Site index curves and autecology of ash, sycamore and cherry in Wallonia (Southern Belgium)

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Summary

The work described in this article forms part of an exploratory study[1] whose aim was to determine the main aspects of the autecology of ash (*Fraxinus excelsior* L.), sycamore (*Acer pseudoplatanus* L.) and cherry (*Prunus avium* L.) in Wallonia (Southern Belgium).

The potential productivity of these species was studied using the site index approach (the height a crop achieves at a given age) which is the most widely accepted means for estimating site quality. As a first step, a set of site index curves were constructed from stem analysis and semi-permanent plots data using the Johnson (1935) and Schumacher (1939) model for ash and the Duplat and Tran-Ha (1986) model II for sycamore and cherry. For ash, dominant height achieved at age 50 is related to various soil-site characters (through adequate multiple regression analysis) in order to make the predictions of site quality applicable to both forested and non-forested land. Furthermore the sites expressed through soil attributes are classified in 'a site catalogue' for each species according to their productivity level.

Introduction

Nowadays, the forest policy in several European countries is to encourage the production of indigenous high quality hardwoods on the most favourable site conditions. In this respect, a thorough knowledge of tree growth on different soils and sites is crucial as an aid to successful forest management and silviculture. Ecological preferences and performances of hardwoods have to be known to encourage the species that might be grown on a particular site. This study deals with the estimation of the productivity and the ecology of ash (*Fraxinus excelsior* L.), sycamore (*Acer pseudoplatanus* L.) and cherry (*Prunus avium* L.) in Wallonia (Southern Belgium). Prediction equations linking site index with ecological factors are derived from data on soil, climate and physiographic variables (Blyth and MacLeod, 1981; Harrington, 1986; Green *et al.*, 1989; Klinka and Carter, 1990; Wang, 1995). The results might help forest managers to choose the best species to plant or regenerate in specific locations.

[1] Conducted in the frame of the EU Project No AIR1-CT92-0608, 'Production of Quality Wood from Broadleaves'.

The study area

Wallonia is divided, from north to south, into five ecoregions:

- The 'Region limoneuse' is a fertile area because of the large amount of loam deposits due to the last glaciation.
- The 'Condroz' is a region of medium elevation (200–300 m) and is characterized by alternate belts of mounds (micaceous sandstone stratum) and hollows (limestone and dolomite stratum) from west to east. Both give very fertile soils.
- The 'Fagne-Famenne' is a long schistose clay basin, the elevation of which is 100–200 m. In the south, a calcareous hill the 'Calestienne'.
- The 'Ardenne' lies in a rather humid climate on siliceous rocks. The site characteristics vary gradually according to the elevation (250–694 m) and geomorphology.
- The 'Region jurassique' includes from north to south: a marly hollow, a set of hills of calcareous sandstone and 'macigno' hills. Near the French border, there are the hills of the 'bajocien' limestone.

The maps derived from a regional forest resource inventory (Rondeux, 1983) in Wallonia were used to locate the plots where ash, sycamore or cherry were measured.

Most of the 33 940 ha of ash stands are located in the Condroz (44 per cent), in the Region limoneuse (23 per cent) and the Famenne (15 per cent). Ash is rare in the Ardenne where the elevation is higher and the soils poorer. More than two-thirds of pure ash stands of Wallonia are found in Condroz which is why the autecology of ash has been studied in that region.

The areas covered by sycamore and cherry are more difficult to estimate because these species are very often scattered in the stands.

Sycamore is common in the hardwood forest of the Region limoneuse, Condroz, Gaume and Famenne and it also appears in Ardenne, especially along the rivers.

Cherries are concentrated in the Condroz and Famenne, but they are also found in the Region Limoneuse and Gaume and exceptionally in the valleys of the Ardenne but they are uncommon on the tableland of Ardenne where the climate and the soils are not suitable for their growth.

Most of the ash stands are established on former agricultural land, sycamore and cherry groups, by contrast, are mostly scattered in old forests.

Methods

Site index curves

A widely used means for estimating the site quality for tree species growth is to measure the dominant height of trees that have not been disturbed by past cutting, silviculture or old agricultural practices. This dominant height at a chosen reference age, such as 50 years, is generally considered as an interesting and consistent index, which is, according to some well-known assumptions, often used to evaluate site quality for even-aged stands of single species (Hamilton and Christie, 1971; Rondeux, 1993).

Site index curves are calculated from two types of information that will be called 'static' and 'dynamic' data. The *static data* are dominant height/age measurements in temporary plots, which are not relevant if their distribution does not cover equally the full range of age and site classes found. They provide temporary information about stands or groups of trees. Each measurement is therefore a point in a dominant height versus age diagram. *Dynamic data* provide information about the evolution of dominant height growth in stands or groups of trees. Dominant heights were measured several times at about 3-yearly intervals in permanent plots. Stem analyses were also used to determine the height development of single trees. Such data are represented by segments of lines in a dominant height over age diagram.

The Johnson (1935) and Schumacher (1939) model for ash and the Duplat and Tran-Ha (1986) model for sycamore and cherry were fitted to the height/age data. Due to its mathematical form the non-linear Johnson–Schumacher model was preferred for ash because only few stem analyses were available, and because of the low age of the analysed stems. The dynamic data were useful to indicate the general direction of the growth curves while the static data fix the level of the different fertility curves.

The sample consists of 85 ash plots, 87 sycamore plots and 97 cherry plots in which trees vary from 25 to 80 years of age.

Relationship between site factors and site index

The relationship between site conditions and stand productivity is determined by the site index which corresponds to the dominant height[2] estimated at age 50 years. The autecology was studied in three stages. The first involves determining the ecological factors or basic site attributes that probably influence productivity, the second is the development of a model that can forecast the site's productivity, and the last step results in a site catalogue.

Ecological factors influencing productivity In order to correlate tree growth with site factors, a study was made of the relationships between the site index and several qualitative ('dummy variables') and quantitative ecological features in all the sample plots. Analyses of variance provide an indication of the relative usefulness of each variable in the stepwise regression procedure.

Productivity forecasting model The major factors that explain productivity are pointed out and a relationship between them and the site index is established. The resulting model for forecasting productivity uses quantitative ecological factors related to each site group as well as gross ecological primary qualitative variables.

Site catalogue The site catalogue is a classification of sites based both on site indexes and ecological site factors. The key factors that identify the site are linked to their effects on the site index and to its coefficient of variation. The different sites are grouped according to the species so that the resulting catalogue is particularly suitable for the species studied.

The data

Sampling units

The selection of stands or tree groups was based upon:

- the information derived from the regional forest resource inventory in Wallonia (concerning 550 000 ha based upon one plot per 50 ha of wooded areas);
- a questionnaire filled in by the Forest Service to locate the groups or the stands of ash, sycamore and cherry;
- an aerial survey when the cherry trees were flowering.

Knowing the stand characteristics (structure, diversity) is important in order to define the type of sampling units (plots or trees) and to appraise the relevancy of measurements. The broadleaves studied often form small groups that are generally mixed and not exactly even-aged (except for ash which is often in homogeneous monospecific stands). Therefore, either well stocked pure stands apparently undisturbed by past cutting (principally for ash) or homogeneous growth sites, in which groups of at least ten trees, sufficiently pure (species basal area ≥ 66 per cent of the total basal area corresponding to all the species) have been chosen. Those almost even-aged groups of trees that form part of regular groups in closed stands were considered in a uniform silvicultural context.

Data were collected from three types of investigation (Figure 1):

- temporary plots (only some trees without area consideration),
- semi-permanent plots[3] (area ranging from 0.01 to 0.1 ha),
- stem analysis.

Data from all these methods provided: circumference at 1.3 m, total height, bole height, age, diameters and ring count at various heights (stem analysis).

Ecological zones

For ash, sampling was restricted to the ecological zone of Condroz owing to the great concentration of ash growing there. For sycamore and cherry, the study included a wide range of sites in each of the five natural regions in Wallonia. For each species the distribution of the sampling units in each ecological region is shown in Figure 2.

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[2] In this study, the dominant height is the mean height of the ten biggest trees per hectare (with a minimum of two trees).

[3] Established by Thill around 1970 (Thill 1970; 1975a; 1975b; 1980; 1986; 1987; Thill and Mathy, 1980) and measured every 3 years.

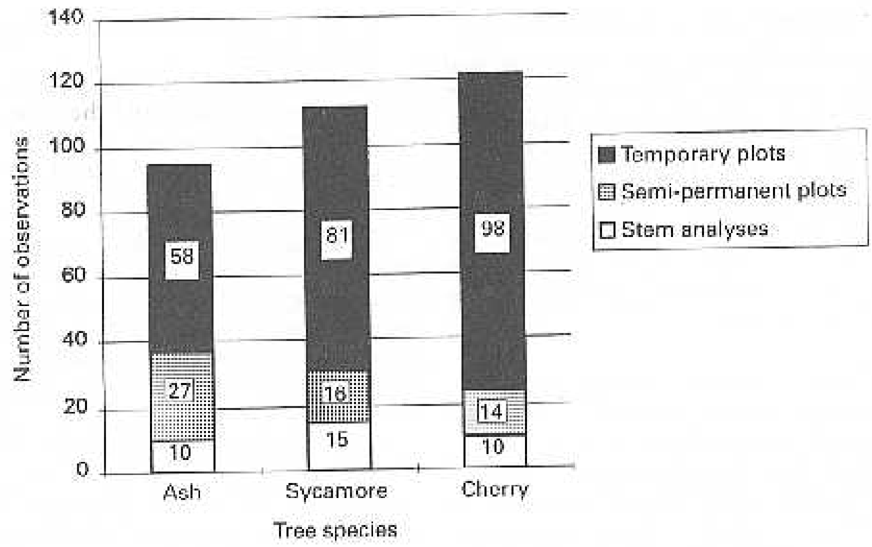


Figure 1. Number and type of data used for studying ash, sycamore and cherry autecology.

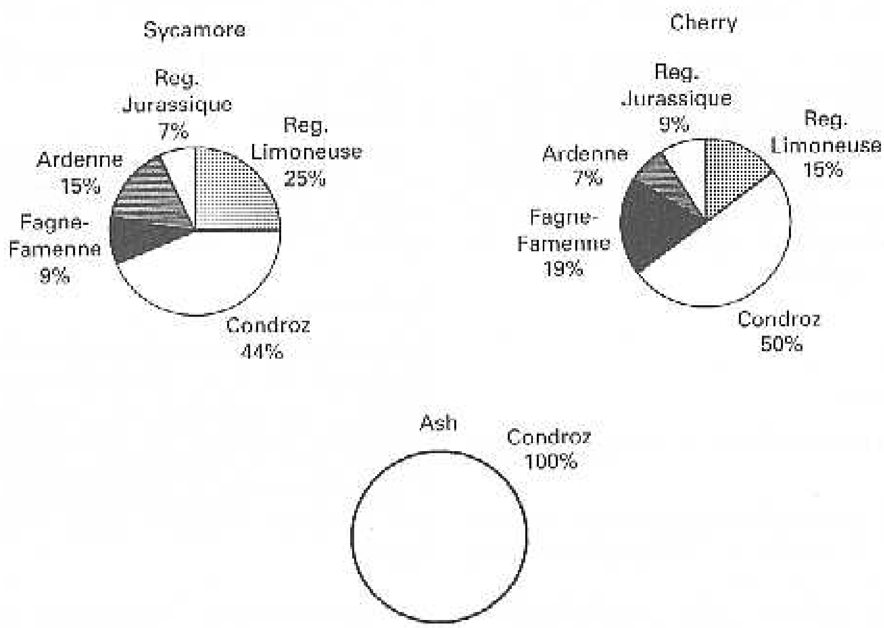


Figure 2. Distribution of sampling units in the ecological regions for ash, sycamore and cherry.

Table 1: Site data collected for ash, sycamore and cherry autecology study

Silvicultural history	• formal land use (agriculture, meadow, forest) • origin of the stands (natural regeneration, planting) • silvicultural treatment (closed or open even-aged stand, plantation)
General environment	• natural region • ecological area based upon climatic and lithological factors (Onclink *et al.*, 1987) • geological strata • geomorphology (elevation, morphology, slope, exposure) • climate (annual mean temperature and precipitation, growing season)
Soil	• pH (only for ash) • humus type according to the Delecour's classification (1990) • moisture (occurrence and depth of ground water-table, gleyed layer and mottled layer) • compactness, load, texture and soil structure • soil depth
Phytosociology	• list of plants (lower vegetation) • phytosociological diagnostic • groups of indicator plants

Ecological data

The ecological data collected for the study are presented in Table 1. Numerous soil and site characteristics were first screened by plotting them against estimated site index. Nevertheless, because of practical considerations, only basic site attributes that could easily be collected by the forest managers were selected.

Data analysis and results

Site index curves

Ash A large number of equations was tested to determine which was best suited to the collected data. Several equations adequately expressed the patterns of height growth. Nevertheless the non-linear Johnson–Schumacher model fitted the data for all age classes best.

The corresponding equation used in this study is:

$$\text{HDOM} = b_0 \exp\left(\frac{-b_1}{A - b_2}\right),$$

where HDOM is dominant height at any age A, b_0 is a coefficient expressing the asymptotic tree height growth, b_1 is a coefficient determining the rate of tree height growth, b_2 is a coefficient expressing the position of the curve on the x-axis.

All the growth curves were forced to start at a common point: 0.2 m height at 1 year of age. The parameter b_0 can then be written as follows:

$$b_0 = \frac{0.2}{\exp\left(\frac{-b_1}{1 - b_2}\right)}$$

The parameters b_1 and b_2 depend on the site index (H50):

$$b_2 = -8.72 + 0.199\ \text{H50}$$

$$b_1 = \frac{(50 - b_2)\,(1 - b_2)\left[\ln\left(\frac{\text{H50}}{0.2}\right)\right]}{49}$$

Four productivity levels that represent all the different site conditions have been defined at successive 3 m intervals from 29 to 20 m of dominant height at 50 years. The harmonized polymorphic height growth curves together with the data they were calculated from are shown in Figure 3.

Sycamore and cherry A set of growth models was tested including Mitscherlich (Richards, 1959), Gauss modified (Grosenbauch, 1965), Johnson (1935) and Schumacher (1939), Gompertz (Amer and Williams, 1957), Duplat and Tran-Ha (1986), and Logistic (Verhulst, 1838).

Table 2: Equations and parameters for sycamore and cherry

	Sycamore	Cherry
Equation	Model II of Duplat and Tran-Ha (1986) $$HDOM = (a_1 A + b)\left[1 - \exp\left(-\left(\frac{A}{a_2}\right)^{a_3}\right)\right] + a_5 A$$ $$b = \frac{H50 - 50\,a_5}{1 - \exp\left(-\left(\frac{50}{a_2}\right)^{a_3}\right)} - 50\,a_1$$	
Parameters	$a_1 = 0.828938$ $a_2 = 10.656667$ $a_3 = 1.055419$ $a_5 = -0.667802$	$a_1 = 0.128658$ $a_2 = 17.148141$ $a_3 = 1.20349$ $a_5 = 0.016035$

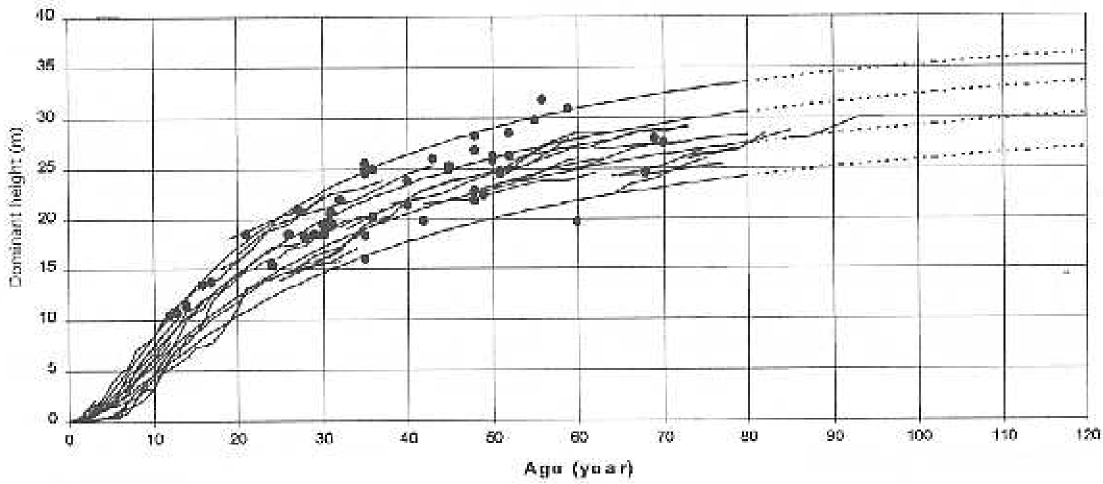


Figure 3. Ash site index curves together with the data from which they were calculated.

Model II of Duplat and Tran-Ha offered the best precision for describing the dominant height growth of sycamore and cherry. The distribution of residuals was unbiased and the quadratic mean square of height is low (about 0.5 m). The resulting equations are shown in Table 2. The levels of productivity were established at 3-m intervals between 29 and 17 m of dominant height at age 50. These curves can be used in Wallonia for trees whose ages are between 20 and 80 years.

The growth curves together with the data they were calculated from are shown in Figures 4 and 5.

Ecological factors affecting the productivity

The ecological variables that most likely affect the site index and which are significant at the alpha = 0.05 level were thoroughly studied. Topography, geology and some soil physical properties including depth and moisture were found to be the most significant to forest growth. The results are summarized in the Tables 3, 4 and 5.

Productivity forecasting model

Ash The ash productivity forecasting model calculates the H50 using seven qualitative variables.

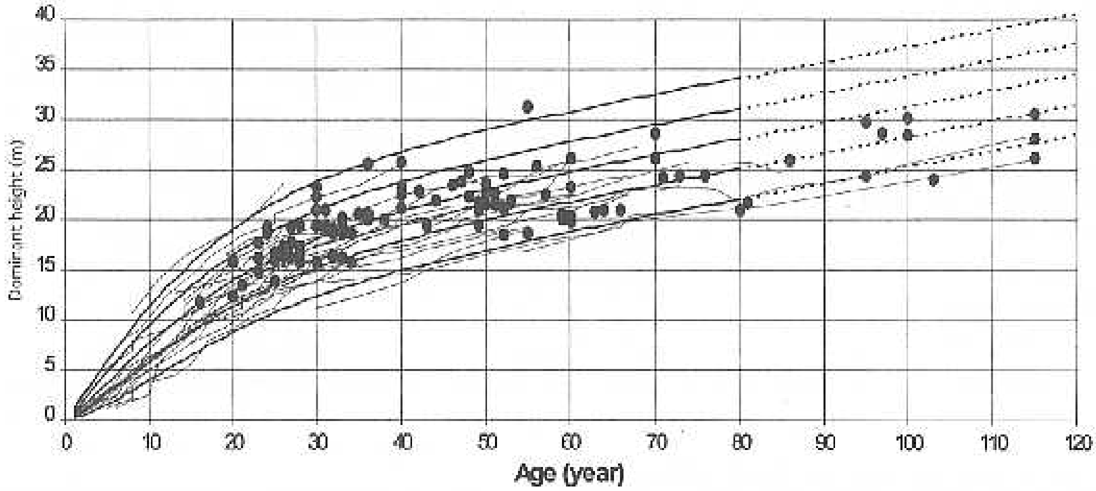


Figure 4. Sycamore site index curves together with the data from which they were calculated.

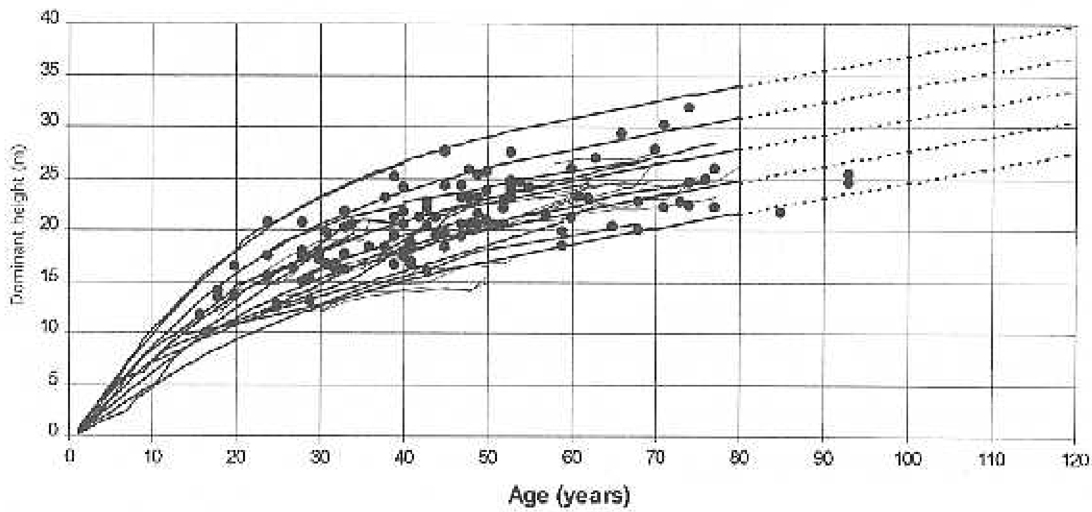


Figure 5. Cherry site index curves together with the data from which they were calculated.

For practical application not more than seven or eight variables should be included in any equation. These variables are equal to 1 or 0 depending on their presence or absence.

The resulting model is:

$$H50 = 23.9 + 3.6\ STA + 1.3\ STC + 0.6\ STB + 3.0\ NPP + 0.9\ NPA + 1.6\ ER - 2.5\ PRO \quad [R^2 = 0.56]$$

where

- H50: dominant height at 50 years (in m)
- STA: alluvial or colluvial sites (group A)
- STB: plateaux loam sites (group B)
- STC: stony slope sites (group C), only on limestone
- NPP: plateaux water-table (linked with STB)
- NPA: alluvial water-table (linked with STA)

Table 3: Ash productivity factors in Wallonia (H50 = height at age 50 years)

	Ash	
Factors	Favourable	Unfavourable
Topography (sites without permanent water-table)	Valleys and hollows H50 = 27.5 m	Plateaux and slope > 10° H50 = 24.2 m
Soil depth	> 100 cm H50 = 26 m	< 40 cm H50 = 22.6 m
Soil moisture (plateaux loam)	Permanent water-table H50 = 27.5 m	Without water-table H50 = 24.5 m
Geological strata	Alluvium H50 = 28.1 m	Famenne, Dinant, Loess H50 = 24.8 m

Table 4: Sycamore productivity factors in Wallonia

	Sycamore	
Factors	Favourable	Unfavourable
Annual mean temperature	> 9°C H50 = 23.6 m	< 8°C H50 = 20.3 m
Natural region	The 'Region Limoneuse' and 'Condroz' H50 = 23.1 m	The 'Ardenne' H50 = 20.2 m
Hydric balance*	Intermediate hydric regime (meso-hydrocline) H50 = 24.2 m	Slightly moist or slightly dry (hydrocline or meso-xerocline) H50 = 21.7 m
Topography†	Bottom of slope and alluvial bank H50 = 23.9 m	Plateaux H50 = 20.6 m
Soil depth	> 120 cm H50 = 23.1 m	< 40 cm H50 = 20.6 m
Presence of pseudogley	> 70 cm or no pseudogley H50 = 23.1 m	< 40 cm H50 = 20.6 m

* Three levels of moisture index were determined by two different methods which give the same results: the method described in the afforestation guide (Weissen *et al.*, 1994) which is based upon physical properties of the site, and the phytosociological typology of Belgium (Noirfalise, 1984) which takes indicator species into consideration.

† Six topographic classes were determined.

PRO: superficial soils (depth < 40 cm)
ER: shade-loving areas (phyto-association of *Tilio-Acerion*).

The percentage of total variation in H50 accounted for in the above equation is 56 per cent. The relationship was not significantly improved by taking into account another easily recorded variable. The residual standard deviation is lower than 1.5 m in 6.6 per cent of cases and exceeds 3 m in 5 per cent of cases. Considering the complexity of the sites and their relationships with the stands, the forecast given by the site equation is acceptable. This model can be used reasonably in Condroz, in forests as well as in agricultural areas.

Sycamore and cherry For sycamore and cherry, the study failed to create a satisfactory productivity forecast model for use in Wallonia. The reason for

Table 5: Cherry productivity factors in Wallonia

	Cherry	
Factors	Favourable	Unfavourable
Annual mean temperature	> 9°C H50 = 22.7 m	< 9°C H50 = 21.5 m
Natural region	The 'Region Limoneuse' and 'Condroz' H50 = 22.8 m	The 'Fagne-Famenne' H50 = 19.6 m
Hydric balance*	Slightly moist or intermediate hydric regime (hydrocline and meso-hydrocline) H50 = 22.7 m	Slightly dry (meso-xerocline) H50 = 21.3 m
Topography†	Bottom of slope and alluvial bank H50 = 24.1 m	Top of slope H50 = 20.9 m
Soil depth	> 40 cm H50 = 22.2 m	< 40 cm H50 = 20.2 m
Presence of pseudogley	> 70 cm H50 = 25.5 m	< 70 cm or no pseudogley H50 = 22 m

* Three levels of moisture index were determined by two different methods which give the same results: the method described in the afforestation guide (Weissen *et al.*, 1994) which is based upon physical properties of the site, and the phytosociological typology of Belgium (Noirfalise, 1984) which takes indicator species into consideration.
† Six topographic classes were determined.

Table 6: Site classification for ash in Wallonia

Ash	
Site type (soil attributes)	H50 (m)
Humid alluvium with water-table	28.4
Alluvium and colluvium	27.5
Deep 'psammit' soils (micaceous sandstone)	25.5
Calcareous loamy soils	25.4
Deep loam (loess)	24.5
Shade-loving areas	24.5
Stony 'psammitic' soils (micaceous sandstone)	23.7
Stony calcareous soils	22.5

Table 7: Site classification for sycamore in Wallonia

Sycamore	
Site type (soil attributes)	H50 (m)
Deep loam (loess)	24.1
Non-calcareous stony soils	23.3
Calcareous stony soils	22.4
Hydromorphic loam	21.6
Superficial soils	20.6

Table 8: Site classification for cherry in Wallonia

Cherry	
Site type (soil attributes)	H50 (m)
Deep loam (loess)	24.0
Deep calcareous soils	24.1
Acid clay	23.5
Mesotrophic soils	23.5
Fresh loamy soils	22.3
Sandstony-schistose soils of 'Ardenne'	22.1
Superficial calcareous soils	20.5
Clayey or schistose soils of 'Famenne'	19.8

this is the huge number of combinations of parameters. The data did not include the repetition of these combinations. Although the model could calculate the productivity in a satisfactory way, it would use variables that appear in too few samples.

The model approach has therefore been abandoned. Instead, the sites were classified to gather information about the expected potential productivity.

Site catalogue

For each species, the sites have been classified into several types which are summarized in the Tables 6, 7 and 8.

The classification for ash [Claessens *et al.*, 1993; 1994] is detailed in Table 9. The sites are linked to productivity and wood quality information. The fitness of each site is then evaluated.

Discussion and conclusion

The ash sites have been classified into three homogenous groups, which are included as independent variables for a model that estimates site productivity. This model can be used in forests as well as in agricultural areas especially, for the latter, in the afforestation of abandoned fields.

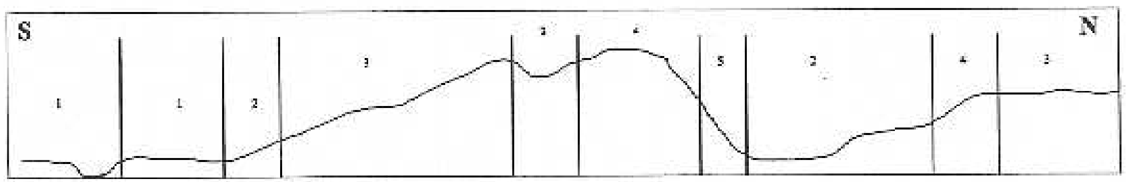
For sycamore and cherry, the factors that influence productivity are not easily determined because the means of the site indexes have a high coefficient of variation ranking from 10 to 15 per cent. This is probably due to the wide sample and the huge number of combinations of parameters. The models produced do not fit the data from which they were derived very well; nevertheless, this study strengthens the knowledge of the underlying importance of the moisture and temperature balances for the broadleaved species growth. In the range of the sites sampled the soil chemistry does not seem to affect site index. Meanwhile, ash, sycamore, and cherry are very uncommon on acid soils (represented by $pH < 5$). The autecology of the three broadleaves under investigation is mostly similar. Their optimum sites are deep and moderately drained soils. Sycamore and cherry seem to be more tolerant of a lack of moisture in the soil than ash which prefers slightly moist sites (alluvial and colluvial sites with water-table). The favourable sites for sycamore are characterized by deep soils without hydromorphy. Cherry does best in warm climates with moderately drained soils.

This study describes different site types on which groups of sycamore, ash or cherry are growing and it classifies them according to their site index. Yet, the variability of the site index within each site is also quite important, especially for sycamore and cherry. Therefore, the site types are not well differentiated. Meanwhile a decreasing tendency in productivity from moist loams to superficial stony soils has been pointed out. All this information can be used to help forest managers in choosing the most suitable species to grow in specific site conditions. This is the first step towards a production of quality wood from broadleaves.

Table 9: Synoptic table of different ash sites

Characteristics	1 Alluvium and colluvium	2 Humid alluvium	3 Loess	4 Calcareous loamy soils	5 Calcareous soils: typical	5 Calcareous soils: shade-loving	6 'Psammit' soils (sandstone): typical	6 'Psammit' soils (sandstone): deep	6 'Psammit' soils (sandstone): shade-loving
Site									
Topography*	2	1	3	3	4	5	4	3	5
Slope (degrees)	0–5 (15)	0–5	0–10	0–10	variable	> 15	variable	0–10	> 15
Exposure	–	–	–	–	–	cold	–	–	cold
Geological strata	variable (allogenic soils)	variable (allogenic soils)	loess	limestone or residual clay	limestone or residual clay	limestone	'psammit'	'psammit'	'psammit'
Soil types[†]	Ahp, Acp, A-Gbp, A-Gcp	Acp, Adp, Aep, (Ahp)	Aba, Aca, Ada, Abb	Gbbk, GbbK, kuAbb, kuEbb	Gbbk	Gbbk	Gbbp	Gbbp, Gbap (Gdap, Gcap)	Gbbp
Depth	> 1 m	> 1 m	> 1 m	> 60 cm[‡]	20–60 cm	variable	40–80 cm	> 80 cm	variable
Moisture	hydrocline	hydrocline to hydrophile	fresh or alternative	mesophile to hydrocline	mesophile to xerocline	hygrophile and shade-loving	mesophile	mesophile to hydrocline	hydrophile and shade-loving
Humus form	mesotrophic to eutrophic mull	mesotrophic to eutrophic mull	oligotrophic to mesotrophic mull (mull-moder)	mesotrophic to eutrophic mull	eutrophic to carbonated mull	eutrophic to carbonated mull	oligotrophic to mesotrophic mull (mull-moder)	mesotrophic mull	mesotrophic mull
Productivity									
H50 (m)	27.5	28.4	24.5	25.4	22.5	25 ?	23.7	25.5	25.8 ?
MAI ($m^3ha^{-1}a^{-1}$)[5]	7	7.5	6	6.25	5.25	6 ?	5.5	6.25	6 ?
Wood quality (Thill, 1970; Leclercq, 1975)									
Potential[¶]	+	+/–	+/–	++	+	+/–	+/–	+	+/–
Risk		coloured heart (moisture)	coloured heart (growth conditions)			asymmetric boles	coloured heart (growth conditions)		asymmetric boles
Fitness									
Valuation	++	+	+	++	–	+/–	+/–	+	+/–
Maturity:									
Age	60	50	60	65	90	?	70	60	?
c130[‡]	180	150	150	180	150	?	150	150	?
AMIc**	3	3	2.5	2.8	1.7	?	2.1	2.5	?

* The codes correspond to the following topographic succession:



[†] In reference of soils map of Belgium (IRSIA)
[‡] More than 60 cm on decarbonated clay
[5] According to unpublished temporary production tables
[¶] ++ = excellent, + = good, +/– = middle, – = poor
[‡] c130 = circumference at the age of maturity measured at 1.3 m height
** AMIc = annual mean increment of circumference at the age of maturity

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