Relationship between tree development, mean annual increment and internal wood decay in veteran *Tilia* trees.

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Summary

This study aimed at classifying nineteen veteran lime trees (*Tilia cordata* Mill., *T. platyphyllos* scop. and *T.* x *europaea* L.) in their development. *Tilia* spp. was chosen because it is long lived and widely present in Belgium. A classification in five steps (A to E) is proposed, based on crown and trunk status, quantity of decaying wood and mean annual girth increment (MAI) as an additionnal criterion. We tested the relationship between veteran tree development and MAI. Threshold values were determined to help distinguish steps A to E. The relationship between trunk growth dynamics, and crown and root development is also discussed.

Introduction

Tree development from seedling to death has been described, with a particular focus on ontogenic development (Raimbault & Tanguy, 1993; Raimbault, 1994; Raimbault *et al.*, 1995) or on veteran features (Fay & Berker, 1997). According to Fay (2007), a lime tree (*Tilia* spp.) is called "fully mature" when it has a girth of between 400 and 450 cm. Above this girth, the tree is considered as "ancient". Those limits, proposed in UK, may be applied in Belgium even if it would have to be modified for other geographical zones or species. An "ancient" tree can also be characterized by the loss of apical dominance, the formation of redundant parts (reiterations) in the crown and the accumulation of dead wood. A "veteran" is a mature or ancient tree presenting additional features: hollowing, rot sites, dead wood, stubs or fungal fruiting bodies. Depending on the tree species and site conditions over time, the chronological age of mature or ancient trees may vary greatly. (Fay, 2007; Delcroix *et al.*, 2009).

Fay (2002) proposed a classification of veteran trees based on crown development, thereby continuing Raimbault's work (Raimbault & Tanguy, 1993; Raimbault, 1994; Raimbault *et al.*, 1995). It is also possible to describe the pattern of growth as being represented by the annual increment (AI) of new wood (White, 1998). This AI can be measured through ring width or trunk girth. White (1998) used the large amount of historical and dendrological records available since 1952 in the UK to calculate ring width for 20 species. Generally, trees progress through 3 phases of growth, each related to AI change over time. During the formative period, the growth of new wood theoretically produces constant ring width and continuous girth increase. The photosynthetical area makes exponential progress, producing ever more wood, which covers an increasing surface of trunk and branches. The second phase corresponds to the maturity of the tree. Foliage no longer increases, but is constant, through branch renewal. Annual wood production is constant but the total area continues to increase in size, inducing a reduction in ring width. The annual increase in girth also slows down. During the third phase, crown dieback is not fully compensated by reiterations. The assimilation area reduces, as does the amount of new wood production. Girth then becomes almost constant. White (1998) considered that this last phase is followed by tree death. Two particular features of veteran trees are not taken into account in his work: (i) the possible reduction in trunk girth caused by cavity formation and partial trunk decay; and (ii) the possible 'phoenix regeneration' of some species. Phoenix regeneration is based on remaining cambium activity or new cambium formation after adventitious buds emerge from dormancy. The ancient cambium, which connects living roots to living buds and leaves, forms what Raimbault called a "cambial column" (Delcroix *et al*., 2009). Adventitious roots or buds form new growth axes, which can complete those cambial columns to form multi-stemmed veteran trees. Several phenomena may result in phoenix regeneration: trunk layering, trunk regeneration, lateral layering, basal rejuvenation, phoenix crown regeneration and crown restoration (Fay, 2002, 2007).

In urban and semi-urban sites, veteran tree management is somewhat different in its goals and methods from general practices. By definition, these trees are colonized by fungi, insects and other living bodies, which would be unacceptable for avenue trees. At each step of veteran tree development, it is necessary to apply appropriate diagnostic techniques to determine tree evolution and to propose intervention for tree preservation. The starting point of all diagnoses is a visual description of the tree (vitality, phytopathology, stability) and its environment. The most generally used method is based on Visual Tree Assessment (VTA) developed by C. Mattheck (Mattheck, 2007). Nevertheless, there is no generalized agreement about critical thresholds in stability evaluation. A study in Helsinki (Finland) illustrated the difficulty of urban tree management based only on visual assessment (Terho, 2009). Contradictions were found in the criteria used for felling decisions, especially for trees presenting cavities or advanced decay, and this happened primarily with *Tilia* spp. The author suggested that old urban trees require a more accurate determination of the rate of degradation in order to improve prognosis and decision making. Non invasive techniques should be preferred for veterans because of the particular importance of compartmentation in those trees. Drilling techniques can be disadvantageous because of the increase in the susceptibility of the wood to decay (Gilbert & Smiley, 2004; Toussaint *et al.*, 2004; Kersten & Schwarze, 2005; Deflorio *et al.*, 2008). Among other non invasive techniques, such as thermography (Catena, 2003) and resistivity measurements (Larsson *et al.*, 2004), tomography is continually being developed and has been applied to several diagnostic situations (Nicolotti *et al.*, 2003). To the best of our knowledge, no publication has addressed the particular case of veteran trees (hollowed, multi-stemmed trunks, high girth values) with this technique. The high girth values of ancient lime trees (> 450 cm at 1.30 m) imply that numerous measuring points are needed. Also, the complex trunk geometry and the presence of cavities would render tomogram interpretation quite difficult.

A lot of veteran trees have been lost following inappropriate treatment (crown topping, soil proofing, or root degradation). The correct diagnosis of veteran tree needs to determine its evolution stage and evaluate further tree development. In this context, the present study aimed at adapting veteran lime tree classification by the addition of mean annual girth increment (MAI) as a criterion.

Material and methods

Nineteen mature and ancient trees were studied throughout Wallonia. Location, species, estimated chronological age and the previous girth measurements (value and date) are historical data that we gathered from the literature (Collectif, 1978; Stassen, 2003). We defined parameters to characterize veteran tree evolution in 5 steps (A to E, table 1 and figure 1).

Table 1: Criteria used in this study to class the 19 observed trees in five steps (A to E)

A	Mature or ancient tree (girth ≥ 400 cm) without any sign of crown dieback. No trunk deformation, no bark degradation, only restricted cavities.
B	First signs of crown dieback (branch centripetal decay and reiteration formation). No trunk perimeter deformation or large cavities.
C	Important crown dieback. First signs of trunk decay, large cavities may be present, but the original perimeter is still observable. Cambial column formation.
D	Decaying, opened or multi-stemmed trunk with increased wood degradation. The initial tree shape is disappearing.
E	Structure stabilization or renewal based on remaining parts of trunk and/or new cambial columns. No further lignolytic fungi activity.

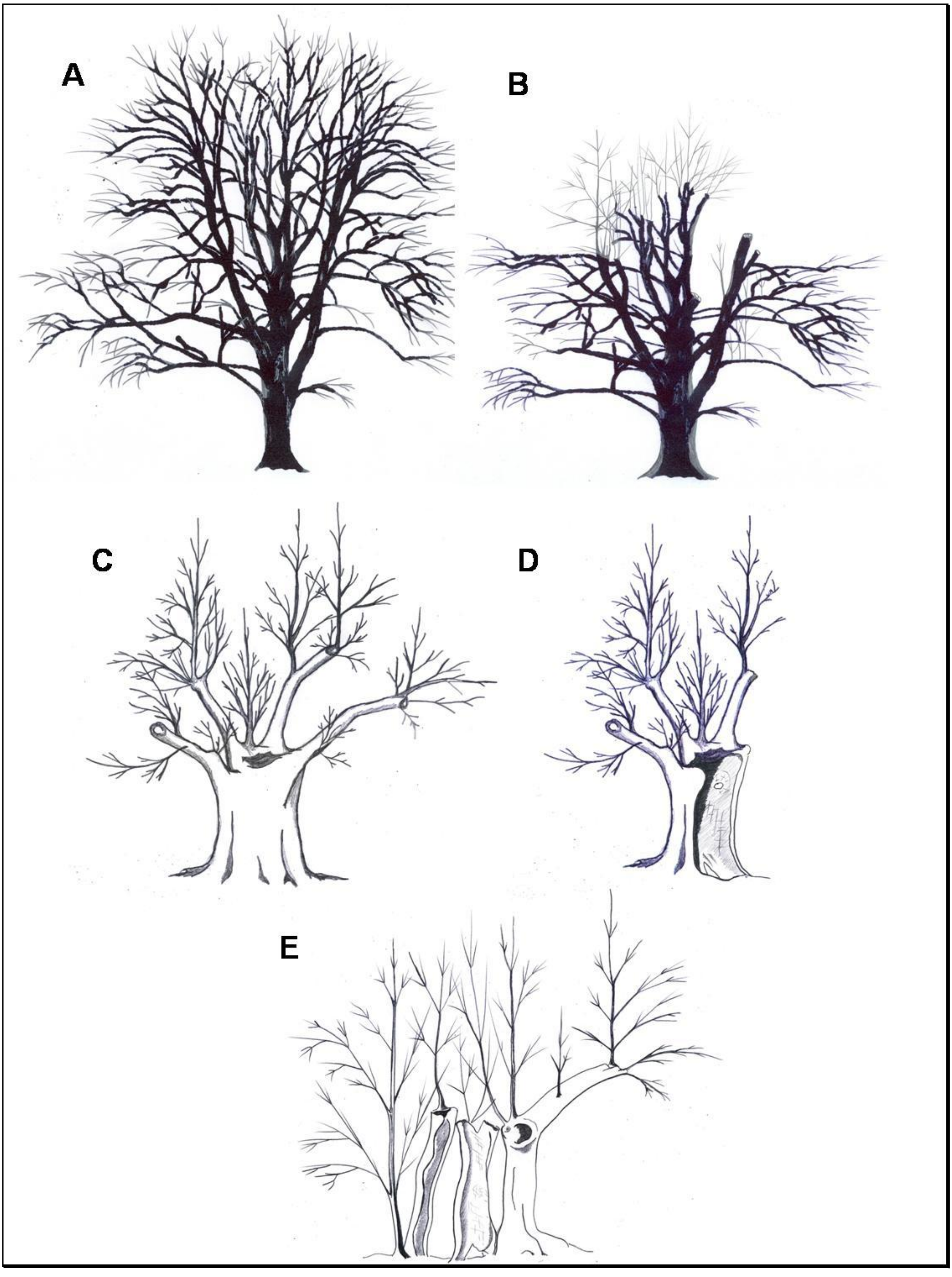

Figure 1 : general aspect of trees representing each step with major features corresponding to criteria described in table 1.

In 2009, the nineteen trees were classified according to the visual description of the crown and trunk. When present, decay fungi were identified on the basis of fruiting bodies. Identification was achieved through the use of a field key (Gonthier & Nicolotti, 2007) and confirmed by comparison with reference descriptions (Schwarze et al., 2000; Delcroix *et al*., 2009). Each tree was also measured (height, crown radius, girth) in 2009. The Specialist Survey Method (SSM, Fay and Berker, 1997) was applied. Girth was measured at 1.3 m height above ground level. For irregular trunks (with swellings, burrs, etc.), girth was measured at the nearest point below 1.3 m. SSM was not used for multi-stemmed trees. If the tree is multi-stemmed from below 1.3 m height, this method advises measuring only the largest stem. Nevertheless, observations made between 1990 and 2000, which we wanted to use to describe girth change over time, considered multi-stemmed trees as a whole. Girth was the criterion for selecting mature and ancient trees from various data bases. It was also used to calculate a mean annual increment (MAI):

MAI = (girth in 2009 – girth in the 1990s)/ number of years   in cm/y

Statistical treatment of MAI data was carried out using the Graph Pad Prism 4.0 software (Graph Pad Software Inc.). After verification of variance homogeneity, means were analysed by ANOVA for mutliple comparisons. Unpaired t-test was also used to confirm significant differences in some cases.

Results

A. Classification of veteran lime trees

Observation of the 19 trees in 2009 revealed some characteristics of their patrimonial status (table 2). A large majority are located in a semi-urban environment, on roadsides or alongside churches or cemeteries (15/19). Two trees are located in parks (one *T. platyphyllos* and one *T.* x *europaea*) and two others (both *T. cordata*) are in a rural environment (meadow). This kind of situation also has implications for tree management, as the risk of branch or tree felling needs to be minimized. Natural crown restoration, phoenix crown regeneration and trunk remnant rejuvenation were the most generally observed phenomena among our 19 trees. Trunk regeneration was also obvious and was clear in one case in Bioul. Basal rejuvenation was quite rare (in only one *T. platyphyllos* in Maibelle), undoubtedly because basal sprouts are generally removed by green landscape services in order to ‘clean’ the trunk base. Trunk layering and lateral layering were not observed because we did not study trees in forest environment.

Most of the trees showed a development where degradation processes are predominant (steps B, C and D, 11/19 trees). Several trees illustrated the negative impact of the pressure of man’s intervention in the development of trees, accelerating their ontogenic development. For example, one mature *T.* x *europaea* in step B (Crupet) presented a fast crown dieback. The accelerated weakening of this tree is related to herbicide used between 1992 and 1996. After a complete disappearance of foliage, reiterations were first observed in 2002. It is now colonized by *Polyporus squamosus* Fr. Without any herbicide application, this tree would be certainly be classified in step A. Few lignolytic fungi fruiting bodies were observed (4/19), representing only three species (table 2). This poverty of fungal biodiversity is the result that, until recently, the mere observation of fruiting bodies implied the felling of trees, even for mature and ancient trees.

Table 2: Historical, geographical and dendrological data collected in litterature and girth, classification and ecological status of the 19 limes in 2009.

Locality	Species	Age (y)	Previous girth (cm)	Girth (cm) in 2009	Visible fruiting bodies	Step	Environment
Annevoie	*Tilia platyphyllos* Scop.	150	378 in 2002	406	no	A	Park
Conques	*Tilia* x *europaea* L.	315	739 in 2000	770	no	A	Park
Walk	*Tilia platyphyllos* Scop.	307	483 in 2003	512	no	A	Semi-urban
Barbençon	*Tilia platyphyllos* Scop.	-	400 in 1993	446	no	B	Semi-urban
Blicquy	*Tilia* x *europaea* L.	250	427 in 1992	442	no	B	Semi-urban
Crupet	*Tilia* x *europaea* L.	150	395 in 1992	409	yes (*)	B	Semi-urban
Florée	*Tilia platyphyllos* Scop.	-	380 in 1992	396	no	B	Semi-urban
Macon	*Tilia cordata* Mill.	270	436 in 1994	480	no	B	Semi-urban
Braffe	*Tilia cordata* Mill.	300	650 in 1992	669	yes (**)	C	Semi-urban
Anthisnes	*Tilia* x *europaea* L.	240	463 in 1993	480	no	C	Semi-urban
Grandhan	*Tilia platyphyllos* Scop.	250	435 in 1999	429	yes (***)	C	Semi-urban
Doyon	*Tilia* x *europaea* L.	325	735 in 2000	750	yes (**)	D	Semi-urban
Maibelle	*Tilia platyphyllos* Scop.	400	757 in 1992	750	no	D	Semi-urban
Méan	*Tilia platyphyllos* Scop.	300	662 in 2000	473	no	D	Semi-urban
Bailièvre	*Tilia cordata* Mill.	-	518 in 1994	565	no	E	Rural
Bioul	*Tilia cordata* Mill.	400	640 in 1996	701	no	E	Rural
Limbourg	*Tilia cordata* Mill.	300	464 in 1997	496	no	E	Semi-urban
Mohiville	*Tilia platyphyllos* Scop.	250	452 in 1992	494	no	E	Semi-urban
Ramelot	*Tilia platyphyllos* Scop.	-	487 in 1997	505	no	E	Semi-urban

(*) *Polyporus squamosus* Fr.

(**) *Kretzschmaria deusta* (Hoffm.) P.M.D. Martin

(***) *Ganoderma adspersum* (Shulz.) Donk.

B. Mean annual girth increment for each step

Mean MAI was calculated for each species. ANOVA analysis showed there is no significant difference between species (*T. platyphyllos* : 1.6+/-1.4 cm, n=9; *T. cordata* : 2.9+/-0.8 cm, n=5; *T.* x *europaea* : 1.5+/-0.7, n=5; P=0.3954). Mean MAI was also calculated for each step (figure 2). Some significant differences appeared and was confirmed by t-test between steps A and B (P = 0.0147, alpha = 0.05) and between steps D and E (P = 0.0208, alpha = 0.05).

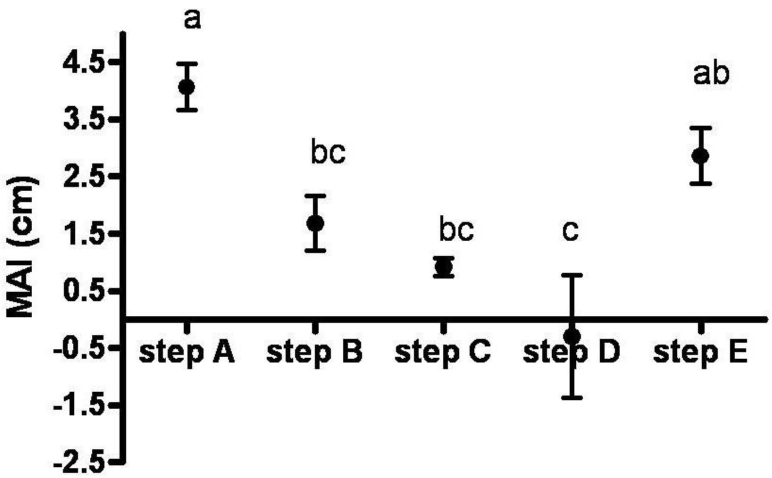

Figure 2: Mean annual increase averaged for each step (cm/y). I: 95% confidence interval, n = 3, 5, 3, 3, 5 respectively for steps A, B, C, D and E

Step D is characterized by the disappearance of trunk girth continuity. Cavities (sometimes pre-existing) are connected to the soil. In some cases, some parts of the trunk have completely collapsed. This is generally related to a main branch falling or to root dieback. Trunk girth is therefore reduced and the MAI may be negative. Transition to step E is associated with MAI returning in positive values. As significant differences exist, MAI could be used as an additional criterion to distinguish between steps A versus B and D versus E. The minimum measured value in step A was 3.4 cm. The maximum value recorded in step B was 2.9 cm. A threshold value should therefore be 3.0 cm for lime trees, even if this value is not significantly different from each mean. Following the same rationale, a threshold value of 1.5 cm should be defined to distinguish between steps D and E. A negative MAI value is typical of step D, where the trunk is suffering degradation. Trees at steps B, C and D present low MAI values.

Discussion

White (1998) highlighted that the MAI of veteran trees that have lost most of their crown could be reduced to almost nothing. Trunk girth may be constant or reduced over time even if some parts are still in growth. Nevertheless, the classification of the development of trees proposed here integrates the possibility of phoenix formation as a beginning of a second life based on cambial columns (step E). Two major features of this step are the absence of fungal pathogens (even if saproxylic organisms are still present) and a new increase in girth size (figure 2). This classification can be used to carry out a veteran tree survey and to determine the current step of a *Tilia* spp. Tree development may be natural or under man's influence. The *T.* x *europaea* located in Crupet is one of the youngest tree of our sampling. Its development has been accelerated by the application of herbicide around the trunk base. Reduced MAI (0.8 cm/y) and tomograph results are consistent with the classification of this tree in step B. There is also a good agreement between crown and trunk characteristics, even though the development of the tree was not 'natural'. The environment of a tree (soil, exposure to wind and light, water availability, etc.) will influence MAI throughout the tree's life. This parameter must therefore be used as a complementary factor for classifying a tree. MAI has been added to the visual criteria to distinguish in five steps the progress of a tree with no symptoms of decay to a phoenix tree. The MAI calculation would be more accurate if historical and dendrological data were more abundant. This highlights the importance of implementing a large survey action, as in the UK, for example. The classification developed here, illustrated by examples of local trees, is also a good communication tool for public managers. They need to be convinced that a veteran tree is not dangerous *per se* and that a tree in step D can progress onto step E for a subsequent period of safe growth. We are currently testing the proposed classification on other species presenting reiteration ability (*Salix* spp.). Some species also produce reiteration easily but are less long living (*Acer* spp., *Fraxinus* spp.), while others present particular longevity through reiteration ability and wood durability, such as *Quercus* spp. For this last genus, the proposed classification would have to be adjusted, mostly for steps D and E. Some oaks show crown dieback and MAI values typical of step C, but conserve an intact trunk base. Transition from step C to E could be direct in *Quercus* spp. *Carpinus* spp. and *Taxus* spp. can also form very old trees but they are naturally multi-stemmed, without any dieback phase. Our visual criteria are not applicable to those two genuses. *Juglans* spp., *Fagus* spp. and *Castanea* spp. demonstrate very poor reiteration ability and crown dieback is generally followed by tree death. Our typology can thus not be applied for those last three genuses.

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