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Forestry Commission Booklet 41

Fertilisers in the establishment of conifers in Wales and Southern England

J E Everard

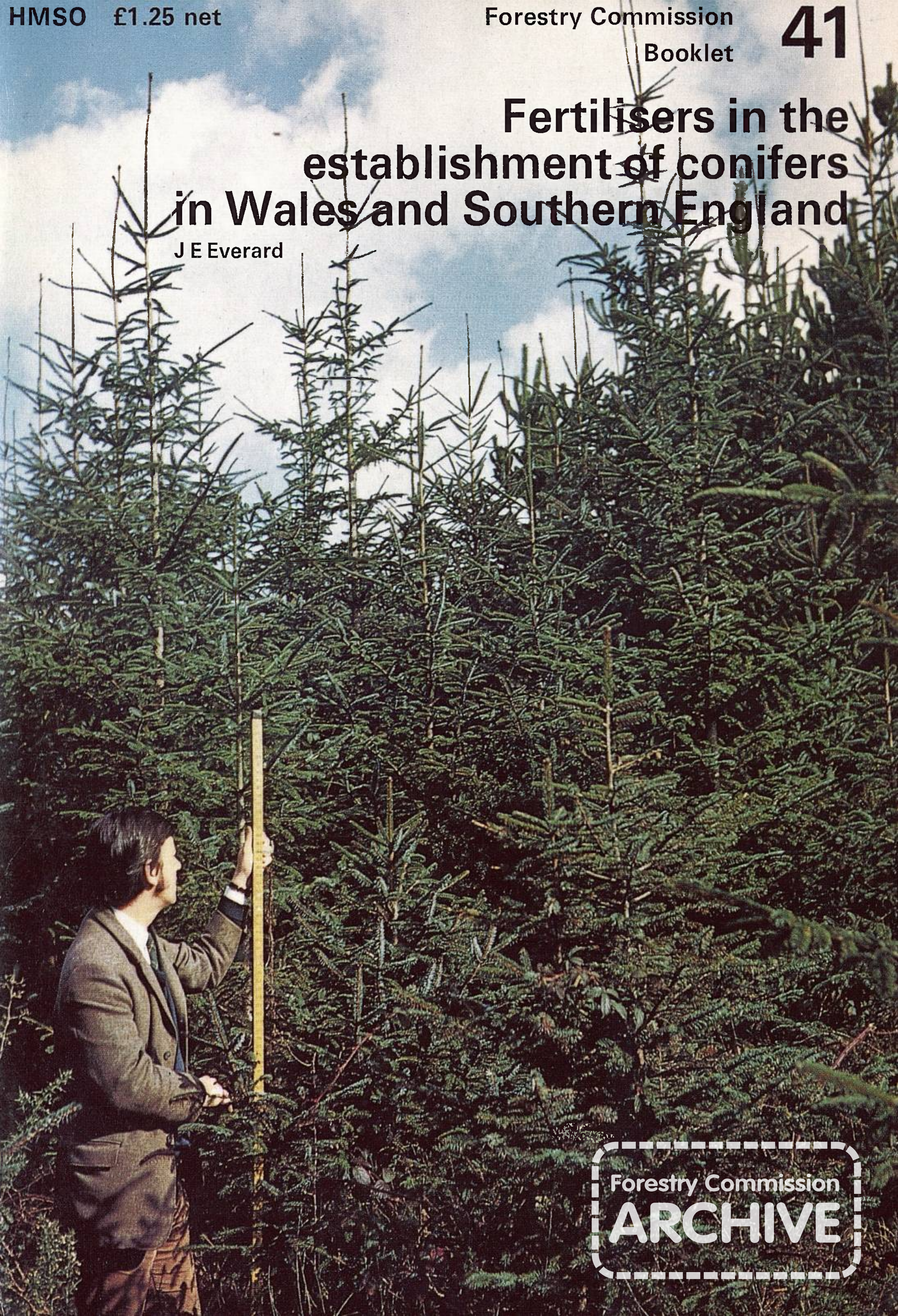

Plate 1, Cover. Sitka spruce at 12 years. The plot in the foreground has received no fertiliser and is P deficient. The plot in the background received 16 kg/ha of element P one year after planting, and 153 kg/ha of element P at 6 years. *Halwill Forest, Devon, Experiment 4. (24388).*

FORESTRY COMMISSION

Booklet 41

Fertilisers in the Establishment of Conifers in Wales and Southern England

by

J. E. Everard, B.Sc.

Forestry Commission

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Monsieur J. P. Maugé, Association Forêt-Cellulose, translated the Abstract into French and it is hoped that this booklet will be of value to French foresters.

The photographs were taken by official Forestry Commission photographers, the author and K. Baker, Research Head Forester at Exeter.

ABSTRACT

The results of about 50 forest experiments, together with practical experience of the use of N, P, K fertilisers and foliar analysis have enabled general recommendations to be made. In Southern England, west of the New Forest, 75 kg element P/ha should be applied at planting on heathland or former heathland soils. In Wales most upland sites should receive 50 kg element P/ha and in Mid and North Wales, soils with more than 25 cm of peat should receive in addition 100 kg element K/ha. N deficiency should be corrected in most cases by controlling *Calluna* with 2,4–D.

Foliar analysis should be used to confirm the need for top-dressing with P, which may be required on some sites between 5 and 8 years after planting.

Unground rock phosphate from North Africa, which is the recommended phosphatic fertiliser, may be broadcast at any season. Urea and crude muriate of potash, the recommended N and K fertilisers should be used only in spring.

Top height/age curves for 0–20 years are used to convert height differences in experiments to the number of years crop development is advanced. This period is then used in deciding if the use of fertilisers is financially justified. The curves are commended as providing objective standards of early height growth.

RESUMÉ

Les résultats d'une cinquantaine de dispositifs expérimentaux, en même temps que l'expérience pratique acquise dans l'utilisation des engrais NPK et de l'analyse foliaire, rendent possible l'élaboration de recommandations générales. Dans le sud de l'Angleterre, à l'Ouest de New Forest, apporter 75 kg d'élément P par ha à la plantation, sur sols de lande ou qui ont été en lande. Au Pays de Galles, sur la plupart des hautes terres, 50 kg d'élément P par ha, dans le centre et au Nord; des sols comportant plus de 25 cm de tourbe nécessitent un complément de 100 kg/ha d'élément K. Une carence azotée devrait être corrigée, dans la plupart des cas, par l'élimination de la callune au 2-4-D.

L'analyse foliaire permet de confirmer l'utilité d'un apport de P en couverture, qui peut être nécessaire, dans certaines stations 5 à 8 ans après plantation.

Le phosphate naturel d'Afrique du Nord, forme recommandée pour la fumure phosphatée, peut être épandu en toute saison. L'urée et le chlorure de potasse recommandés pour les fumures azotée et potassique, ne doivent être épandus qu'au printemps.

Les courbes d'évolution de la hauteur totale en fonction de l'âge, de 0 à 20 ans permettent de convertir les différences de hauteur dans les essais, en nombre d'années gagnées. Ce gain estimé permet alors de décider si la fertilisation est financièrement justifiée. Ces courbes sont tout indiquées pour servir de références objectives de croissance en hauteur.

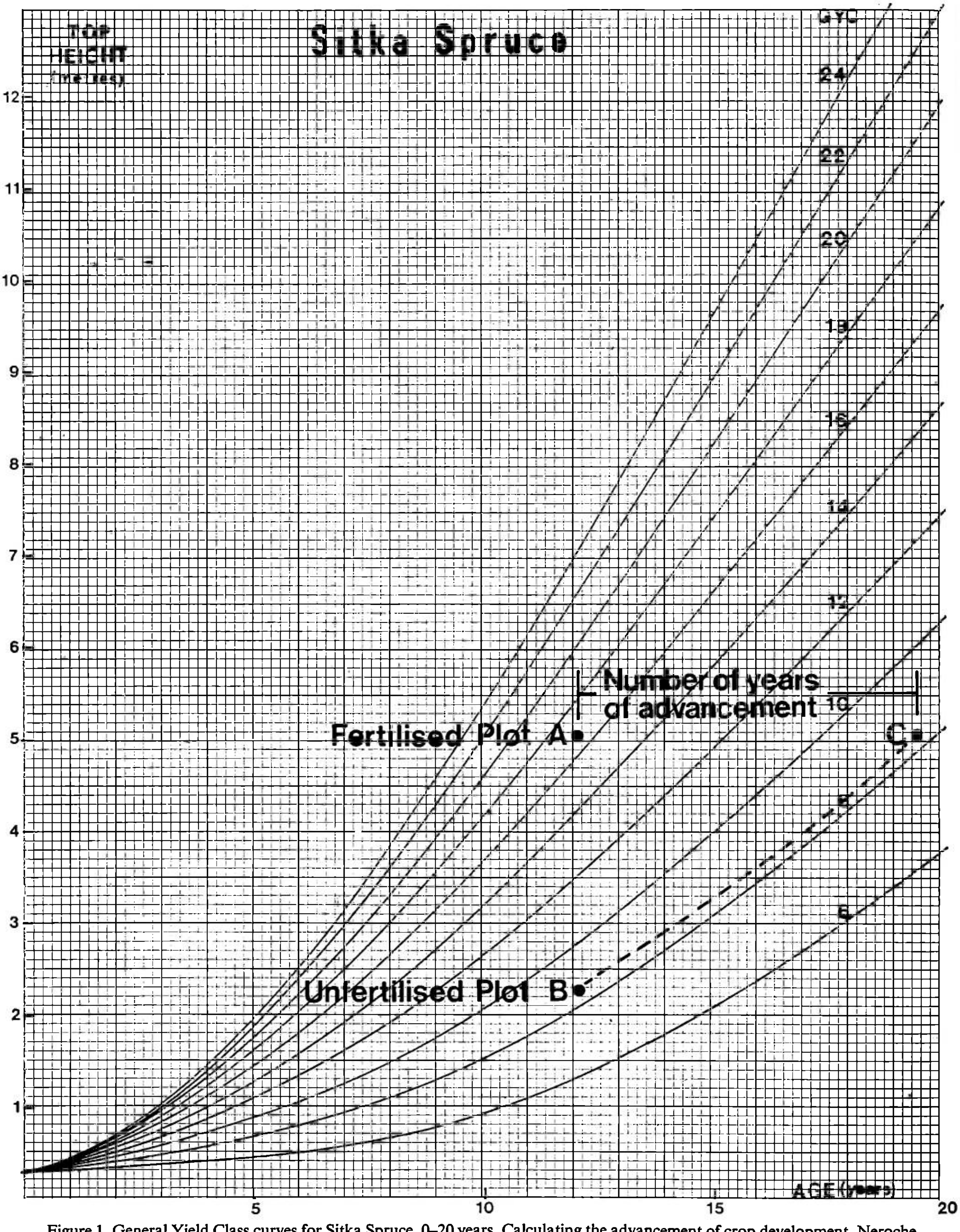


Figure 1. General Yield Class curves for Sitka Spruce, 0–20 years. Calculating the advancement of crop development. Neroche Experiment 1.

1. INTRODUCTION

The purpose of this publication is to answer some of the questions commonly asked about the use of fertilisers in young forest crops in Southern Britain, that is south of the counties of Lancashire and Yorkshire, and to summarise the evidence on which recommended practice is based. The three main sources of information are:

i. experiments in which deficient crops were topdressed or where different rates of nitrogen (N), phosphorus (P) and potassium (K) fertilisers were applied at planting.

ii. the results of fertilising forest crops in which nutrient deficiency had been diagnosed by foliar analysis.

iii. experience of the practical use of fertilisers at or following planting.

No attempt is made here to report all the results of current fertiliser experiments, about 70, nor are their predecessors, which date back to 1927, dealt with.

The probability of nutrient deficiency causing a fall-off in height growth, is much greater before canopy closure than after. In extreme cases height growth of the trees is checked; this condition is commonly referred to as "check". For this reason it may be preferable to regard a crop as established only when the ground vegetation has been shaded out, rather than when beating-up and weeding are finished, as is the present convention. During the establishment phase, crops – particularly those on sites which carry heathy vegetation – should be inspected periodically.

It was once said that: "an ounce of patience was worth a ton of slag". Today, it should be remembered that two years delay in crop development may be more costly than an application of fertiliser. For example, the Discounted Revenue (5% interest rate) for Sitka spruce General Yield Class 14 is about £250 per hectare, and two years' delay results in a loss in Discounted Revenue of about £26 per hectare.

Foliar Analysis

As foliar sampling and analysis is frequently mentioned in this publication it is important that the basis of the technique is understood. Current lateral shoots are collected from representative dominant trees at the start of the dormant season. These are analysed chemically and the concentrations of the nutrient elements are expressed as percentages of the oven-dry weight of the needles or leaves.

Over the last fifteen years, samples have been collected in the different treatment plots in fertiliser experiments, and these have been related to height growth. The relationships between height growth and foliar nutrient concentrations have been used to establish what concentrations of nitrogen, phosphorus and potassium (N,P,K) are commonly associated with poor and good growth. These standards are used to interpret the results of foliar analysis of samples collected by forest managers who are contemplating top dressing.

2. WHY FERTILISE?

Fertilisers are used to augment the natural supply of plant nutrients from the soil in order to correct or forestall deficiency. Since by its very definition, deficiency causes growth to fall below the site optimum (Everard, 1973), *fertilisers are used to improve growth where it is unsatisfactory or, preferably, to produce and maintain a satisfactory rate of growth.*

With one exception, fertilisers are not recommended for use in forest crops lying east of a line from Chester to Southampton; in this region nutrient deficiencies are seldom limiting. To the west of this line, where climatic conditions are often very favourable, tree growth can be most severely restricted by nutrient deficiencies, as shown in the foreground of the cover plate.

To find out if it is worth spending money on fertilisers it is necessary to carry out some form of calculation of costs and benefits. One possible method of evaluation is to assume that by applying fertilisers and correcting deficiency, the crop is able to maintain a normal pattern of growth. Or, on the other hand, the reduced rate of growth, caused by deficiency, delays crop development and all revenues from thinnings and felling are delayed accordingly. The financial implications can be determined by calculating the discounted revenues, and any discounted costs for the crop if it is fertilised, or if it is not. Obviously, there are exceptions where the difference between the fertilised and unfertilised crop is so clear cut, that formal cost/benefit evaluation is unnecessary. For example, at Wilsey Down, Kernow Forest, Cornwall, Sitka spruce grew to only about 1 metre in height in 20 years. Yet after the application of phosphatic fertiliser, the height of the crop doubled in the next three years.

For a formal evaluation it is necessary to estimate:

i. The yield class likely to be achieved by the fertilised crop. This is best based on measurements made in crops in similar climatic conditions to those at the site to be fertilised, and which have not been obviously affected by nutrient deficiency.

ii. The number of years which crop revenues are advanced as a result of fertilising. This can be done by using the evidence from fertiliser experiments on similar sites, such as is given in Appendix I page 18. The last two columns in the four tables of this appendix give the benefit of the treatment as the number of years saved by applying fertilisers. The "Current benefit", column 13 or column 16, gives a conservative estimate as the effect of the fertiliser is unlikely to be completely spent. Only when the foliar nutrient concentrations in the plots are equal, can it be assumed that the effect of the fertilisers is exhausted. In column 14 and column 17, "Predicted total benefit", the differences in foliar nutrient concentrations have been used to predict the total benefit of the treatment.

The method of calculating the "number of years saved" is shown in Figure 1. This shows the average top height of the fertilised plots A, and the unfertilised plots B, in an experiment in Devon, plotted on the General Yield Class curves, 0–20 years for Sitka spruce. If plot B continues to grow at the rate consistent with its present position, it will take slightly more than seven years to reach point C. The number of years separating A and C is the period of advancement due to the added fertiliser, or conversely the delay due to deficiency.

Two worked examples of the way to calculate the costs and benefits of fertilising are contained in Appendix II, page 43, as are the General Yield Class curves 0–20 years for the commonly-planted coniferous species (pages 29 to 41).

3. WHICH NUTRIENT IS REQUIRED?

Where fertiliser is required it is almost invariably phosphate. Nitrogenous fertilisers should be used very rarely, even though N deficiency is often diagnosed. This is because it occurs when "heather-sensitive" species are growing in heather (*Calluna vulgaris*), or when P deficiency is pronounced. In the former case the cheapest and most reliable treatment is to eradicate the heather and if necessary to apply P or PK fertiliser. This aspect is dealt with more fully later.

Where N and P deficiencies occur together on sites not dominated by heather, an application of P fertiliser is usually sufficient to correct both. Figure 2 shows how, in an experiment, Sitka spruce which was both N and P deficient, grew equally well whether given P, or P together with N.

Exactly the same response pattern occurred with Douglas fir in Exeter Forest, Devon, Experiment 20. Here, shown in Plate 2, 3 years after treatment, the top heights[1] were:

Unfertilised	2·7 metres
P	4·2 metres
NP	4·2 metres

Potash fertilisers are recommended at present for use in Wales only. However, uncompleted work on experimental results from Wareham Forest, Dorset, together with the findings of Leyton and Armson (1955) at Bramshill Forest, Berkshire, suggests that potash may be beneficial on some sandy soils also.

[1]Top height is used even in young crops to facilitate reference to General Yield Class curves (see Explanatory notes in Appendix I, page 18).

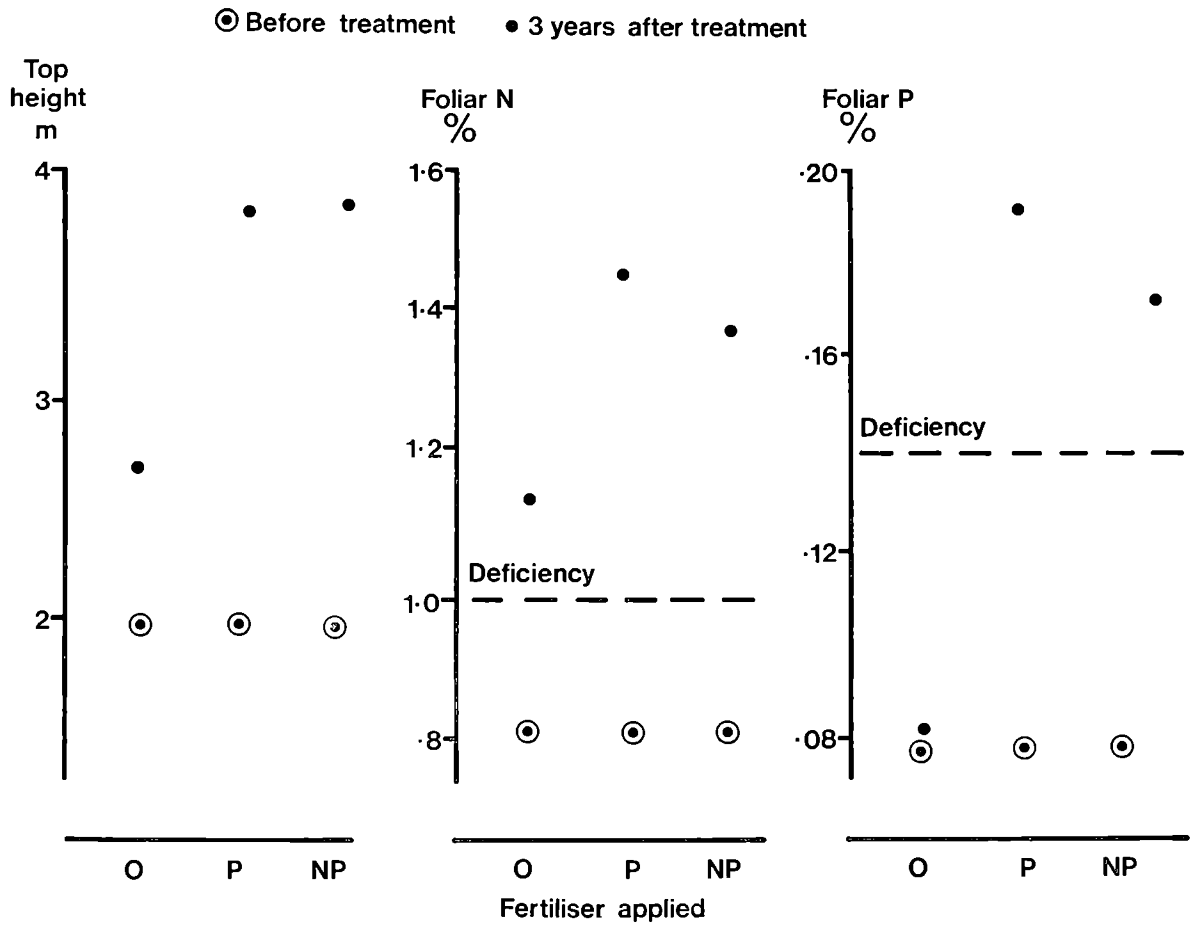


Figure 2. The effect of P and NP fertilisers. Neroche Forest, Somerset, Experiment 1.

4. WHERE FERTILISERS SHOULD BE USED

Central and Southern England

Phosphate should be applied to young crops on heathland or former heathland soils in the counties to the west of the New Forest, i.e. Cornwall, Devon, Somerset, Dorset and western Hampshire, also in south-east England on the Hastings Beds in the Weald of Kent, Surrey and Sussex. Outside these areas fertiliser should not be used unless there is local evidence to the contrary. A few cases of moderate P deficiency have been recorded in Berkshire, and in parts of Hampshire to the east of the New Forest, but these are not enough to support a general recommendation to fertilise. Also, phosphatic fertilisers have been beneficial on some Brown Earth soils in south-west England, but the area is insufficient to justify fertilising all brown earths.

Tansley (1953) distinguishes between Upland and Lowland heaths, but for present purposes they can be considered as one. The heaths can usefully be divided into dry and wet types, characterised respectively by heather (*Calluna vulgaris*) and purple moor grass (*Molinia caerulea*). Dry heaths frequently occur on podsols which may or may not have a distinct ironpan. The dominant heather can be associated with various species of heaths *(Erica)*, dwarf gorse (*Ulex gallii and U. nana*) bilberry (*Vaccinium myrtillus*) and the grass *Agrostis setacea.*

On the more fertile heaths, bracken (*Pteridium aquilinum*) occurs and where the ecological succession is unhindered by fire and intensive grazing, Scots pine, birch and other hardwoods may eventually become dominant. The benefit of phosphate on these better soils varies, so unless there is local evidence that fertiliser is beneficial, it should not be applied at planting. If the rate of growth after two or three years is not satisfactory, foliar samples should be taken and used to provide a basis for the diagnosis of deficiency.

The soils of wet heaths are surface water gleys and to a lesser extent ground water gleys and peaty gleyed podsols. Purple moor grass is the dominant vegetation under grazing. Some years after afforestation, *Erica tetralix,* dwarf gorse and heather become obvious, although they may often be inconspicuous at planting.

Wales

Phosphate is commonly applied at planting on most upland sites in Wales where it generally benefits growth. There are however instances where its use has not brought about improvements in growth; indeed there are cases where the application of phosphate alone has resulted in a slightly reduced rate growth. Potash has been used for about fifteen years to alleviate deficiency in newly planted crops in certain forests.

Classification of Sites for Fertiliser Requirements

The following factors have been used to classify sites for fertiliser requirements:

i. the depth of peat or peaty humus;

ii. the ground vegetation that can be expected after enclosure;

iii. in a limited number of instances, the underlying geology.

The system of site classification described by Pyatt *et al.* (1969) has not been used here, principally because some of Pyatt's types are sub-divided for present purposes and in other cases types have been aggregated and then sub-divided on a different basis. However, the correlation of Pyatt's types and those used here are to be found in Appendix III, page 47.

Recommendations

The depth of peat or peaty humus is the first factor to consider, and recommendations are made on the following basis:

A. Peat or peaty humus absent.

B. Peat or peaty humus less than 25 cm deep.

C. Peat more than 25 cm deep.

A. PEAT OR PEATY HUMUS ABSENT

Prescription: **A1 No Fertiliser**

Relevant experiments[1]: None

Growth is usually good on these soils, and even where this is not so foliar analysis has usually indicated an adequate supply of nutrients. These soils are brown earths and the non-peaty surface water gleys and recent alluvial deposits. The range of vegetation is extensive with the commonly occurring species being:

Brown earth: bracken (*Pteridium aquilinum*), bramble (*Rubus fruticosus*), grasses including *Deschampsia flexuosa, Holcus, Agrostis, Festuca,* and hardwood scrub.

Surface water gley: *Deschampsia caespitosa, Molinia, Holcus,* thistle (*Cirsium*), rushes (*Juncus effusus* and *J. conglomeratus*).

Note: [1]Relevant experiments, where they exist are listed in Appendix I, page 18.

B. PEAT OR PEATY HUMUS LESS THAN 25 cm DEEP

Consider each pair of alternatives and follow the most appropriate path in the decision tree, until reaching a fertiliser prescription.

Tall rushes (*Juncus effusus* or *J. conglomeratus*) common
Prescription: **B1 No fertiliser**

Tall rushes not common

Heathy vegetation (*Calluna, Erica* or *Vaccinium*) common
Prescription: **B2 50 kg P/ha**

Heathy vegetation not common

Geology
Silurian
Ordovician
Cambrian
Millstone grit (Carboniferous)
Prescription **B3 50 kg P/ha**

Geology
Devonian
Carboniferous
(exc Millstone grit)
Prescription: **B4 No fertiliser**

Relevant experiments **B1** none

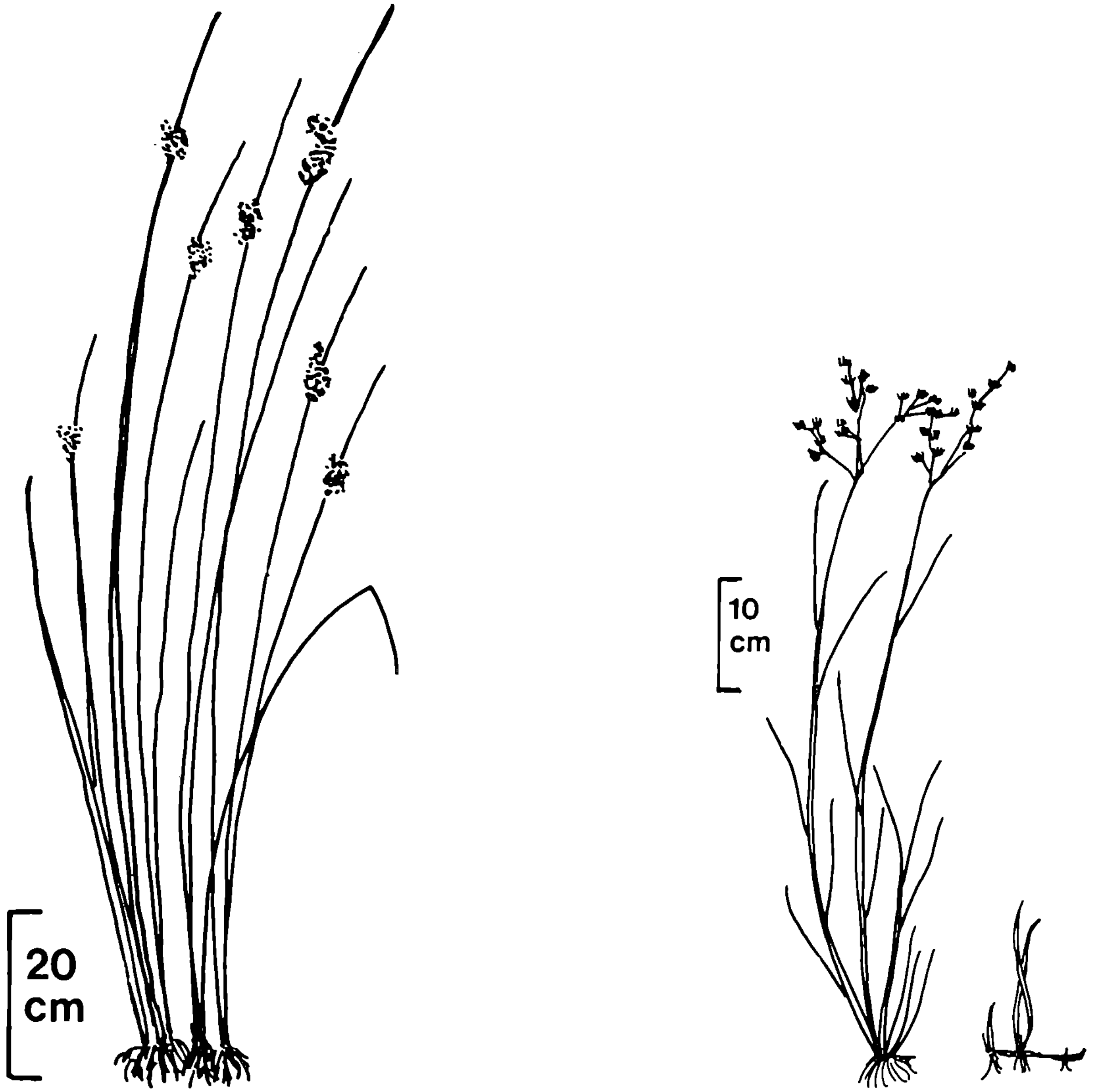
B2 Taliesin 4 (Rheidol Forest)
Aeron 2
Tarenig 2, 4 (Ystwyth Forest)
Clocaenog 52 (iv–vi)

B3 and **B4** } none

It is not surprising that there are no experiments on those sites for which fertilisers are not recommended and where growth is usually good. In numerous instances foliar analysis has shown high concentrations of N, P and K on soils which carry tall rushes (*Juncus effusus* and *J. conglomeratus*). These two species should be distinguished from *J. articulatus* and *J. acutiflorus* which usually indicate poorer conditions (see Figure 3).

The recommendation not to apply fertilisers on non-heathy sites on the Carboniferous and Devonian geologies has no experimental backing at present. However, foliar analysis, principally in the forests of the South Wales coalfield, show no general nutrient deficiencies in crops that were not fertilised at planting. Phosphate deficiency does occur on soils derived, either *in situ* or on glacial drift, from the Millstone Grit measures of the Carboniferous, so these sites are included with the Silurian and Ordovician geologies. Prescription B3 applies mainly to *Molinia*-dominated soils common in mid-Wales, where peat depth is greater than 15 cm and where *Eriophorum vaginatum* is common in the dominant *Molinia* vegetation, K deficiency may occur or may be induced by the application of phosphate alone. Where local evidence exists that this is occurring, K should be applied with P at planting.

Important indicator species may not be obvious immediately after planting because of past heavy grazing, so it is desirable to check the vegetation on comparable soils that have been planted for some years. Very rarely, heather (*Calluna vulgaris*) is associated with bracken, and on such sites P may not be necessary. On many heathy sites, heather quickly becomes the dominant vegetation. Heather "check" then



Juncus effusus &
J. conglomeratus
Height 60–150 cm
No leaves on flower stems
Pith continuous

Juncus articulatus &
J. acutiflorus
Height 40–80 cm
Leaves on flower stem
Chambered pith

Figure 3. Identification of rushes, *Juncus* species.

occurs in most conifers other than pines or larches. The trees appear to be unable to form the normal mycorrhizal association with the result that N, and to a lesser extent P and K, becomes deficient (Handley 1963). This leads to stagnation of growth, which may in extreme cases last for more than 30 years if untreated. The methods of treating such crops are dealt with later. See also Plate 3.

C. PEAT, DEEPER THAN 25 cm

- Tall rushes (*Juncus effusus* or *J. conglomeratus*) common
  Prescription: **C1 No fertiliser**
- Tall rushes not common
  - Heathy vegetation (*Calluna, Erica, Vaccinium*) common
    - *Geology* Carboniferous Devonian
      Prescription: **C2 50 kg P/ha**
    - *Geology* Silurian Ordovician Cambrian
      Prescription: **C3 50 kg P and 100 kg K, both per ha**
  - Heathy vegetation not common
    - Dominant vegetation: *Molinia* with *Eriophorum spp*
      Prescription: **C4**
      50 kg P and 100 kg K, both per ha
    - Dominant vegetation: *Molinia* with *Deschampsia flexuosa*
      Prescription: **C5**
      No fertiliser

Relevant experiments		
	C1	None
	C2	Rheola 7
	C3	Clocaenog 51, 52 (i–iii), 53 Tarenig 11 (Ystwyth Forest)
	C4	Tywi 1, 10, 12 (part) Rheidol 5 Tarenig 7, 9 (Ystwyth Forest)
	C5	Taliesin 15 (Rheidol Forest) Tywi 12 (part)

Deep peats are generally regarded as infertile soils, but on some types the nutrient requirements of Sitka spruce are, in fact, met throughout the rotation. The most fertile types are the basin peats which are "flushed" by water rich in mineral nutrients and oxygen. These usually carry a vegetation of tall rushes (*J. effusus* or *J. conglomeratus*), *Molinia*, thistle (*Cirsium palustre*) and *Polytrichum* moss. As on the soils with shallow peat, although there is no experimental evidence available, growth and the results of foliar analysis indicate adequate nutrients. Another type which should be given no fertiliser at planting is where *Molinia* and *Deschampsia flexuosa* form the dominant vegetation. This is often a hill peat and occurs commonly in mid- and South Wales.

The deep peats that carry heathy vegetation, particularly those that have a mixture of *Trichophorum* (*Scirpus*), *Eriophorum* and *Sphagnum* moss can be regarded as the least fertile. In South Wales, this type is not common and where it does occur in this area, K deficiency has not often been diagnosed. However, on the geologies of mid- and North Wales, both P and K are required at planting. As mentioned previously, it is necessary to control heather if this becomes dominant.

Perhaps the most difficult fertiliser problem in Wales is the treatment of the non-heathy deep peats on the Ordovician and Silurian geologies. It is fortunate that there are now a number of experiments to provide guidance, in what is a complex situation. In the early 1960s, K deficiency was diagnosed in mid-Wales in crops that had received only a low rate of phosphate at planting, and so experiments were established at Tarenig, Ystwyth Forest, Cardiganshire. On similar soils some 20 to 30 km to the south, K deficiency has recently been demonstrated in Tywi Forest, Cardiganshire, Experiments 1, 10 and 12. With the exception of Tarenig Experiment 9, where there was no response, potash has generally been beneficial. Figure 4 shows the effect of topdressing a crop that received phosphate alone at planting. These data are taken from Tarenig Experiment 7, the oldest on this soil type.

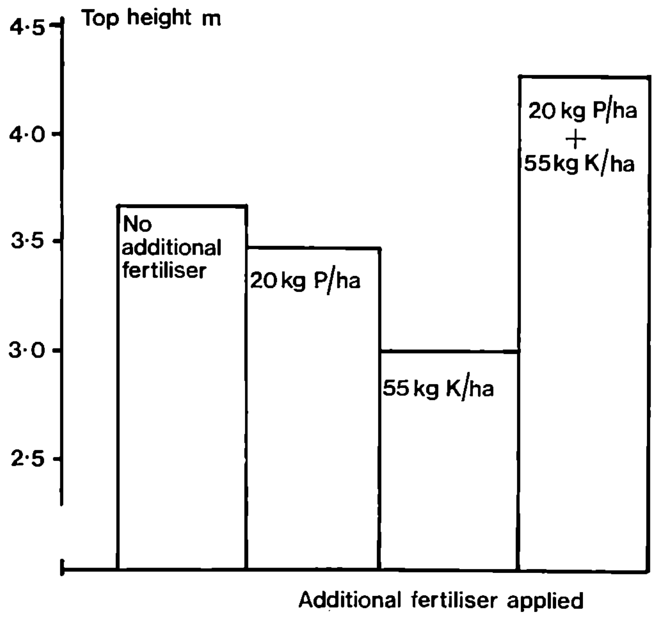


Figure 4. The effect of P and K fertilisers. Tarenig Experiment 7, Ystwyth Forest.

A number of experiments indicate that the K deficiency may disappear naturally when the crop is between 2 and 3 metres top height, but by this time growth will have been affected to varying degrees. It is probable that K deficiency leads to an increase in the incidence of frost damage, and thereby poor growth. If P alone is applied at planting the concentration of foliar K is likely to be reduced, as is shown in Figure 5.

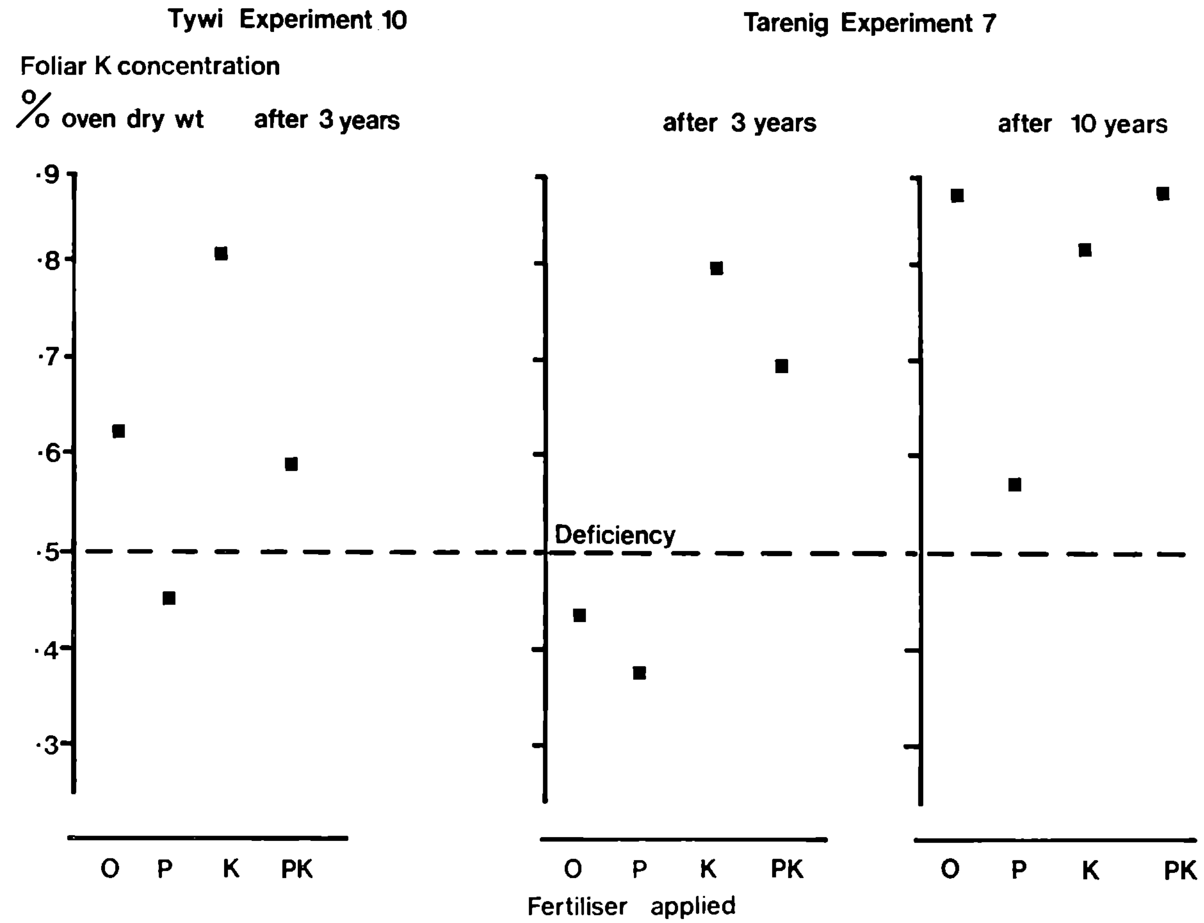


Figure 5. The effect of applied P and K fertilisers on the concentration of K in the foliage of Sitka spruce in two experiments. (Tarenig is part of Ystwyth Forest).

5. HOW MUCH FERTILISER TO USE

The results of experiments indicate that the efficacy of the various phosphatic fertilisers in common use is proportional to the quantity of element P which they contain. Unground rock phosphate is the cheapest source of element P, and so is commonly used. Some less frequently used forms of rock phosphatic fertiliser e.g. from Kola, Russia, do however, appear to be inferior (Mackenzie 1972) and should therefore be avoided.

Urea and crude muriate of potash are recommended as the cheapest source of N and K respectively, but there is little experimental evidence in the south of their efficacy compared with other forms of N and K fertiliser.

RECOMMENDATIONS

Prescription	*Material*	*Quantity kg/ha*
Nitrogen to provide 150 kg N/ha	Urea (46%N)	300
	"Nitram" (35%N)	400
Potash to provide 100 kg K/ha	Crude Muriate of Potash (50% K/60% K_2O)	200

Continued overleaf

Continued from page 9

Phosphorus

Southern England, To provide 75 kg P/ha:	Unground phosphate rock (Gafsa) (13% P/29% P_2O_5)	600
	Triple superphosphate (21% P/47% P_2O_5)	375
Wales, To provide 50 kg P/ha:	Unground phosphate rock (Gafsa) 13% P/29% P_2O_5)	375
	Triple superphosphate (21% P/47% P_2O_5)	250

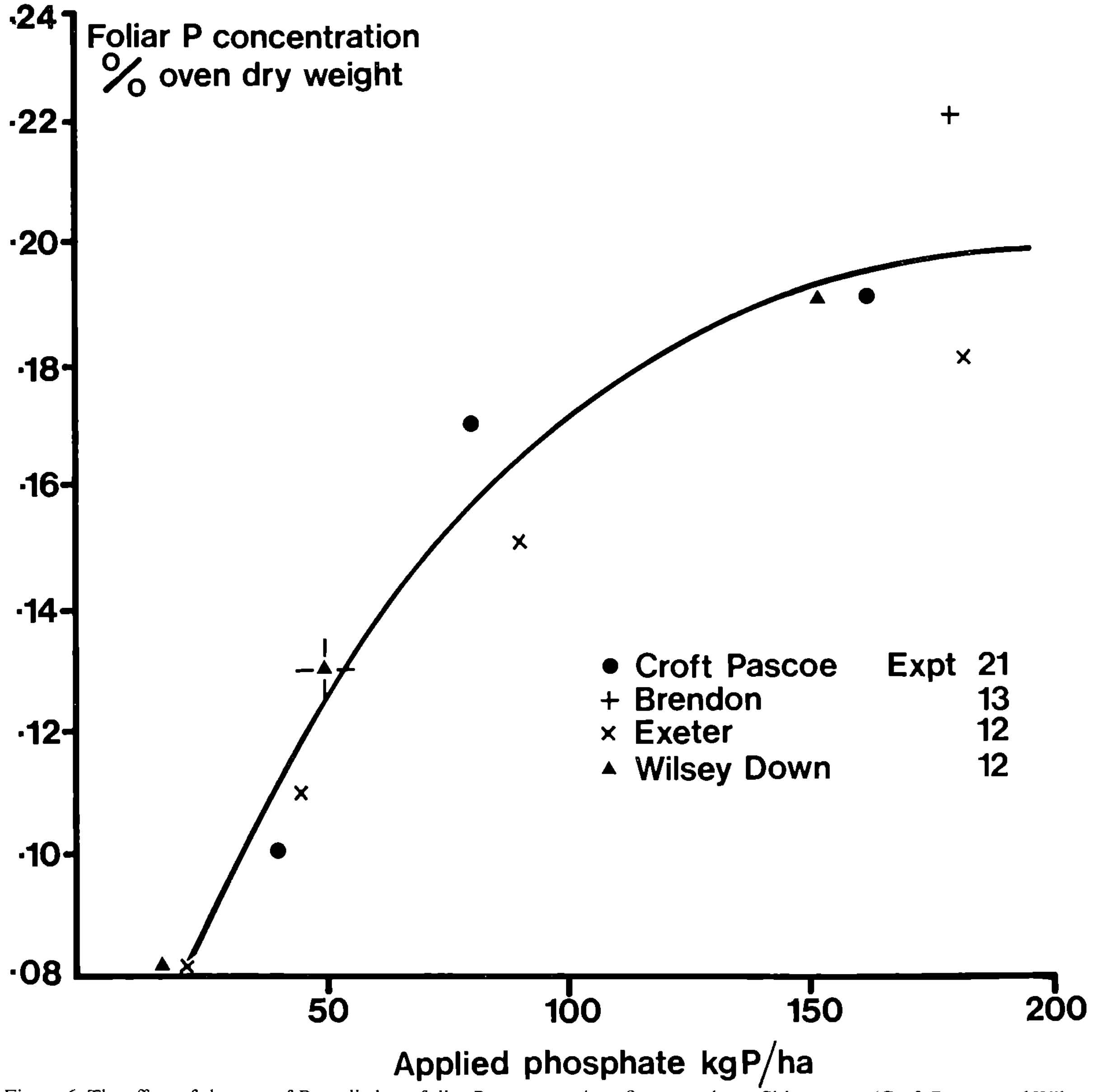


Figure 6. The effect of the rate of P applied, on foliar P concentrations five years later. Sitka spruce (Croft Pascoe and Wilsey Down are parts of Kernow Forest, Cornwall.)

The use of the heavier rate of P in southern England is based on evidence from a number of experiments, some of which is to be found in Appendix I, page 18.

The effect of higher rates of applied phosphate on foliar P can be seen in Figure 6.

As 0·14% P is regarded as the concentration in Sitka spruce at which top dressing is justified, 75 kg P/ha must be regarded as an initial treatment only. From Figure 6 a rate as high as 150 kg P/ha might appear justified. However, from the little evidence available, 75 kg P/ha at planting followed by a similar application six or seven years later is likely to be preferable to one very heavy application at planting. Experiments investigating this problem should provide the answer within a few years.

6. FERTILISER REQUIREMENTS OF DIFFERENT SPECIES

The recommendations made in the previous paragraphs can be applied to all species, with the exception of the coastal provenances of Lodgepole pine. The evidence from experiments in which more than one species received the same fertiliser treatments, indicates that if one species benefits from a higher rate, then other species suited to the same site, also benefit. Table 1 illustrates some of the evidence. See also Plates 4 – 6.

TABLE 1
RESPONSE TO FERTILISERS BY DIFFERENT SPECIES

Experiment	Species	Top Height (m)		Response
		Without fertiliser or with low rate of fertiliser (1)	With fertiliser or with high rate of fertiliser (2)	(2) as % of (1)
Clocaenog 52	Sitka spruce	1·5	2·5	167
	Lodgepole pine (intermediate provenance)	1·5	2·1	140
Tarenig 2 (Ystwyth Forest)	Sitka spruce	1·7	2·4	141
	Norway spruce	1·1	1·8	163
New Forest 21	Douglas fir	0·9	2·9	322
	Western hemlock	3·1	5·4	174
	Grand fir	1·1	1·4	127
Wareham 143	Corsican pine	1·5	2·2	147
	Monterey pine	3·5	4·5	129
	Scots pine	2·4	2·9	121
	Western hemlock	2·5	3·6	144
Halwill 4	Sitka spruce	3·8	5·7	150
	Lodgepole pine (coastal provenance)	8·3	8·4	101

In Halwill, Devon, Experiment 4 a South Coastal provenance of Lodgepole pine has grown very well over a period of 12 years without P fertiliser, whereas the adjacent Sitka spruce has shown a dramatic response to fertiliser. However, on some ericacious peats in Wales, coastal Lodgepole pine has been found to be P or PK deficient. It is therefore recommended that in south-west England the coastal provenances of Lodgepole pine are given fertiliser only where there is local evidence that this species has suffered from P deficiency. In Wales P or PK fertiliser should be applied to Lodgepole pine at planting only where ericaceous vegetation is likely to become common.

7. WHEN TO FERTILISE

At planting

Where fertilisers are recommended, they should be applied at planting, or as soon after as possible. Crops which did not receive the recommended treatment at planting should be topdressed as soon as the omission is discovered.

Top dressing

A second application of the recommended rate of P fertiliser is likely to be necessary at about six years on heathland soils in those parts of southern England specified earlier. In Wales, the need for early top dressing is far less but should be considered at about eight years in crops growing in heathy vegetation.

The first step in determining where topdressing is desirable is to assess whether the rate of growth is satisfactory. Clearly, site factors other than nutrient supply affect the rate of growth, but there are many indications that phosphorus deficiency is the factor most limiting to early growth, particularly on southern heaths. The best guide to assessing whether the rate of growth is satisfactory is to compare with crops of the same species on fertile soils in the same locality. Where this cannot be done use Figure 7 as a standard.

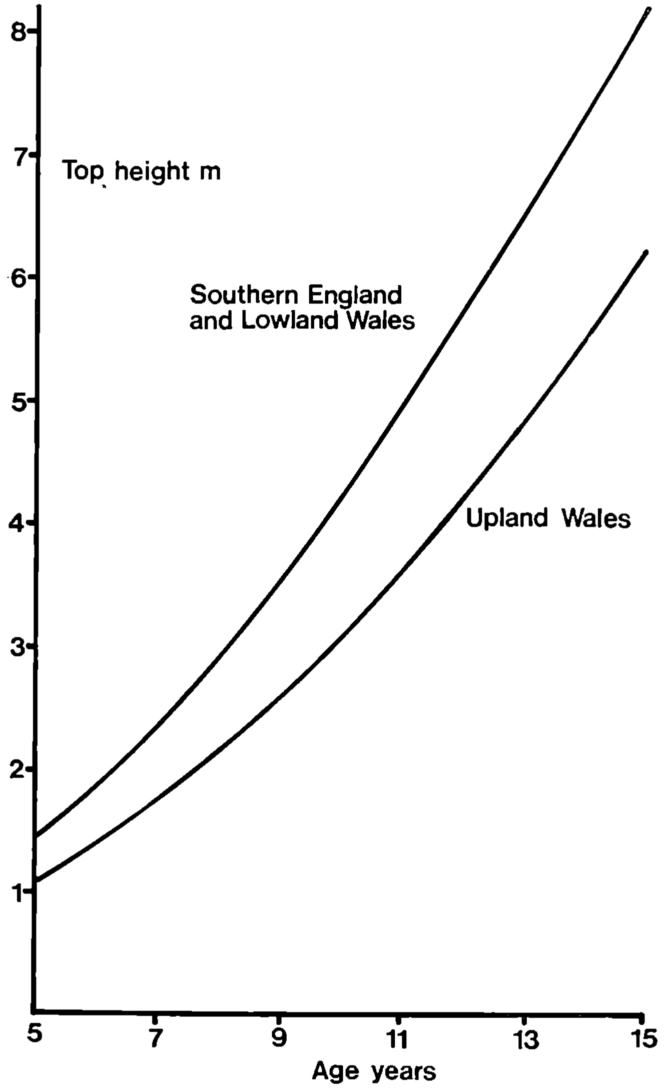


Figure 7. Growth and nutrient deficiency in coniferous crops. Where top height is less than that indicated, nutrients may be deficient and foliar samples should be collected.

The lines represent the rates of growth that can be expected if the recommended fertiliser regimes are used. Top height for this purpose is taken to be the average height of the tallest tree in at least five randomly sited 0·01 ha plots (radius 5·6m). Where height growth is less than shown in Figure 7, there is a possibility of nutrient deficiency and foliar samples should be taken as recommended (Everard 1973).

The two patterns of early growth shown in Figure 7 have been obtained by plotting experimental results on the Top height/Age curves which appear in Appendix II. Since most of the experimental results refer to Sitka spruce, the patterns are taken from this species. However, they can be applied to other species except perhaps larch, as the shape of the top height/age curve for fertilised crops of the commonly planted species is not markedly different. What does differ between the different species, is the General Yield Class predicted by the top height at a given age. Where forest managers wish to differentiate between species in setting acceptable rates of growth, staff of Silviculture Branch, Forestry Commission, Research and Development Division will provide the latest experimental data for the particular species and site.

Season of Application

P may be applied throughout the year, but N and K should be used only between early March and the end of June, otherwise there is a risk of reduced uptake and loss by leaching or breakdown.

When planning aerial application of phosphate it is often advantageous to aggregate two years' plantings for treatment at the same time. Little disadvantage is likely unless this leads to an increase in weeding costs. Except on wet peatland it is possible to treat an even larger area if the third year's planting ground is fertilised before planting or even before ploughing.

8. HOW TO APPLY FERTILISERS

Experimental evidence from England and Wales indicates that tree growth is not seriously affected whether P fertilisers are broadcast or are placed in a ring around each tree, and this is supported by evidence from Northern Ireland (Dickson, 1971) and Scotland (Mackenzie, 1972). It is however, harmful to heap fertiliser close to the stem of the tree. Broadcasting phosphate rock does however have a marked effect on the ground vegetation. In general, ericaceous species, which may have been favoured by enclosure and ploughing, develop less vigorously than grasses and gorse after fertiliser is broadcast. This differential development is generally favourable to tree growth, since trees compete less effectively with heather and other ericaceous species.

Where a ready-mixed 0:20:20 fertiliser is not available, crude muriate of potash should be thoroughly mixed with unground phosphate rock prior to application and the mixture should be broadcast.

In southern Britain nitrogenous fertilisers are recommended only for the special circumstances described in the next section, and in such cases there is no alternative to broadcasting.

Fertilisers have now been successfully broadcast in forest crops in a number of ways. Where ground conditions allow tractor access, tractor-mounted spreaders are as cheap as aerial methods – fixed wing plane or helicopter. For small programmes, that is about 100 hectares or less, tractor spreaders are cheaper as the costs of moving to the site are less. See Plate 7.

Where tractors can not be used, helicopters are usually preferred for mountainous country and fixed wing planes on gently sloping or flat areas. See Plates 8 and 9. Hand spreading can be a useful stop-gap job and is likely to be the cheapest way of treating very small areas.

9. TREATMENT OF HEATHER

Weatherall (1953) appears to have been the first to use the expression "heather-sensitive" species, when referring to Sitka and Norway spruce, Douglas and Silver firs, Western hemlock and Lawson cypress. Whereas pines and larches are able to grow apparently normally in dense heather, he showed that the heather-sensitive species are liable to go into "check".

Handley (1963) however, quotes instances of Norway spruce growing without check on ground completely covered by heather. Similarly, Sitka spruce occasionally grows quite well on heather-dominated sites in Britain. In contrast, experiments at Wareham Forest in Dorset and Exeter Forest in Devon clearly indicate that the removal of heather can be beneficial to the growth of Corsican pine.

Since, as has been mentioned earlier, the effect of heather competition is to reduce the uptake of N and to a lesser extent P and K, the extent to which tree growth is "checked" will depend on the capacity of the soil to supply these nutrients. Where soils are extremely impoverished, even pine or larch will benefit from the removal of the heather. Conversely where the soil is relatively fertile, heather-sensitive species will grow in rank heather without "check". Unfortunately, even with the aid of soil analysis, it is not possible to predict with absolute certainty the need to control heather.

Practical experience and the experimental evidence suggest the following guidelines:

A. Pines and Larches

1. Heather control is usually unnecessary in crops of pine and larch, particularly if the ground has been ploughed and if the recommended fertilisers have been applied at planting.
2. Exceptionally, heather control has led to an improvement in slow growing pine crops. The evidence however is both complex and conflicting, but can be summarised as follows:
   a. Well stocked crops over 3m top height do not usually benefit from heather control,
   b. the response to heather spraying is greater when P is very deficient,
   c. improvements in growth are possible when neither N or P are deficient. This suggests that competition for moisture may have been a limiting factor before the heather was killed,
   d. Cases of pine crops being N deficient but not P deficient are rare but not unknown.

Therefore before heather control is carried out in pine or larch crops it is recommended that foliar samples are taken and the results of analysis are interpreted by Forestry Commission research staff.

B. Other Species of Conifers

Heather control is recommended in crops of the following commonly planted species:

Norway and Sitka spruce
Douglas fir, Silver firs
Western hemlock, Red cedar and Lawson cypress,

with the following exceptions:

i. Where heather covers less than 50% of the ground.
ii. Where gorse (*Ulex* species) or broom (*Sarothamnus scoparius*) is common in the heather.
iii. In crops of top height more than 3 metres.

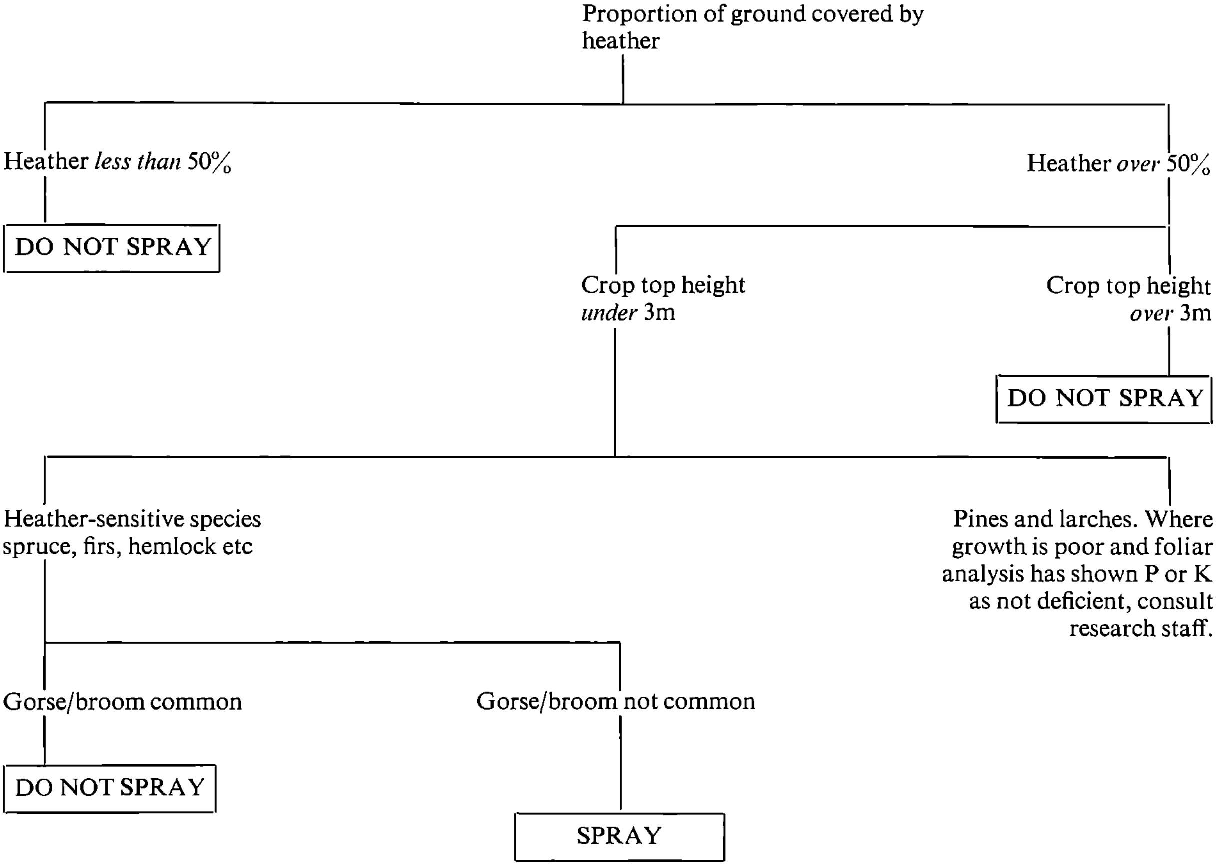
On most heathy sites, particularly in south-west England, the stimulation of gorse or broom by enclosure and phosphating has often resulted in suppression of heather and satisfactory crop growth. Whether this has resulted from the physical suppression of the heather or an increase in nitrogen caused by these leguminous species, is uncertain.

Spraying of heather in slow grown crops over 3 metres top height is not recommended for two reasons. Firstly, movement within such crops is difficult and secondly, canopy closure is likely within a short period if P or PK deficiency is corrected. If the check is severe and N is very deficient it may be necessary to apply N, together with P or PK. In such cases expert advice should be obtained or a small trial comparing the additional benefit of N fertiliser should be carried out.

If for any reason spraying is considered undesirable, "heather sensitive" species can be established using "luxury" culture regimes. This can take two forms. One, for dry sites, entails complete ploughing, followed by inter-row cultivation, the other an NPK fertiliser regime. In this latter case, the recommended rate of P or PK should be applied at planting, and this followed two years later with 150 kg N per hectare. Since the effect of applied nitrogen is unlikely to last more than 4 or 5 years, a second application of N or perhaps NP or NPK may be necessary if the growth rate falls off.

The above recommendations are summarised in the following decision tree.

The Need to Spray Heather in Southern England and Wales



Spraying Methods

Controlling heather by spraying with 2,4–D has been done successfully for a number of years. In the past the recommended treatment for areas planted with conifers was to spray at a rate of 8·5 litres per hectare of 2,4–D ester containing 0·5 kg 2,4–D (acid equivalent) per litre, diluted according to whether medium or low volume spraying equipment was used (Aldhous 1969). This recommendation applied to overall spraying during the period mid-August to early September.

In recent years foresters have successfully extended the spraying season to cover the whole of the period from mid-May to mid-September, by using directed knapsack spraying operating at low pressure to minimise drift. In addition, experimental work in Scotland has shown that satisfactory control of heather is possible with ultra-low volume (ULVA) equipment. These sprayers are extremely light to handle and are therefore particularly appropriate for use on broken terrain (Brown and Mackenzie, 1972).

Current recommendations for the chemical control of heather in southern Britain can be summarised as follows:

	SPRAY EQUIPMENT		
	Knapsack (Medium Volume)	Mistblower (Low Volume)	ULVA (ultra-low volume)
Rate of application	8 litres 2,4-D concentrate in 220 – 450 litres of water per hectare	8 litres 2,4-D concentrate in 150 litres of water per hectare	10 litres per hectare of special formulation 2,4-D in oil
Herbicide	50% 2,4-D ester emulsifiable concentrate		40% 2,4-D in oil, special formulation
Spraying season	*Directed spray* mid-May to mid-September	*Overall spray* early August to mid-September* A less reliable but useful alternative is just before trees flush, i.e. mid-April to mid-May	

Notes: *This recommendation applies to spruce crops in upland areas. When treating crops of other species or in localities with a long growing season, spraying should be carried out between late August and late September.

Heather control is the subject of a forthcoming Forestry Commission publication – Chemical control of heather – and this should be consulted for more detailed recommendations on spraying techniques and equipment. In addition consult Forestry Commission Leaflet 51, *Chemical Control of Weeds in the Forest*, for safe working procedures.

Crop Age

Where possible spraying should be carried out from 4 to 6 years after planting.

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APPENDIX I

TABULATED RESULTS OF FERTILISER EXPERIMENTS

A. Southern England, listed by county

I. Fertilisers applied at planting

II. Fertilisers applied as top-dressing

B. Wales, listed by site type

I. Fertilisers applied at planting

II. Fertilisers applied as top-dressing

Explanatory Notes

1. Forest names. These are the names of the forest blocks at the time the experiments were established, except that Exeter is used instead of Haldon. Where necessary, Forest names are appended.

2. Soil type. These are the commonly accepted types used in southern England.

3. Site type. In Tables BI and BII, sites have been listed under the classification used in the text and according to the system used by Pyatt (1969). The correlation of these two systems is given in Appendix III, page 47.

4. Vegetation. The vegetation is given in the order of dominance. The descriptions refer to the plant species that occurred some 3 to 5 years after planting, i.e. when the effects of grazing had ceased and when the changes brought about by ploughing were obvious.

5. Geology. These are the Geological Formations and Index Numbers that are given on the Geological Survey, 1 inch – 10 miles, Sheet 2, 1957.

6. Fertilisers applied. Numerous experiments have compared factors other than rates of fertilisers, e.g. method of application or forms of fertilisers. In order to simplify the tables, the results given refer, as far as possible, to the fertilisers in common use and to broadcast application. The rates are given as the weight (kg/ha) of the nutrient element and not the actual fertiliser applied. To convert the rates given to weights of fertiliser, multiply the % composition of the fertiliser by the rate given. For example, 45 kg P/ha is equivalent to 346 kg/ha of unground phosphate rock (Gafsa), containing approximately 13% P or 29% P_2O_5.

$$\frac{100}{13} \times 45 = 346 \text{ kg/ha}$$

7. Latest Results. Top height. Experiments in crops under about 5m top height are normally assessed by measuring the height of 16 to 36 trees and so determining mean height. However, as height/age graphs are expressed in Forest Management Tables in terms of top height, mean height has been converted to top height, using the graph which appears in Appendix II, page 30.

8. Benefit of treatment. The technique described on page 2 has been applied to latest assessment results using the top height/age graphs which appear in Appendix II. The figures appearing in the final column, Predicted total benefit, are estimates based on the current height differences and the estimated effect on height growth of the differences in foliar nutrient concentrations determined by foliar analysis.

9. List of tree names

English name	*Botanical name*
Scots pine	Pinus sylvestris L.
Corsican pine	Pinus nigra Arnold var. maritima (Ait.) Melville
Lodgepole pine	Pinus contorta Douglas ex Loud.
Monterey pine	Pinus radiata D. Don
Sitka spruce	Picea sitchensis (Bong.) Carr.
Norway spruce	Picea abies (L.) Karst.
European larch	Larix decidua Miller
Japanese larch	Larix kaempferi (Lambert) Carr.
Douglas fir	Pseudotsuga menziesii (Franco) Mirb.
Western hemlock	Tsuga heterophylla (Raf.) Sarg.
Western red cedar	Thuja plicata D. Don
Grand fir	Abies grandis Lindl.
Noble fir	Abies procera Rehd.

A. SOUTH[illegible]

I. FERTILISER APP[illegible]

County	Forest & Experiment No.	Soil type	Vegetation	Geology	Tree Species
(1)	(2)	(3)	(4)	(5)	(6)
Cornwall	Croft Pascoe 1 (Kernow Forest)	Gleyed Podzol	*Calluna*, *Molinia*, *Ulex*	Igneous (u)	Monterey pi[illegible]
Devon	Exeter 12	Gleyed Podzol	*Calluna*, *Ulex*, *E. tetralix*	Eocene (i 4-7)	Sitka spruce
	Exeter 15	Gleyed Podzol	*Calluna*, *Ulex*, *E. tetralix*	Eocene (i 4-7)	Corsican pine
Devon	Halwill 4	Surface water gley	*Molinia*, *Ulex*, *E. tetralix*	Carboniferous (d^4)	Sitka spruce Lodgepole pi[illegible]e
Somerset	Brendon 13	Podzol	*Calluna*, *Vaccinium*, *Ulex*	Middle Devonian (c^2)	Sitka spruce
Dorset	Wareham 143	Gleyed Podzol	*Calluna*, *Molinia*, *E. tetralix*	Eocene (i 4-7)	Scots pine
					Corsican pine
					Western hemlock
					Monterey pine
Hampshire	New Forest 21	Surface water gley	*Molinia*, *Vaccinium*, *E. tetralix*, *Calluna*	Eocene (i 4-7)	Douglas fir
					Western hemlock
					Grand fir

NGLAND

T PLANTING

Experimental Treatment				Latest Results		Benefit of treatment, expressed in the number of years saved when compared with treatment x	
Fertilisers applied kg element/ha			Herbicide	Age	Top Ht (m)	Current	Predicted total benefit
N (7)	P (8)	K (9)	(10)	(11)	(12)	(13)	(14)
—	—	—	Nil	9	1·6	x	x
—	22	44	Nil		3·8	7	> 10
—	22	—	Nil	7	2·9	x	x
—	45	—	Nil		3·4	1	2
—	90	—	Nil		3·5	1	3
—	180	—	Nil		3·5	1	5
—	17	—	Nil	9	3·1	x	x
—	62	—	Nil		3·7	1·5	3
—	124	—	Nil		4·0	2	4
	0		Nil	12	2·1	x	x
	16		Nil		3·8	> 8	> 10
	0		Nil		8·3	x	x
	16		Nil		8·4	0	0
—	50	—	Nil	6	2·0	x	x
—	50	—	2,4-D		2·6	1·5	> 3
178	178	150	Nil		2·9	2	> 5
178	178	150	2,4-D		3·1	2·5	> 5
—	30	—	Nil	6	2·4	x	x
—	30	—	Paraquat		2·4	0	0
311	168	291	Nil		2·6	0·5	3
311	168	291	Paraquat		2·8	1	3
—	30	—	Nil	6	1·9	x	x
—	30	—	Paraquat		1·4	0	0
311	168	291	Nil		2·3	1·5	3
311	168	291	Paraquat		1·9	0	2
—	30	—	Nil	6	2·5	x	x
—	30	—	Paraquat		1·9	0	0
311	168	291	Nil		3·3	1·5	5
311	168	291	Paraquat		3·0	1	4
—	30	—	Nil	6	3·5	x	x
—	30	—	Paraquat		3·2	0	0
311	168	291	Nil		4·5	1	4
311	168	291	Paraquat		4·6	1	4
—	—	—	Nil	7	0·9	x	x
—	—	—	Paraquat		1·0	0	0
228	128	242	Nil		2·9	7	> 10
228	128	242	Paraquat		2·9	7	> 10
—	—	—	Nil	7	2·2	x	x
—	—	—	Paraquat		3·1	2	2
228	128	242	Nil		4·9	5	> 10
228	128	242	Paraquat		5·4	6	> 10
—	—	—	Nil	7	0·7	x	x
—	—	—	Paraquat		0·8	0	0
228	128	242	Nil		1·1	1	3
228	128	242	Paraquat		1·4	2	3

II FERTILISER APPLIED

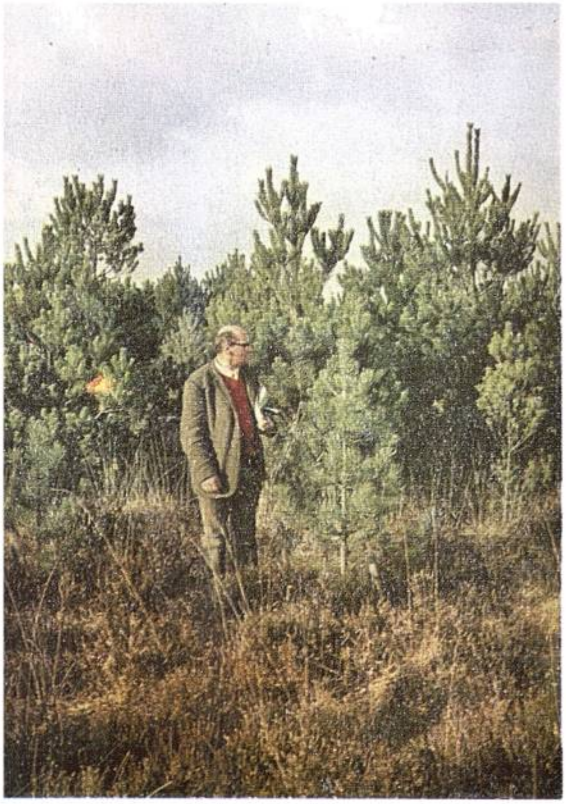
County	Forest & Experiment No.	Soil type	Vegetation	Geology	Tree Species
(1)	(2)	(3)	(4)	(5)	(6)
Cornwall	Croft Pascoe 21 (Kernow Forest)	Gleyed podzol	*Calluna, Molinia, Ulex*	Igneous (u)	Sitka spruce
Cornwall	Wilsey Down 8 (Kernow Forest)	Gleyed podzol	*Calluna, Molinia, Ulex, Agrostis setacea*	Carboniferous (d^4)	Sitka spruce
Cornwall	Wilsey Down 12 (Kernow Forest)	Gleyed podzol	*Calluna, Molinia, Ulex, Agrostis setacea*	Carboniferous (d^4)	Sitka spruce
Devon	Halwill 4	Surface water gley	*Molinia, Ulex, Agrostis setacea, Calluna*	Carboniferous (d^4)	Sitka spruce
Devon	Exeter 20	Humus podzol	*Molinia, Calluna, Ulex*	Eocene (i 4-7)	Douglas fir
Somerset	Neroche 1	Podzol	*Molinia, Ulex, Calluna*	Eocene (i 4-7)	Sitka spruce
Dorset	Wareham 117c	Podzol	*Calluna*	Eocene (i 4-7)	Corsican pine
Hampshire	Ringwood 24	Podzol	*Calluna, E. tetralix*	Eocene (i 4·7)	Corsican pine
Sussex	Maresfield 1 (St. Leonard's Forest)	Podzolised brown earth	Birch, *Holcus, D. flexuosa, Rubus fruticosus*	Cretaceous (h)	Douglas fir
Kent	Bedgebury 7	Podzolised brown earth	*Ulex, Rubus fruticosus*, Fine grasses	Cretaceous (h)	Douglas fir

ate 2. Douglas fir planted 10 years previously on dry heath at Exeter Forest, Devon (Expt. 20). Foreground plot is extremely deficient. Background plot had same appearance before it was fertilised with 75 kg/ha element P, when six years old. ·icacious vegetation now contains high proportion of gorse so spraying with 2,4–D is not necessary. (*24383*).

ate 3. Sitka spruce at 6 years. Foreground plot is growing slowly in dense heather.
ɜather in background plot has been controlled since planting, by spraying with 2,4–D. Both plots received 50 kg/ha element P planting. *Brendon Forest, Somerset, Expt. 13.* (*24387*).

Plate 4. Forester standing in Western hemlock planted on wet heath eight years earlier. Trees are extremely P deficient. *New Forest, Hampshire, Expt. 21. (24386).*

Plate 5. Forester standing in front of Western hemlock of same age as above. Although this plot received NPK Mg fertiliser annually for four years, 75 kg/ha element P would probably have had same effect. *New Forest, Hampshire, Expt. 21. (24385).*



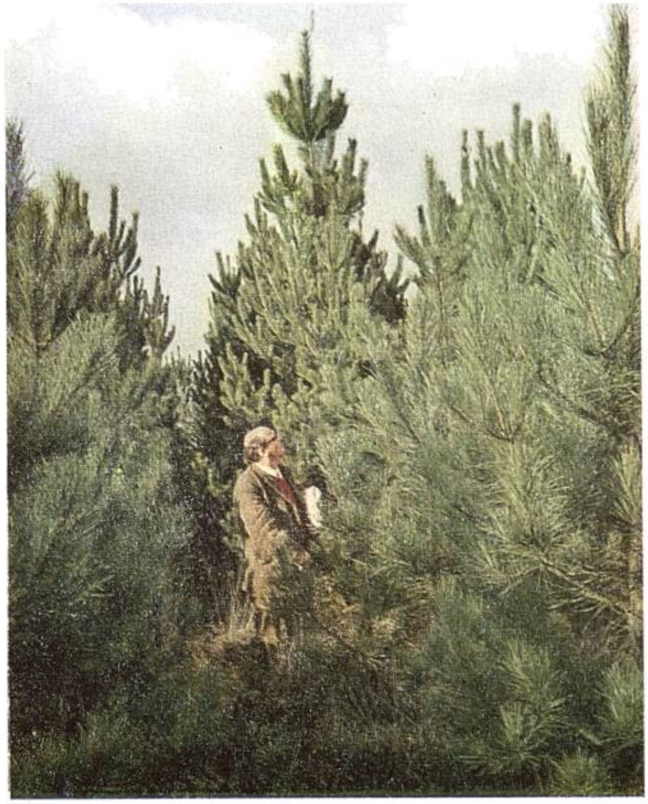


Plate 6. Corsican pine, foreground; Monterey pine background, at 7 years. Plots in photo on left received only 30 kg/ha of element P at planting and are P and K deficient. Plots in right-hand photo have had NPK fertiliser. *Wareham Forest, Dorset, Expt. 143. (24382, 24384).*

Plate 7. Tractor-mounted spreaders are cheapest means of applying fertiliser for all but very large programmes. *Ringwood Forest, Hampshire. (25721).*

Plate 8. Fixed-wing aeroplanes are usually restricted to flatter country. *Ringwood Forest, Hampshire and Dorset. (17788)*.

Plate 9. Helicopters are commonly used to apply fertilisers in mountainous country. *Coed y Brenin Forest, Merioneth. (12955)*.

ENGLAND

AS TOP DRESSING

Crop before Treatment			Experimental Treatment				Latest Results		Benefit of treatment, expressed in the number of years saved when compared with treatment x	
Age	Top Ht (m)	Deficiency	Fertilisers applied kg element/ha			Herbicide	Age	Top Ht (m)	Current	Predicted total benefit
			N	P	K					
(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
3	0·7	P	—	—	—	Nil	11	1·0	x	x
			—	20	—	Nil		1·5	2·5	4
			—	60	—	Nil		1·9	4	> 8
			—	140	—	Nil		2·3	5	> 10
8	1·3	P	—	—	—	Nil	25	3·5	x	x
			—	39	—	Nil		9·0	> 10	> 10
			—	78	—	Nil		8·8	> 10	10
			—	78	62	Nil		8·2	> 10	10
23	1·7	P	—	17	—	Nil	39	5·7	x	x
			—	50	—	Nil		8·1	7	> 10
			—	150	—	Nil		9·4	11	> 15
7	1·1	P	—	—	—	Nil	12	3·8	x	x
			—	53	—	Nil		5·2	3	> 5
			—	168	—	Nil		5·7	4	> 7
6	1·8	N.P.	—	—	—	Nil	9	2·7	x	x
			112	—	—	Nil		3·0	1	1
			—	73	—	Nil		4·2	3·5	> 5
			112	73	—	Nil		4·2	4	> 5
6	2·0	N.P.	—	—	—	Nil	12	2·2	x	x
			—	50	—	Nil		5·0	7	> 8
			105	50	—	Nil		4·9	7	> 8
			90	105	—	Nil		5·9	9	> 10
6	1·7	N.P.	—	—	—	Nil	20	7·0	x	x
			—	—	—	2,4-D		7·0	0	0
			—	36	—	Nil		9·0	2	5
			—	36	—	2,4-D		10·0	4	7
12	2·2	N.P.	—	—	—	Nil	17	3·5	x	x
			110	140	—	Nil		5·2	6	> 10
4	0·8	P	—	—	—	Nil	8	1.1	x	x
			—	23	—	Nil		2·5	5·5	> 8
			—	70	—	Nil		3·0	7	> 9
9	1·7	P	—	—	—	Nil	13	3·3	x	x
			—	23	—	Nil		3·3	0	0
			—	70	—	Nil		3·6	1	1

I. FERTILISER APPLIE)

Forest & Experiment No	Site Classification		Vegetation	Geology	Tree Species
	for fertiliser	after Pyatt			
(1)	(2)	(3)	(4)	(5)	(6)
Taliesin 4 (Rheidol Forest)	B2	Intergrade	*D. flexuosa, Vaccinium, Calluna, E. tetralix, Ulex*	Ordovician (b^3)	Sitka spruce
Clocaenog 52 blocks iv-vi	B2	Ironpan	*D. flexuosa, Calluna* (suppressed by complete ploughing)	Silurian (b^7)	Sitka spruce Lodgepole pine
Clocaenog 52 blocks i-iii	C3	Peaty gley	*Calluna*	Silurian (b^7)	Sitka spruce Lodgepole pine
Clocaenog 51	C3	Deep peat	*Calluna, E. tetralix, Trichophorum*	Silurian (b^7)	Sitka spruce Lodgepole pine
Clocaenog 53	C3	Deep peat	*Calluna, E. tetralix, Trichophorum*	Silurian (b^7)	Sitka spruce
Tywi 1	C4	Peaty gley	*Molinia, Eriophorum*	Silurian (b^5)	Sitka spruce (K applied at 4 years)
Taliesin 15 (Rheidol Forest)	B4	Peaty gley/deep peat	*Molinia, D. flexuosa*	Ordovician (b^3)	Sitka spruce

WALES
AT PLANTING

Experimental Treatment				Latest Results		Benefit of treatment, expressed in the number of years saved when compared with treatment x	
Fertilisers applied kg element/ha N (7)	P (8)	K (9)	Herbicide (10)	Age (11)	Top Ht (m) (12)	Current (13)	Predicted total benefit (14)
—	—	—	Nil	15	3·3	x	x
—	17	—	Nil		4·3	2·5	4
—	34	—	Nil		4·5	3	5
—	13	—	Nil	6	2·3	x	x
—	13	—	2,4-D		2·2	0	0
168	88	233	Nil		2·2	0	0
168	88	233	2,4-D		2·3	0	0
—	13	—	Nil	6	1·6	x	x
—	13	—	2,4-D		1·3	0	0
168	88	233	Nil		1·4	0	0
168	88	233	2,4-D		1·4	0	0
—	13	—	Nil	6	1·5	x	x
—	13	—	2,4-D		2·5	3	>5
168	88	233	Nil		2·5	3	>7
168	88	233	2,4-D		2·8	3·5	>7
—	13	—	Nil	6	1·5	x	x
—	13	—	2,4-D		1·6	0·5	2
168	88	233	Nil		2·0	2	4
168	88	233	2,4-D		1·9	1·5	4
—	45	47	Nil	5	1·5	x	x
	90	94	Nil		1·7	1	3
—	45	47	Nil	5	2·0	x	x
	90	94	Nil		2·2	0·5	2
—	36	—	Nil	6	2·0	x	x
—	41	47	Nil		2·1	<0·5	1
—	82	94	Nil		2·3	1	2
—	166	188	Nil		2·8	2·0	2·5
—	—	377	Nil		2·7	1·5	2·5
—	—	—	Nil	7	1·2	x	x
—	45	90	Nil		1·4	1	2
—	—	—	Nil	14	4·8	x	x
—	30	—	Nil		4·8	0	0

Forest & Experiment No.	Site Classification		Vegetation	Geology	Tree Species
	for fertiliser	after Pyatt			
(1)	(2)	(3)	(4)	(5)	(6)
Tarenig 2 (Ystwyth Forest)	B2	Intergrade	*Ulex, Calluna, Vaccinium*	Silurian (b^5)	Sitka spruce
Tarenig 4 (Ystwyth Forest)	B2	Intergrade	*D. flexuosa, Vaccinium, Calluna*	Silurian (b^5)	Sitka spruce
Aeron 2	B2	Ironpan soil	*Calluna*	Silurian (b^5)	Sitka spruce
Rheola 7	C2	Deep peat	*Molinia, E. tetralix, Vaccinium*	Carboniferous (d^5)	Sitka spruce
Tarenig 11 (Ystwyth Forest)	C3	Deep peat	*Molinia, Calluna, Eriophorum, E. tetralix*	Silurian (b^5)	Sitka spruce
Rheidol 5	C4	Deep peat	*Molinia, Eriophorum, E. tetralix*	Silurian (b^5)	Sitka spruce
Tarenig 7 (Ystwyth Forest)	C4	Deep peat	*Molinia, Trichophorum, Eriophorum, E. tetralix*	Silurian (b^5)	Sitka spruce
Tarenig 9 (Ystwyth Forest)	C4	Deep peat	*Molinia, Eriophorum*	Silurian (b^5)	Sitka spruce
Tywi 10	C4	Deep peat	*Molinia, Eriophorum*	Silurian (b^5)	Sitka spruce
Tywi 12	C4/C5	Deep peat	*Molinia, Eriophorum, D. flexuosa*	Silurian (b^5)	Sitka spruce

WALES
AS TOP DRESSING

Crop before Treatment			Experimental Treatment				Latest Results		Benefit of treatment expressed in the number of years saved compared with x	
Age	Top Ht (m)	Defi-ciency	Fertilisers applied kg element/ha			Herbicide	Age	Top Ht (m)	Current	Predicted total benefit
			N	P	K					
(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
25	1·5	P	—	—	—	Nil	40	3·9	x	x
			—	26	50	Nil		5·8	6	7
			—	105	200	Nil		6·8	9	10
20	2·1	P	—	—	—	Nil	33	4·8	x	x
			—	18	—	Nil		7·1	6	8
			—	52	—	Nil		7·9	7	9
			—	156	—	Nil		7·2	6	8
5	0·6	N	—	—	—	Nil	12	2·0	x	x
			—	—	—	2,4-D		2·9	2·5	3
			20	25	60	Nil		2·9	2·5	3
24	0·4	N.P. (Un-drained)	—	—	—	Nil	35	2·5	x	x
			—	75	—	Nil		3·3	3	6
			—	75 + 3 yrs later	50	Nil		3·5	4	8
		Drained	—	—	—	Nil	35	4·5	x	x
			—	75	—	Nil		5·5	3	5
5	0·8	K	—	—	—	Nil	11	2·1	x	x
			—	85	95	Nil		3·0	3	4
1	0·3	K	—	—	—	Nil	9	1·6	x	x
			applied 1 yr		62	Nil		2·2	3	3
3			applied 3 yrs		62	Nil		2·0	2	2
3	0·4	K	—	—	—	Nil	13	3·7	x	x
			—	19	—	Nil		3·5	0	0
			—	—	55	Nil		3·0	0	0
			—	19	55	Nil		4.3	1·5	2
3	0·4	K	—	—	—	Nil	9	2·3	x	x
			—	25	—	Nil		2.5	0·5	1
			—	50	—	Nil		2·5	0·5	1
			(Potash was applied at 4 rates without benefit)							
2	0·4	K	—	—	—	Nil	6	1·8	x	x
			—	50	—	Nil		1·8	0	1
			—	—	94	Nil		2·2	1	1
			—	50	94	Nil		2·1	1	3
8	1·4	K	—	—	—	Nil	11	2·9	x	x
			—	25	—	Nil		2·8	0	0
			—	50	—	Nil		2·8	0	0
			—	100	—	Nil		2·7	0	0
			—	—	90	Nil		3·0	0	0
			—	25	90	Nil		3·2	1	1·5
			—	50	90	Nil		3·3	1	1·5
			—	100	90	Nil		3·1	0·5	1·5

APPENDIX II

TOP HEIGHT/AGE CURVES

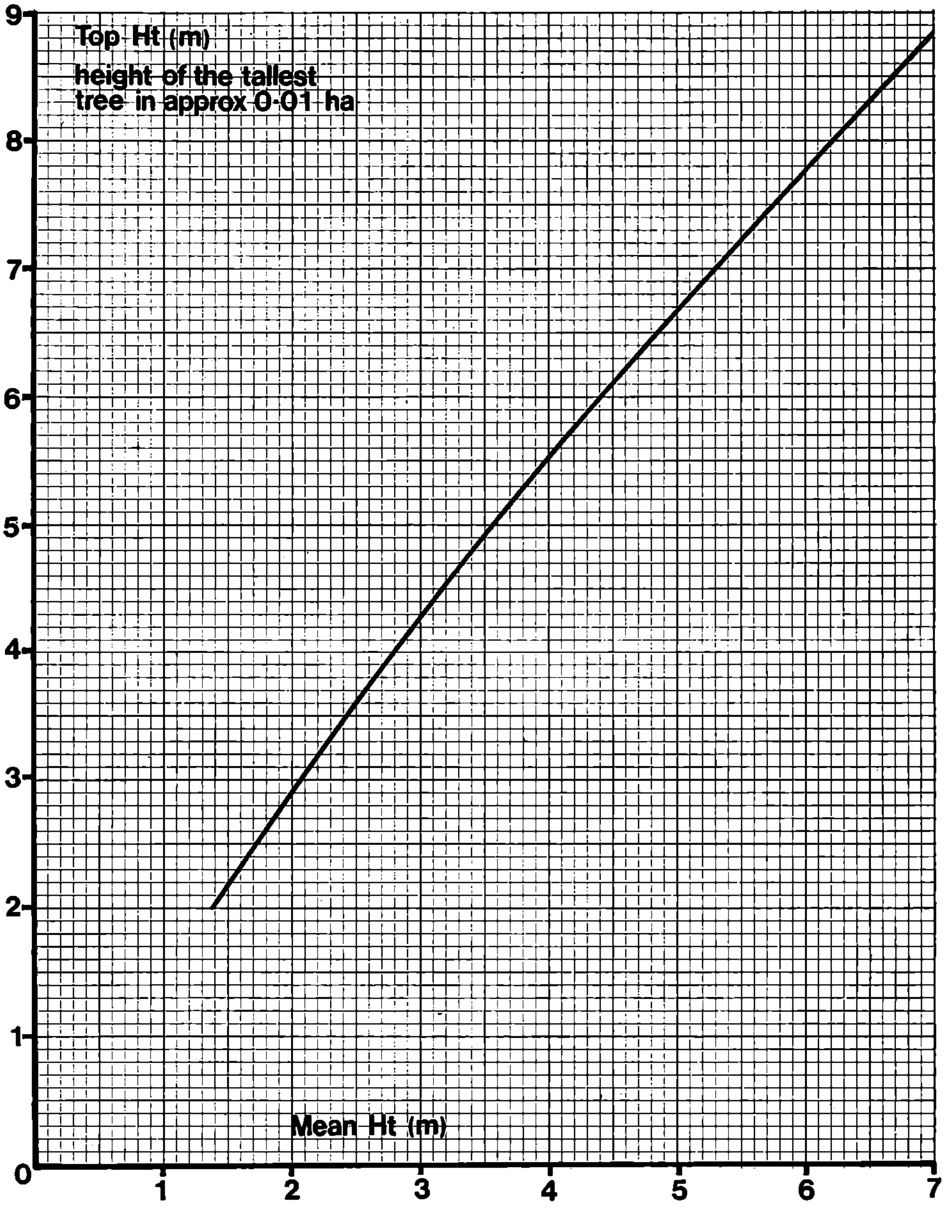


Figure 8. Relationship between mean height and top height.

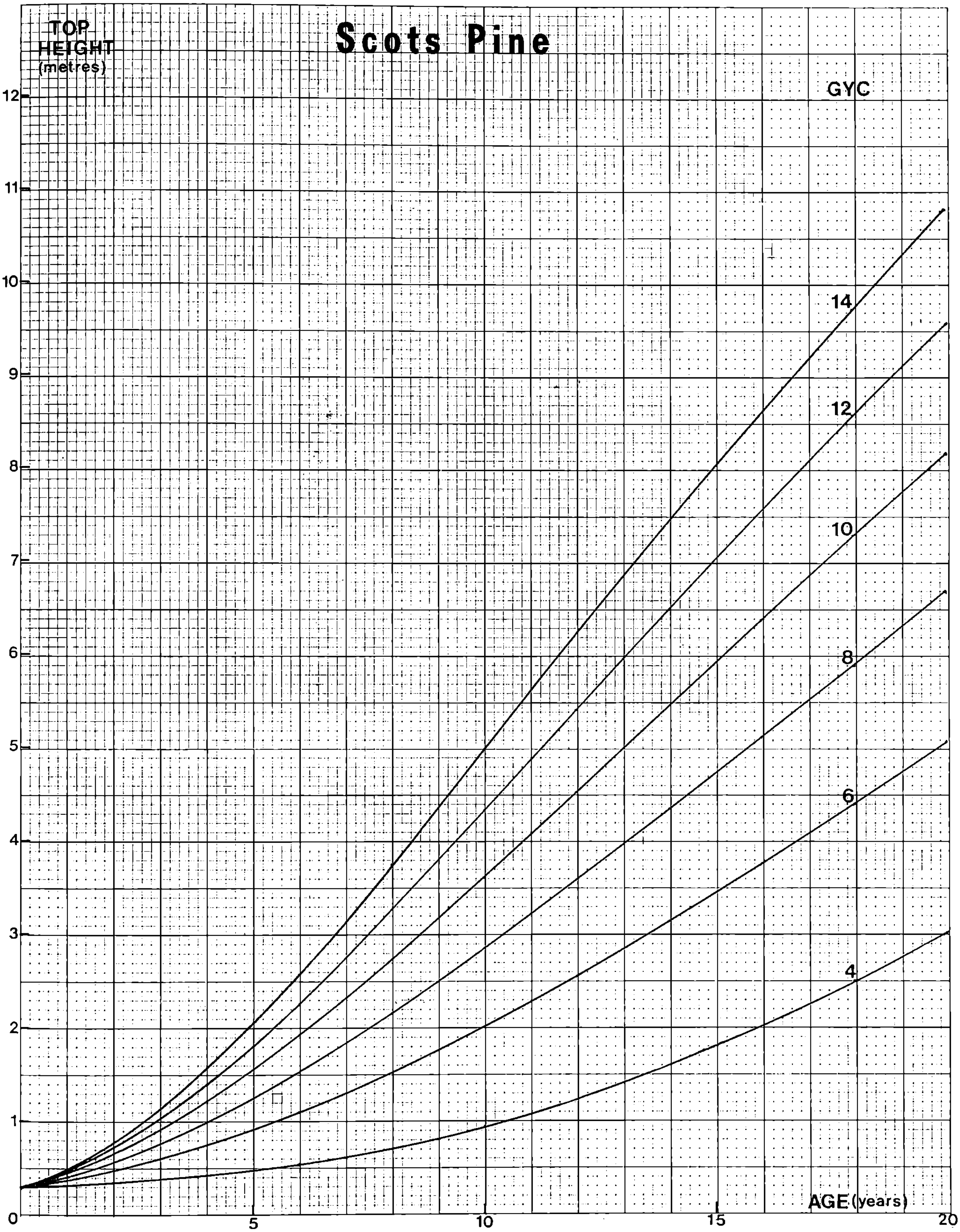


Figure 9. Top height/age curves for Scots pine. General yield classes 4 to 14.

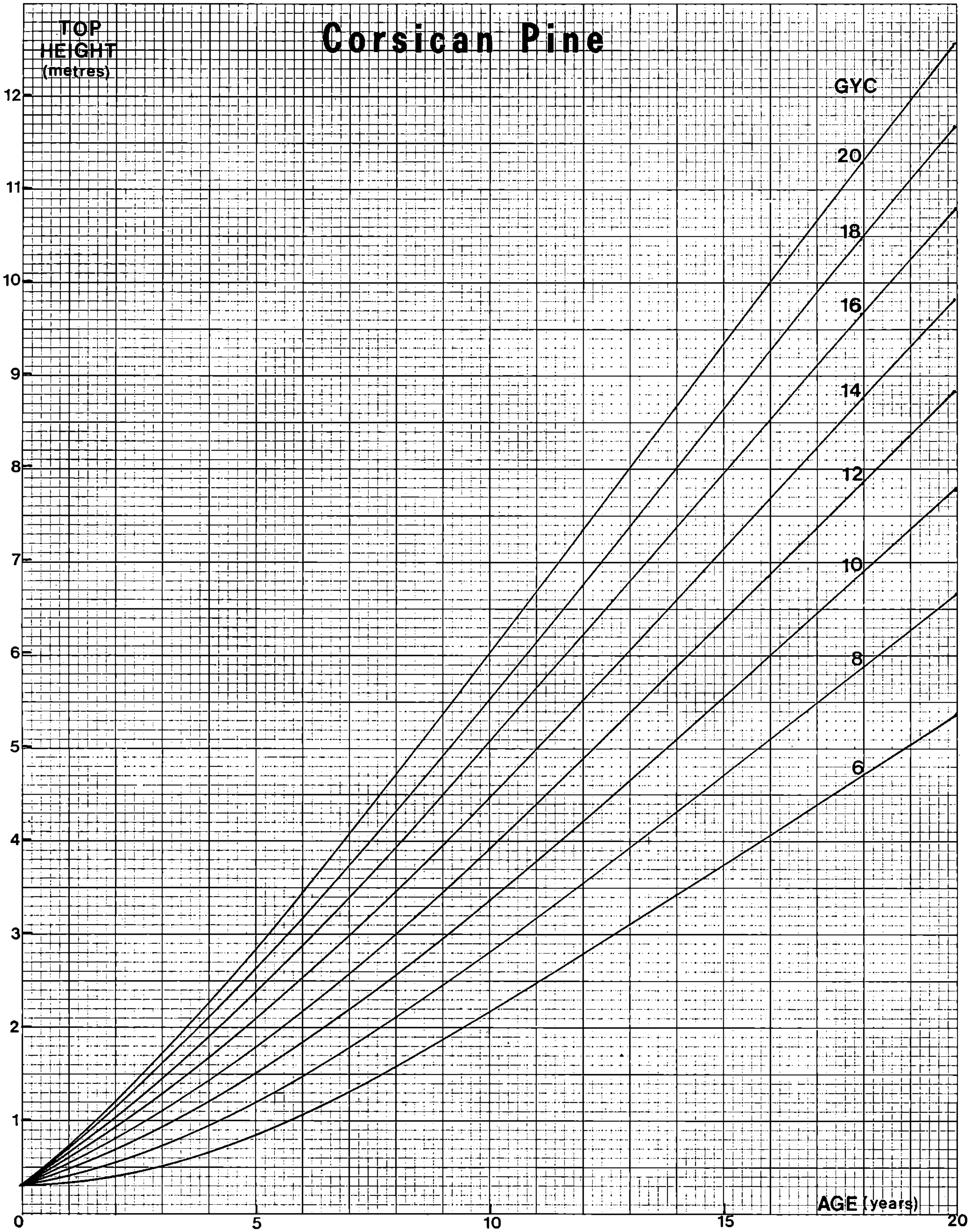


Figure 10. Top height/age curves for Corsican pine. General yield classes 6 to 20.

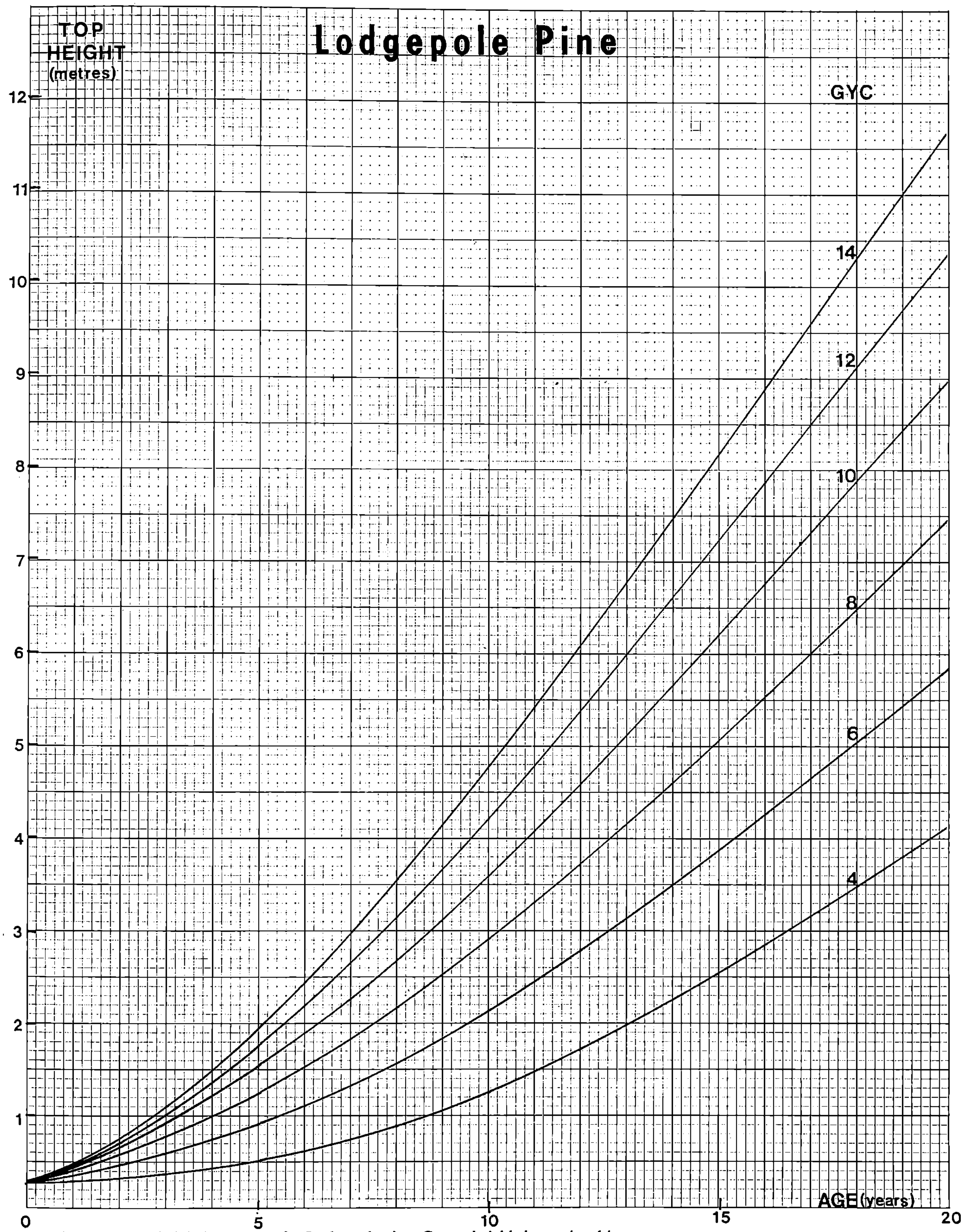


Figure 11. Top height/age curves for Lodgepole pine. General yield classes 4 to 14.

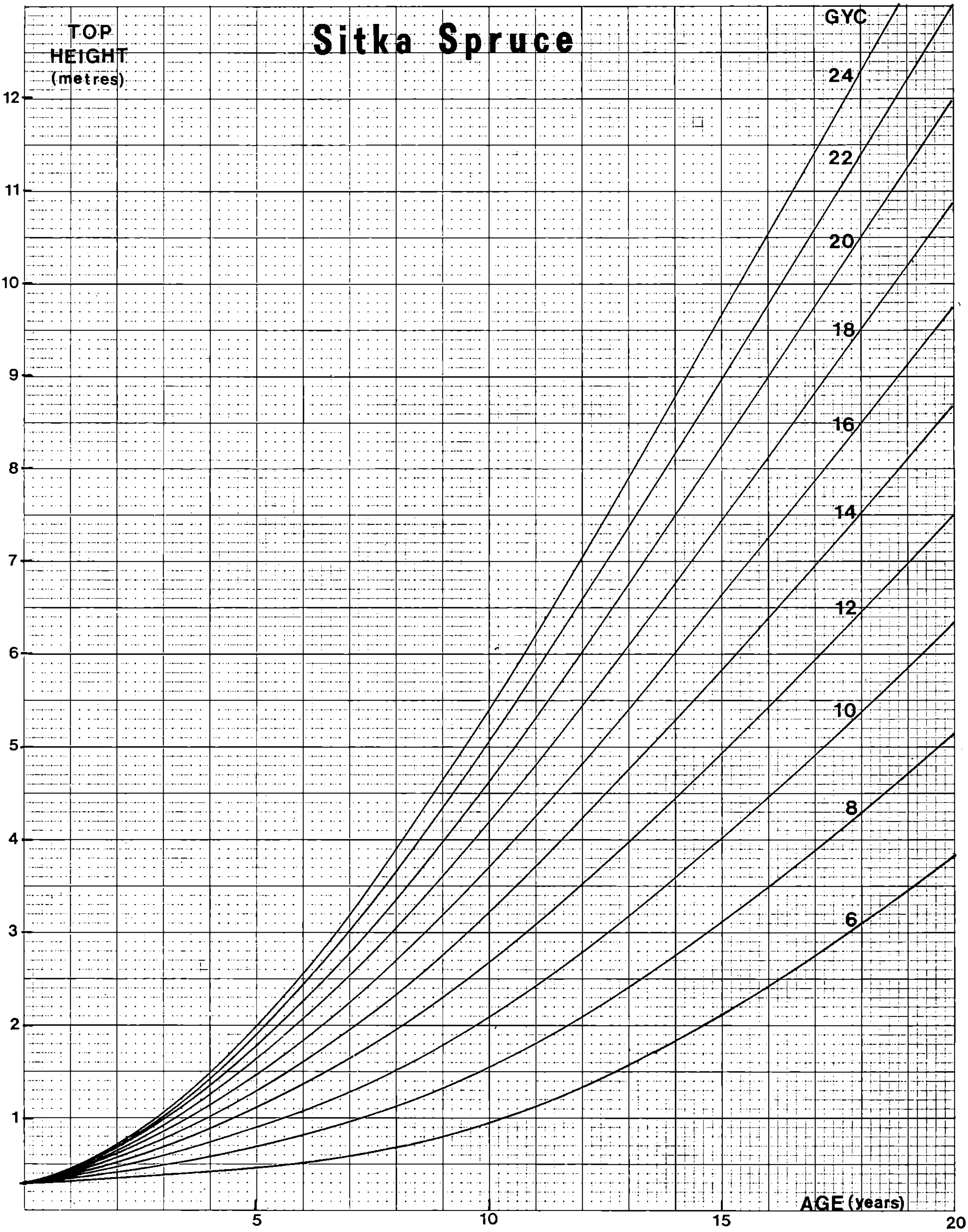


Figure 12. Top height/age curves for Sitka spruce. General yield classes 6 to 24.

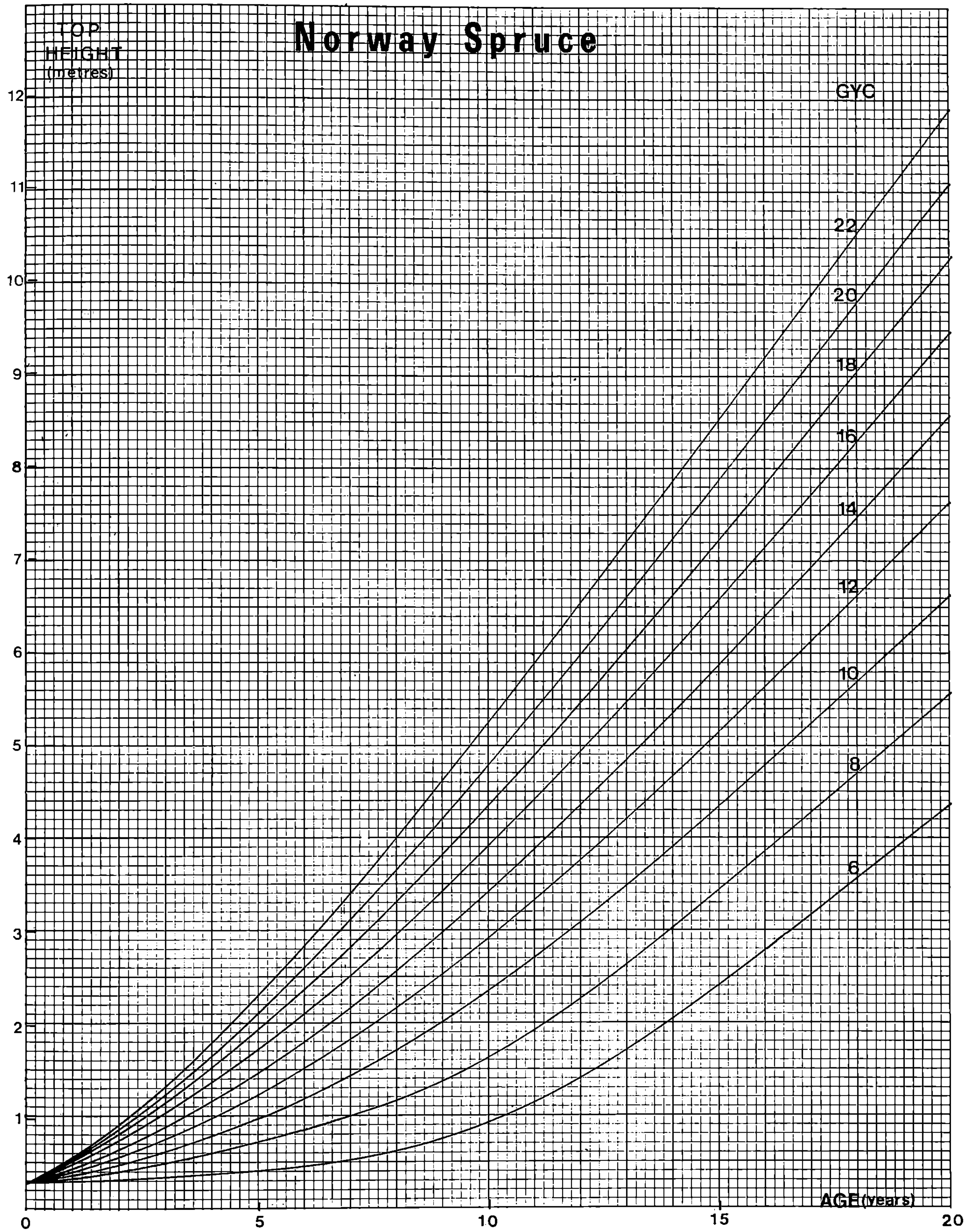


Figure 13. Top height/age curves for Norway spruce. General yield classes 6 to 22.

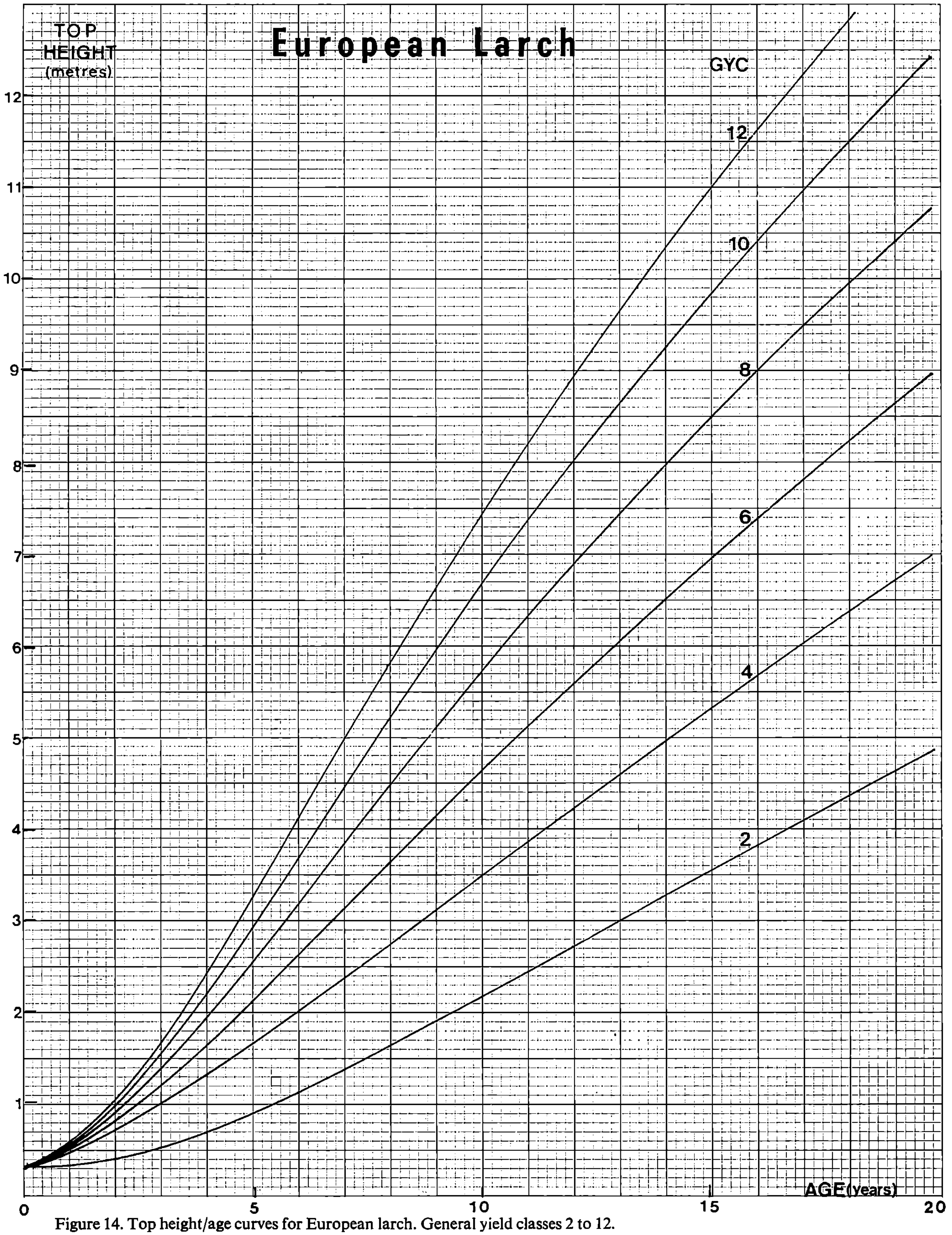


Figure 14. Top height/age curves for European larch. General yield classes 2 to 12.

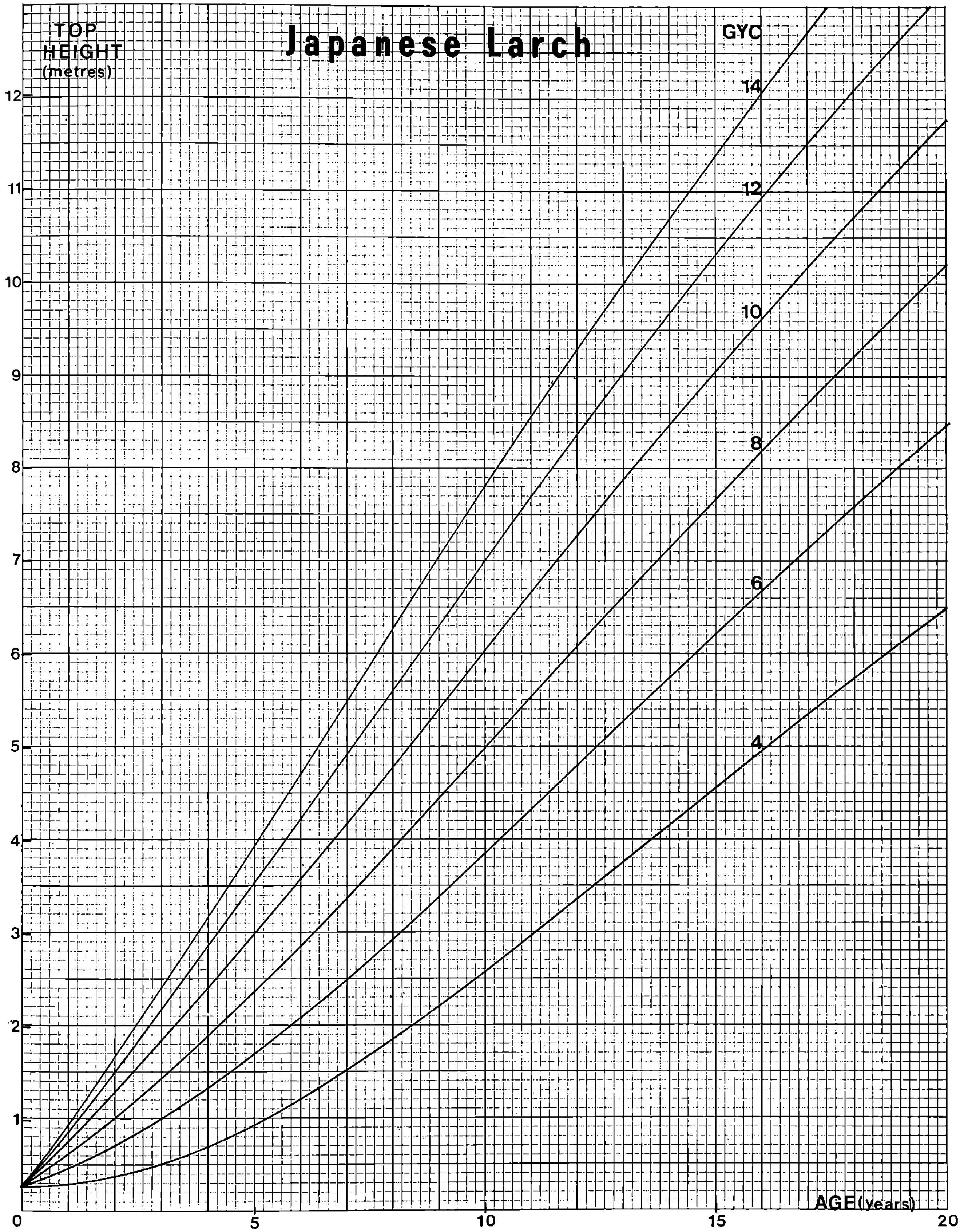


Figure 15. Top height/age curves for Japanese larch. General yield classes 4 to 14.

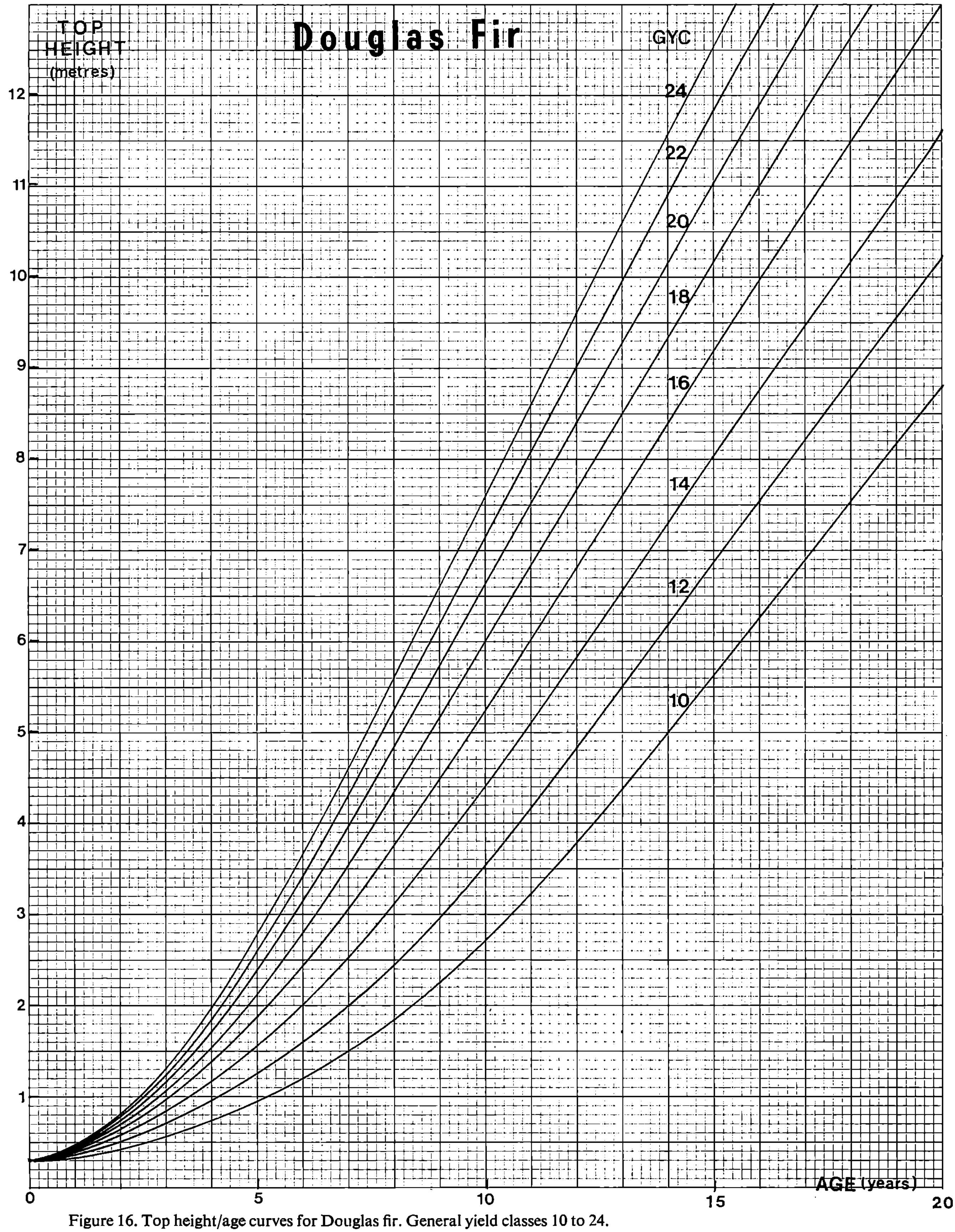


Figure 16. Top height/age curves for Douglas fir. General yield classes 10 to 24.

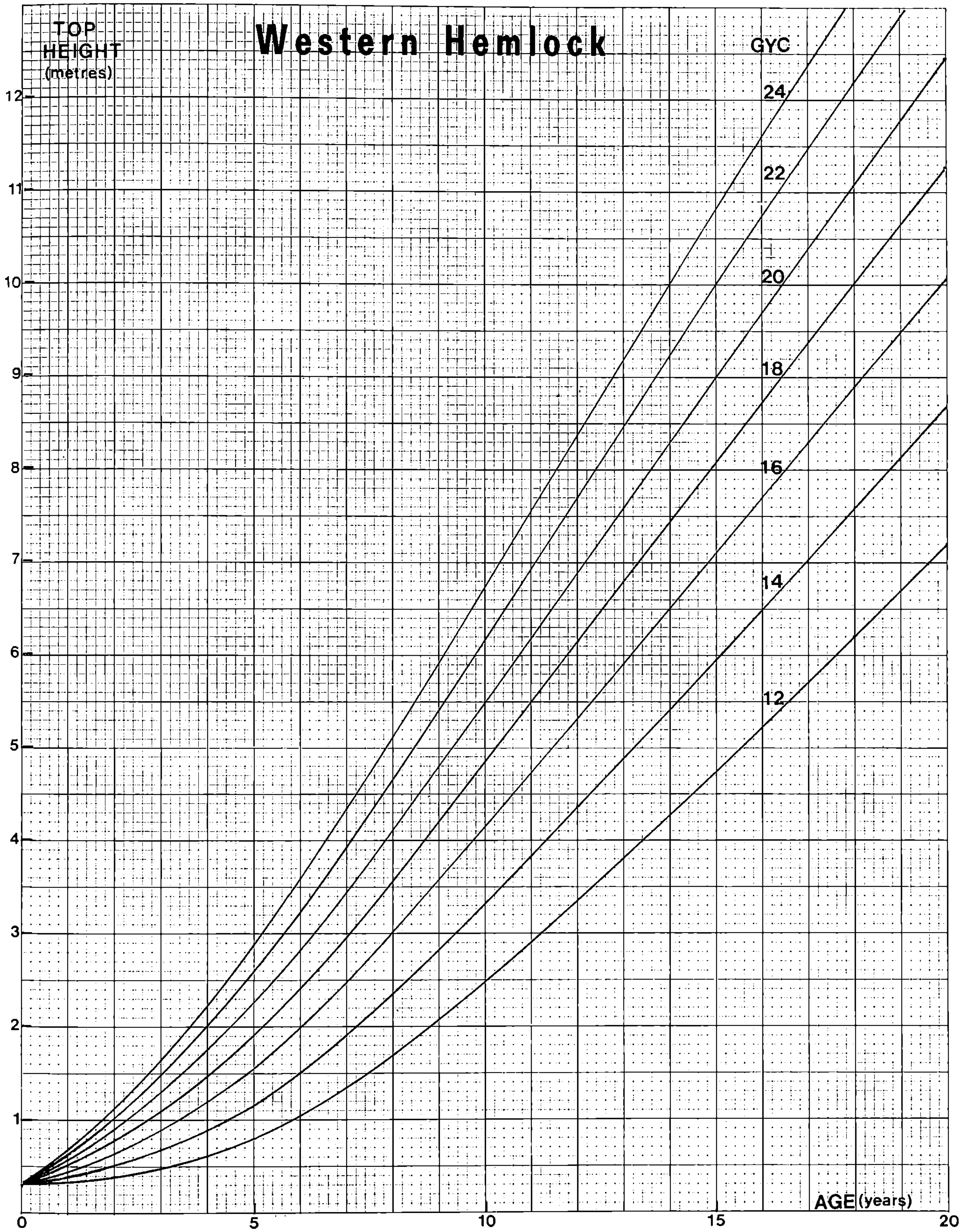


Figure 17. Top height/age curves for Western hemlock. General yield classes 12 to 24.

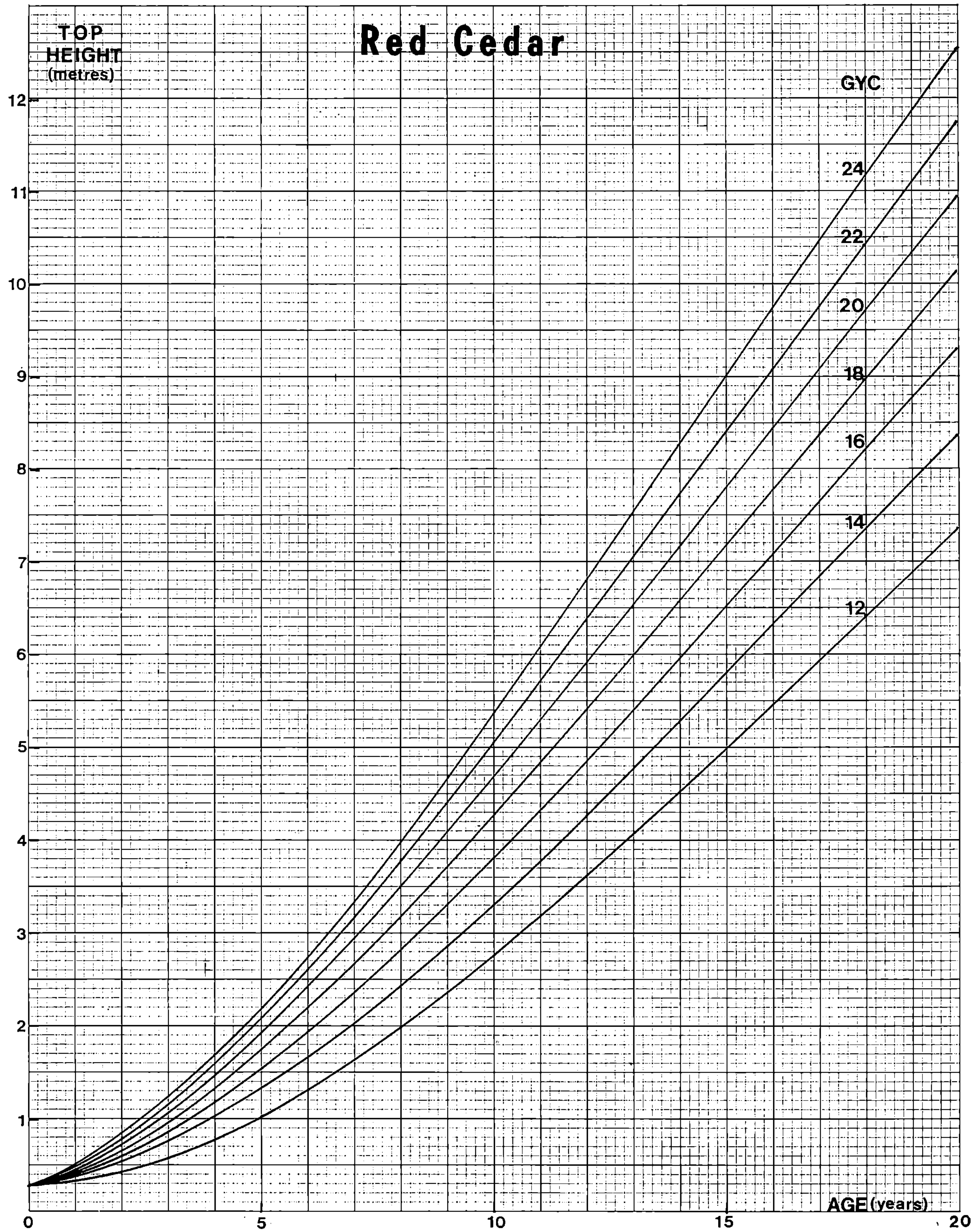


Figure 18. Top height/age curves for Red cedar. General yield classes 12 to 24.

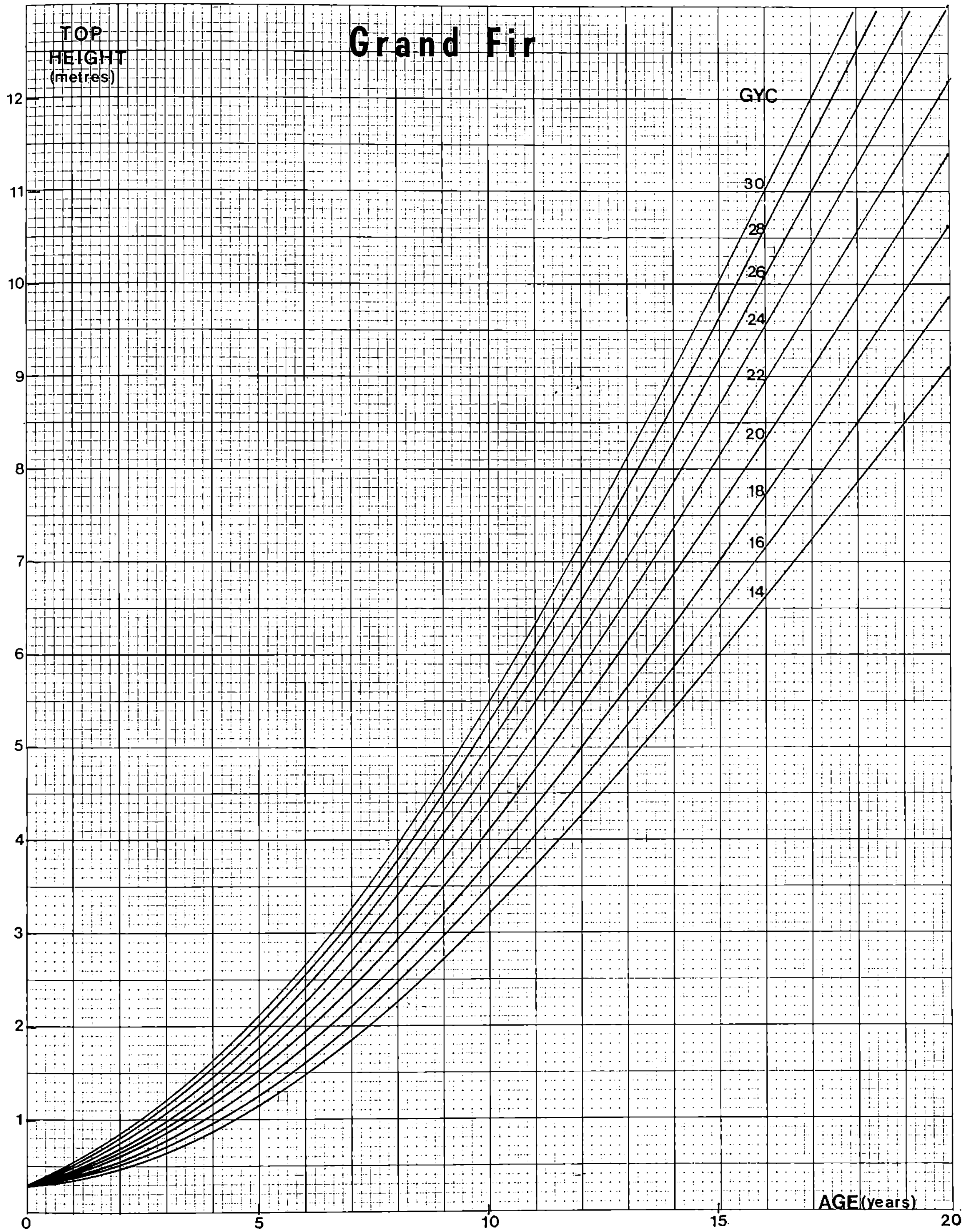


Figure 19. Top height/age curves for Grand fir. General yield classes 14 to 30.

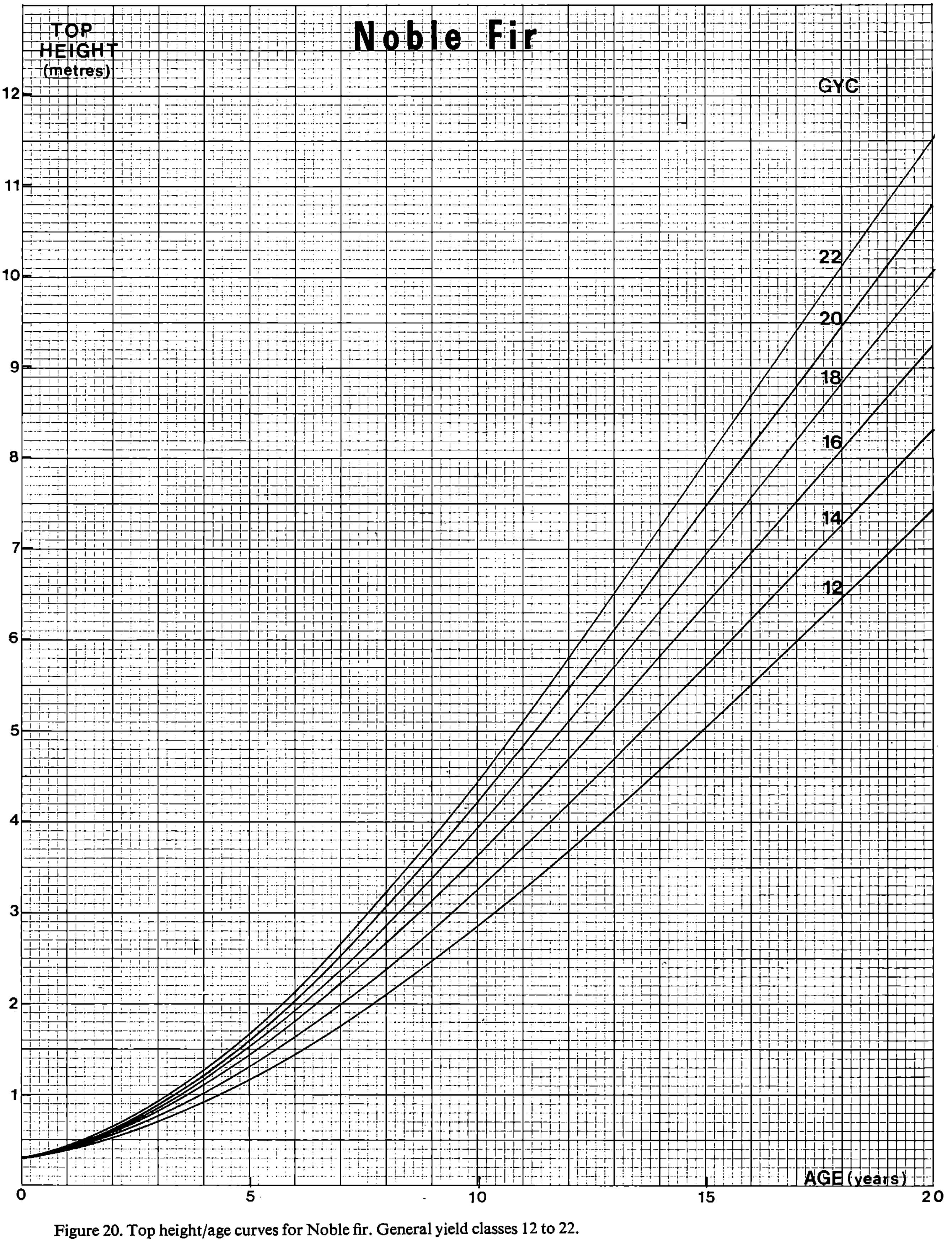


Figure 20. Top height/age curves for Noble fir. General yield classes 12 to 22.

APPENDIX II

EVALUATING THE RESPONSE TO FERTILISERS IN YOUNG CROPS

The use of height/age curves

With young crops it is difficult to relate, with any certainty, increases in height to ultimate gains in volume production and hence revenues. It is not unreasonable however, to regard gains in height growth as an advancement of the whole development of the crop or as an avoidance of the delay which would result from not applying fertilisers. This period, or "number of years saved" as it has been called in Appendix I, can be deduced from the top height/age curves, 0–20 years which appear at the end of this appendix, using the method described on page 2.

It is stressed that although each line on the top height/age curves is labelled with a General Yield Class (G.Y.C.), this will be achieved only if the pattern of growth does not change throughout the rotation. On some sites, particularly in the uplands, currently used establishment methods often result in very fast early height growth. This is usually followed by a slowing-down until a normal pattern of height growth is reached at about the time of canopy-closure. Therefore these curves should not be used to predict G.Y.C. until the crop is near canopy-closure or until height growth has been plotted for a number of years and a regular pattern of growth has been established.

Despite the uncertainty regarding the stability of early growth patterns, the top height/age relationship does give an objective if somewhat crude indication of crop performance. This can be usefully employed when comparing the performance of different species. For example, if Lodgepole pine and Sitka spruce are both 5m top height at 15 years the predicted G.Y.C. is:

Lodgepole pine 8
Sitka spruce 12

Calculating the financial implications

To decide if it is worthwhile applying fertiliser, calculate the Discounted Revenues (D.R.) for the crop – a. if it is fertilised, and b. if it is not fertilised.

To do this two factors must be estimated:

1. The G.Y.C. likely to be achieved on the site, if the proposed regime is employed.
2. The number of years that crop development will be advanced if the treatment is employed or conversely the number of years delay that will result from not treating the crop.

This information must come from two distinct sources:

1. The likely G.Y.C. must be based on the best available information for the site under question, and this is best obtained from the actual G.Y.C. of older crops on the same site type or estimates based on top height/age of crops well into the production stage, say over 15m top height.
2. The expected period of advancement must be taken from the results of experiments or previous fertilising on the same site type. For example, a forester contemplating whether to top-dress P deficient Sitka spruce on a heather/gorse heathland site in Devon should use the experimental results for that area, given in Appendix I. In this case the "predicted total benefit" (Table AII, Col 17) of applying 75 kg P/ha is estimated to be about 5 or 6 years.

Worked examples

EXAMPLE 1. FERTILISER AT PLANTING

The question posed is should phosphate be applied when planting on a steep hill slope in mid-Wales, which carries or which can be expected to carry heathy vegetation. The site type is classified for fertilisers as B_2 or by Pyatt as an Intergrade to Ironpan soil.

i. The G.Y.C. for such sites in the locality is 12.
ii. The experiments which are most pertinent are:
Taliesin 4, and to a lesser extent Tarenig 2 and Tarenig 4.

These indicate a "predicted total benefit" of at least 5 years. The D.R. to year 0 ($D.R._0$) for Sitka spruce G.Y.C. 12, at 5% = (say) £200 per hectare. If the crop is not fertilised this D.R. will be obtained 5 years later and so the D.R. of the unfertilised crop will be:

$$\text{£}200 - \frac{\text{£}200}{1{\cdot}05^5}$$
$$= \text{£}200 - \frac{\text{£}200}{1{\cdot}28}$$
$$= \text{£}200 - \text{£}157$$

Loss in D.R. = £43 per hectare.

The cost of the fertiliser together with the cost of application is estimated to be £12 per hectare. This would be incurred at the start of the rotation and so is not discounted.

Another cost that should be considered is the increased Discounted Costs of any roading or brashing. If we assume that roading and brashing will be required at, say year 25, instead of year 30 – if the crop is not fertilised – the discounted costs are therefore increased as follows:

Estimated cost of roads, £5000 per kilometre, or £5 per metre.

Estimated road density 20 metres per hectare.

Cost of roads per hectare £100.

Brashing is estimated to cost £25 per hectare.

The increase in discounted costs is thus:

$$\frac{\text{£}100+\text{£}25}{1{\cdot}05^{25}} - \frac{\text{£}100+\text{£}25}{1{\cdot}05^{30}}$$

or, if discounting factors are used:

$$\text{£}125 \times 0{\cdot}30 - \text{£}125 \times 0{\cdot}23$$
$$\text{£}37{\cdot}5 - \text{£}28{\cdot}75$$
$$= \text{£}8{\cdot}75$$

The discounted cost of the fertiliser treatment and the subsequent advancement of other costs is:

$$\text{£}12 + \text{£}8{\cdot}75$$
$$= \text{£}20{\cdot}75 \text{ per hectare}$$

These costs and benefits are usually expressed as a $\frac{\text{Benefit}}{\text{Cost}}$ fraction and would in this case be:

$$\frac{\text{£}43}{\text{£}20{\cdot}75} = 2{\cdot}1$$

or as a Cost:Benefit ratio, i.e., 1:2·1

EXAMPLE 2. TOP-DRESSING ESTABLISHED CROPS

In this example it is assumed that foliar analysis has shown P deficiency in Sitka spruce on a wet heath in Devon. The crop is nine years old and has a top height of 1·5 metres.

The information required is:

i. The expected G.Y.C. of a crop of Sitka spruce on the site in question is 14.
ii. From the data in Appendix I, it would appear that Halwill 4 is the most pertinent fertiliser experiment. This suggests that if 75 kg P/ha are applied the number of years saved is about 6.

The $D.R._0$ for Sitka spruce G.Y.C. 14 is, say £250 per hectare. However, as our crop is some years from planting the D.R. is increased. Because the crop has been growing slowly it is necessary to calculate its "effective" age, rather than using its actual age. The effective age can be calculated using the top height and the G.Y.C. estimated in 1. above. In this case these are:

Top height 1·5m
G.Y.C. 14

Consult top height/age curves 0–20 years for Sitka spruce, and these show that G.Y.C. 14 achieves 1·5m top height in 5 years.

The effective age is 5 years.

The D.R. at age 5 is calculated as $£250 \times 1{\cdot}05^5$

$$= £250 \times 1{\cdot}28$$

$$= £320 \text{ per hectare}$$

If fertilisers are not applied this D.R. will be received 6 years later, the loss in D.R. will therefore be

$$£320 - \frac{£320}{1{\cdot}05^6}$$

$$= £320 - \frac{£320}{1{\cdot}34}$$

$$= £320 - £239$$

$$= £81$$

The cost of fertilising with 75 kg P/ha is estimated to be £18 per hectare. Roads have already been built and it is unlikely that the crop will be brashed.

$$\frac{\text{D.R.}}{\text{Cost}} = \frac{£81}{£18} = 4{\cdot}5$$

Compound/Discount factors, 5%

No. of Years	Compound	Discount
1	1·05	0·95
2	1·10	0·91
3	1·16	0·86
4	1·22	0·82
5	1·28	0·78
6	1·34	0·75
7	1·41	0·71
8	1·48	0·68
9	1·55	0·64
10	1·63	0·61
11	1·71	0·58
12	1·80	0·56
13	1·89	0·53
14	1·98	0·51
15	2·08	0·48
20	2·65	0·38
25	3·39	0·30
30	4·32	0·23
35	5·52	0·18

APPENDIX III

CORRELATION OF SOIL CLASSIFICATIONS IN WALES

Explanatory Notes

1. Soil Type names in () were *not* described in Forest Record No. 69. These are soils on the Carboniferous and Old Red Sandstone series, and some deep peats.
2. The Manod Series is now recognised as Denbigh (Mor Phase).
3. The Gelligaer Series may be recognised as Garth Hill (Mor Phase).
4. The Wenallt Complex is a peaty gley with local occurrence of Kentisbury (ironpan soil) series.
5. U/P:- Undifferentiated peat (Rudeforth 1970) recognised as Caron series in North Wales.
6. Site Survey definitions of organic and organo mineral soils:-
   Non-peaty surface water gley 0–5cm H horizon.
   Peaty (surface water) gley 5–15cm H horizon.
   Peaty gley – deep peat sub type 25–45cm H horizon.
   Ironpan soil < 15cm H horizon.
   Peaty ironpan soil 15cm – 34cm H horizon.
   Deep peat (over gleyed profile) O horizon > 45cm.
   Deep peat (over ironpan soil) O horizon > 40cm.
7. Correlation of Forestry Commission Regional and National Soil type Nos:-

Soil type	*Site type*	*Regional Soil type No.*	*National Soil type No.*
Peaty gley	B1 & C1	6	6f and 6pf
Intergrade to ironpan soil	B2	2	2e
Peaty gley – ericaceous sub type	C2 & C3	6e	6pe
Peaty ironpan soil	C2 & C3	4p	4pe
Upland raised bog	C2 & C3	10	10b
Hill peat	C3	11	11b

Soil Classification for determining fertiliser requirements	Pyatt, Forest Record No. 69		Regional Soil Type (Note 7)
	See Note:	Soil Type (Note 1)	
A. Soil with peat or peaty humus absent	1 2 3 3a 4 4a 7	} Alluvium } (Imperfectly drained B.e.) Lowland B.e. Steep B.e. } Upland B.e. Surface water gley (Humic gley) (Seepage gley)	1G 1g 1d 1 1u 7 7h 7f
B. Soil with peat < *25 cm.* B1 Tall Rushes Common	8/8a	Peaty gley	6/6a 6R/6H
B2 Calluna, Vaccinium Heathy vegetation	5/5a 6/6a 8	Intergrade to ironpan soil Ironpan soil Peaty gley ericaceous sub type	2/2a 4/4p 6e
Non Heathy Vegetation B3 Silurian	5/5a 6/6a 8/8a	Intergrade to ironpan Ironpan soil Peaty gley	2 4/4p 6
Non Heathy Vegetation B4 Carboniferous Devonian	— — — —	(Intergrade to ironpan) (Ironpan soil) (Ironpan soil) (Peaty gley)	2 4 4 6H/6R/6M
C. Soil with peat < 25 *cm.*[6] C1 Tall Rushes Common	8 9 —	Peaty gley Flushed basin peat (Molinia bog)	6 6H/6R/6M 8 } 9b }
Heathy Vegetation C2 Carboniferous	— — — —	(Peaty gley ericaceous sub type) (Peaty I.P.S.) Upland raised bog (Hill peat)	6e 4p 10 11
Heathy Vegetation C3 Silurian Ordovician	10 11 6 8	Raised bog Hill peat Peaty gley Peaty gley	10 11 4p 6
Non Heathy Vegetation C4 Molinia/Eriophorum	8 —	Peaty gley (Molinia blanket bog)	6 9c
C5 Molinia/D. flexuosa	— 8	(Molinia blanket bog) Peaty gley	9b 6/6H/6R/6M

Correlation with England and Wales Soil Survey		
Silurian/Ordovician	Carboniferous	O.R.S. (Devonian)
Conway, Rheidol, Clwyd	Undifferentiated Alluvium	Marshfield
Denbigh (Mull phase)	Neath, Radyr	Castleton, Eardiston
Denbigh, Powys (Cymmer)	part Garth Hill	Whitcott
Denbigh (Mor Phase)	part Garth Hill	part Talybont
(or Manod)[2] Powys (Cymmer)	(or part Gelligaer)[3]	
	Pendoylan	Frogmoor
Cegin, Sannan		
Ynys	—	Wenallt/Beacon
—	Rhondda, Hirwaun	—
(Manod) to Hiraethog	part Gelligaer	part Talybont
Hiraethog	Ebbw	Kentisbury (Wenallt Complex)[4]
Ynys	Merthyr	Wenallt/Beacon
(Manod) to Hiraethog	—	—
Hiraethog	—	—
Ynys	—	—
—	part Gelligaer	part Talybont
—		
—	Ebbw	Kentisbury
—	Hirwaun/Rhondda/ Merthyr	Wenallt/Beacon
Ynys	—	Wenallt/Beacon
—	Hirwaun/Rhondda/Merthyr	—
U/P	U/P	U/P[5]
—	Merthyr	Wenallt/Beacon
—	—	Kentisbury
—	U/P	(Wenallt complex)
—	U/P	U/P
U/P	—	—
U/P	—	—
Hiraethog	—	—
Ynys	—	—
Ynys	—	—
U/P	U/P	U/P
U/P	U/P	U/P
Ynys	Hirwaun/Rhondda/Merthyr	Wenallt/Beacon

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