substantial volume of documented results and examples of successful, practical implementation.

Research and Development

The adoption of agroforestry systems in New Zealand has been accompanied by research and development on both biological and economic aspects of the systems. Research results are also available from elsewhere in the world, although there is a shortage of quantitative data.

In the UK, research related to agroforestry has been relatively sparse. Over the last few decades most attention has probably been paid to studies of direct or indirect relevance to the use of trees for shelter; some consideration has been given to the physiological aspects of tree crop mixtures, to the grazing of livestock in existing forestry plantations (i.e. forest grazing), and to upland and lowland silvopastoral systems. Very recently, research on agroforestry in the UK has expanded; some indication of this is given below.

Future Prospects

Technical possibilities

The technical prospects for various agroforestry systems and practices are listed below in order of technical feasibility (footnotes indicate institutes with recent current or proposed research projects relevant to particular applications)[5]:

Shelter[6]

There is enough evidence to suggest that use of trees for shelter can be of benefit to farming in a number of contexts: overwintering cattle or sheep in forests on better drained soils would seem a feasible and economic alternative to the use of buildings. The use of shelterbelts and windbreaks is well established.

Forest grazing[7]

The grazing of sheep for short periods of rotational grazing in direct planted forests on free-draining soils would seem possible, although there is likely to be little herbage available. It is unclear whether problems of root damage to tree roots by sheep on wetter soils can be easily overcome, but further investigation of optimum stocking rates and grazing management might be worthwhile. There seems to be less scope for grazing cattle in UK forests, but there may be a need to re-examine the scope for grazing livestock in orchards.

Silvopastoral systems on the hills and uplands[8]

Experience in New Zealand and elsewhere, coupled with current levels of agricultural profitability in the hills and uplands, suggests that the most immediate prospects for agroforestry in the UK lie in the establishment of trees, at wider spacings than conventional plantations, on upland grazing areas. Such systems would seem to have more scope on better uplands where species of greater value than Sitka spruce, which would repay the necessary intensive pruning, can be grown, and

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[4] 'Silvopastoral systems' are agroforestry systems which include woody perennials and pastures or animals.

[5] Institutes with studies covering a number of types of agroforestry system of general relevance to agroforestry include: the Centre for Agricultural Strategy, East Malling Research Station, the Forestry Commission, the Institute of Terrestrial Ecology and the Open University.

[6] Experiments on overwintering cattle in forest plantations have been and are being carried out in the Department of Forestry, University of Aberdeen.

[7] Experiments on sheep grazing in forest plantations have been carried out at Queen's University, Belfast.

less on the poorer hill areas where the value of Sitka spruce, which may be even less at close spacings, would not repay the labour inputs for pruning.

Trees on lowland pastures[8]

New Zealand experience and recent research in the UK indicate that silvopastoral systems might also be established in lowland areas. On better land in the lowlands the species choice is even greater, and there is scope for growing both higher value conifers (e.g. Douglas fir) and broadleaved species.

Novel silvopastoral systems

There may be some potential for systems based on animal species other than sheep or cattle. Of particular interest is the scope for integrating free range egg production with plantation forestry, for silvopastoral systems involving deer and for integrating forestry with game rearing.

Agrosilviculture

There are very little data available, at present, on the performance of tree-plus-crop systems, although certain advantages can be envisaged and some practical experience has been gained; an evaluation of existing knowledge and further investigation are needed.

Complex systems

While temperate climates would probably be unable to sustain complex systems comparable to the the homegardens[9] of the tropics, there may be scope for small-scale highly integrated agroforestry systems involving a number of components and incorporating a number of the technologies.

Implementation

Assuming agroforestry is technically feasible its implementation is likely to depend on three major factors.

Advice and information

The absence of a farm forestry tradition in the UK may mean many farmers lack interest or skills in forestry. The adoption of agroforestry systems on farms will therefore depend strongly on effective promotion, education, advice and information dissemination.

Markets and marketing

The success of agroforestry may depend on the development of new or expansion of existing markets for wood products, and on effective marketing by the farmer (who may be disadvantaged by the small-scale of his operations). Farmer—forester co-operatives may help.

Financial arrangements

The initial costs of establishing an agroforestry enterprise may be high and there may be a considerable time lag before the benefits accrue. The severity of cash flow problems will depend on technical factors, levels of government support and whether suitable financial arrangements can be made (e.g. reverse mortgages).

Conclusions

There are a number of reasons why agroforestry is worth considering for the UK; these relate to the supply and demand for forest products, agricultural surpluses, environmental issues and practical and research evidence, from the UK and elsewhere, of the benefits of agroforestry.

A number of systems and practices for the UK can be identified which vary in relation to their state of the art and potential: the practices about which most is known and which, therefore, appear most technically feasible (e.g. the use of trees for shelter, forest grazing) have limited application; the possibilities with wider potential application, such as upland and lowland silvopastoral systems and agrosilviculture, are less understood or developed; while a third group of possibilities (e.g. the rearing of poultry in forestry plantations) are both undeveloped and limited in application, but may be of great consequence in specific circumstances.

[8] Institutes with recent or current experimental research on upland and/or lowland silvopastoral systems include: Queen's University, Belfast; University College of North Wales; Hill Farming Research Organisation; Forestry Commission Northern Research Station; and the Department of Forestry and Natural Resources, University of Edinburgh. Most of these organisations have theoretical components to their research, and also envisage further work; other centres which have done some theoretical work or are interested in the subject include: the Welsh Plant Breeding Station; and the Animal and Grassland Research Institute.

[9] Homegardens, such as occur in more humid tropical regions, involve the cultivation of a number of forestry species (for timber and fuelwood), tree crops and annual and perennial herbaceous crops (often with the inclusion of small livestock) in small units in a mixed, multi-storey arrangement (in some cases comparable to a tropical rain forest.)

The future of agroforestry depends, therefore, very strongly on further research and development on technical aspects, combined with an examination of the social, organisational and economic factors affecting the adoption of such systems on UK farms.

Woodlands on the Farm — Beginning to see the Wood from the Trees

E.S. Carter

Farming and Wildlife Advisory Group, Sandy, Bedfordshire

Small woods on farms make up a significant proportion of the area of tree cover within the country. Most cover less than 10 hectares and two-thirds cover less than one hectare. They are on land mostly unsuited to agriculture and made up mainly of broadleaved trees. In some areas there is a mixture of conifers from past efforts at 'improvement' and the 10 per cent or so recently replanted are mainly conifers. It is difficult to arrive at an accurate figure for the total area but the best estimates are 340 000 hectares in England and Wales.

Small woodlands make a number of contributions to the countryside.

1. *Landscape* — woodlands are an integral part of the landscape, softening angularity and providing diversity and contrast. They are of strong visual importance, give great pleasure and would be greatly missed by residents and visitors.
2. *Wildlife* — some woods may be ancient but all have considerable value as habitats for wildlife or as a refuge for wildlife from non-woodland habitats.
3. *Historical* — many woodlands protect ancient earthworks or other artefacts or the woodland itself may be of historic interest.
4. *Timber* — even in a dilapidated state most woodlands have a value. Work by the Countryside Commission suggests that unmanaged woodland including coppice and scrub may average £1332 per hectare. Although small in the relation to turnover from agriculture it does represent a useful capital source.
5. *Game* — the actual and potential value of woodland for game is high and many are retained for this purpose.

Despite these valuable features the majority of farm woodland is neglected and unmanaged. This dereliction and deterioration can significantly reduce the landscape, wildlife, historical and recreational value of woods. In some cases these woods have been cleared and the land used for agriculture. But such action seems less likely now with reduced margins from crops and stock and pressure to take land out of cultivation rather than bring it into agricultural use.

As a country we no longer make full use of lowland broadleaved woods. Traditional markets for this type of timber have declined or have disappeared altogether. There has also been an important change in land tenure. At the end of the last century 82 per cent of occupiers of land were tenants. In 1960 this figure was 47 per cent and today it is around 30 per cent. Estates almost always retained woodlands in hand and farmers had no part in managing them. There is no experience or tradition of woodland management to pass on and woods are regarded as something of a nuisance or at best tolerated. There has, with a few exceptions, been no training at agriculture colleges in woodland management nor an appreciation of their use.

How can farmers interest in woodlands be aroused?

Interest will vary as with any other aspect of the farm but it is as well from the beginning to make it clear that farm woodland is not likely to be a major profit source. Any income will be small and produce is likely to be used on the farm rather than sold. Management will be for some other purpose, giving timber for farm use or firewood as a spin off.

Most farmers are interested in managing their woodland to improve its value for game, or wildlife or to maintain and improve its clearance and long-term value to the property.

The problem is to fit the work into the farming operations. Sale (or on-farm use) of wood may just about cover the costs but management is bound to be labour intensive. Farm labour may also lack the necessary skills and require training, or contractors may be used. In a few cases conservation volunteers may be used but they are more suited to small tasks such as clearing undergrowth and coppicing.

If conservation is the primary aim then a simple management scheme will be effective, some income will be possible but over time and not immediately. Derelict woods may have a lower commercial value but this will not reduce their conservation value so leaving it for a few more years will not matter. Tackling small areas each year over a long time period will give satisfactory results.

The availability of farm labour is likely to be the greatest restraint and some farmers have formed successful groups to employ a skilled woodman to manage their woods. The man is self-employed and works for each member of the group on a shared basis. This provides skilled management and continuity and enables the farmers concerned to follow a management plan for their small areas of woodland.

There is increasing interest in access to the countryside and in recreation. Woods can provide this more readily than open countryside.

1. They provide interest at all times of the year.
2. They can absorb large numbers of people while still giving a feeling of isolation, especially where paths and rides are curved and not straight.
3. It may be possible to create trails which the public pay to use; another small income source.

The great majority of farmers seem to have an undeveloped but genuine appreciation of their own woods and of woods in the landscape generally. A small number are sympathetic towards wildlife in their woods provided it does not impinge adversely on their agricultural or sporting interests. The majority go beyond sympathy to some degree of enthusiasm for different aspects of the woods, notably their wildlife and their value for recreation. There is also a substantial minority, perhaps as high as 1 in 5, who are either indifferent or hostile to woods and trees for personal or financial reasons.

Despite the appreciation and sympathy there is a widespread lack of care for woods and in some cases an abuse of them. It is not generally realised that woods need care and thinking about woodland management is outside the normal management pattern of most farms. This means that the first action must be to attract the attention of farmers and landowners and offer them information so that they can take a new approach to attitudes and policies. It is essential to appreciate that woodland management on farms must be integrated with other essential farming activities.

There is no doubt that goodwill exists and that a significant number of competent and well respected farmers and landowners will take action to improve their woods. That they need help and advice to ensure that they do the right things for the right reasons is clear from the number of requests received for information. But there must at the same time be a definite effort on the part of all concerned and who wish to influence the situation in the country, to contact the much larger group, to make them aware of the woods and to offer advice and help.

The FWAG experience confirms the Countryside Commission study findings. Taking a sample of farm conservation advisers covering a range of counties, some 20 per cent of their work concerns advice and enquiries about farm woodland.

The approach must be to assess the value of the wood as it stands:

1. to assess the use being made of it (for example, is it being grazed or used for firewood?); and
2. to consider the farming wishes and objectives — design a scheme and make proposals which will incorporate management for conservation, wildlife or game and with some small return from timber perhaps for sale or on farm use.

Despite the fact that this country imports most of its timber and that some sections of the media and some politicians advocate farm timber as a solution to agricultural problems, farm woodland will not be a major profit centre. Management must be for other purposes.

However, we can now see the wood for the trees. The many studies which have been carried out and the more active discussion about woodland and its potential has stimulated interest; this is clear from the number of requests for advice. These discussions and closer study have also demonstrated the likely role which farm woodland will play in the economy of the farm. The answer is not very great in the short term and we therefore need to approach this problem from the standpoint of interest in landscape, wildlife, recreation, timber for on-farm use, firewood and in some locations letting the site for war games; but those involved should be careful not to encourage farmers to believe that they will make enough profit out of their woods to compensate for lower returns from crops and stock.

List of Contributors
(listed in order of paper presentation at the meeting)

Mr George Holmes, CB, FRSE
Director General
Forestry Commission
Edinburgh

Dr Melvin G.R. Cannell
Principal Scientific Officer
Institute of Terrestrial Ecology
Bush Estate
Penicuik
Midlothian

Mr Geoff Keighley
Forestry Consultant
86 Buriton Road
Winchester
Hampshire

Mr Larry Martindale
Energy Technology Support Unit
Building 156
AERE
Harwell
Oxfordshire

Mr Ken Stott and Mr Rodney Parfitt
Long Ashton Research Station
Bristol

Mr John Aldhous
Head, Silviculture Division
Forestry Commission
Edinburgh

Dr Julian Evans
Director, Forestry and Land Use Programme
International Institute for Environment and Development
3 Endsleigh Street
London

Miss Sîan Henman
Research Assistant
Department of Forestry and Wood Science
University College of North Wales
Bangor

Mr Trevor Wignall
Postgraduate Research Student
Pomology Department
East Malling Research Station
Maidstone
Kent

Dr George Peterken
Woodland Ecologist
Chief Scientist Directorate
Nature Conservancy Council
Northminster House
Peterborough

Professor Laurence Roche
Department of Forestry and Wood Science
University College of North Wales
Bangor

Dr S. Peter Carruthers
Centre for Agricultural Strategy
University of Reading
Reading
Berkshire

Mr Eric S. Carter, CBE
Farming and Wildlife Advisory Group
The Lodge
Sandy
Beds

Section Officers at 1986 Meeting

President:	Mr G.D. Holmes, CB
Vice-Presidents:	Mr J.R. Fletcher
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