Original Article

Simulated Comparisons of Thinning Effects Using SIBYLA Program

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ABSTRACT

Thinning effects comparisons were undertaken based on two selective thinning options-thinning from below (TB) and thinning from above (TA)-and no thinning (NT). Growth and tree characteristics were investigated using the SIBYLA growth simulation program (originally designed for Czech forests) that was adapted to simulate the growth characteristics of tree species available in Thailand. Specifically, *Carpinus viminea* (Betulaceae) was chosen as a representative Thai species. The study investigated the effects of TB, TA, and NT on tree productivity (mean height, mean diameter, volume per stem, volume per hectare), biomass, and biodiversity. Pairwise comparisons and statistical analysis were applied. Based on the results, TB could increase the growth potential of trees after thinning more than TA and NT. Although there were similar results for TB and TA in each period, the TB data were slightly higher. However, TA and TB were not significantly different in productivity yields ($p>0.05$). Therefore, both TA and TB would be effective in increase production yields.

Based on the study, selective thinning model of growth using the SIBYLA program substantially reduced the computational and practical workload. This opens possibilities for further exploration of thinning algorithms and their integration into the SIBYLA program, for application in forestry simulations or the management of Thailand's diverse plantation forests.

Keywords: *Carpinus viminea*; Thinning; Growth simulation; SIBYLA

INTRODUCTION

Thinning is the selective removal of trees from a forest stand to improve its overall health, growth, and biodiversity. There are many different approaches that can be applied such as thinning from above (TA) and thinning from below (TB) (Ekholm *et al*., 2023). TA involves the removal of trees from the upper canopy, involving some dominant and co-dominant trees. In contrast, TB removes trees from the lower canopy, involving suppressed and sub-dominant trees. Both these methods focus on opening space for the remaining trees in the stand to encourage the development of clumps of dominant trees that are distributed depending on the purpose of each thinning practice (Kerr and Haufe, 2011).

SIBYLA was developed by Technical University in Munich by Assoc. Prof. Dr. Marek Fabrika, Head Developer in SIBYLA Triquetra Development Team, with comprehensive documentation of the model and software being published in 2007 SIBYLA is a simulator that strives to imitate the behavior of trees in the context of forest ecosystems. It consists of a set of mathematical models and algorithms that are combined in an integrated software package called the SIBYLA Suite (Fabrika and Dursky, 2005).

SIBYLA can be used in Thailand to investigate options to achieve efficient thinning using TA or TB. Inbuilt models for species such *Tilia sp., Robinia sp.,* and *Betula sp.* can be used to experiment with timber harvesting experimental applications and to simulate a treatment or productivity goal based on various methods in the software (Fabrika, 2002). However, because of climatic, edaphic, and species distribution differences, the European-based models available for use in SIBYLA limit its applicability in Thailand. Consequently, *Carpinus viminea* was selected as the most suitable tree species in the SIBYLA software to model the Thai situation. An additional goal of the study was to test the operational efficiency of the software when applied to the Thai situation.

Capinus viminea Lindl. ex Wall (Himalayan Hornbeam) from the *Betulaceae* family is a medium-sized deciduous tree that usually grows to a height of 10–20 m. The wood is moderately hard and is used for fuel, making furniture, decorations, sports articles and weaving shuttles. Himalayan hornbeam can be found in the Himalayas, China, and Southeast Asia (De Langhe, 2013), including in northern and northeastern Thailand, typically at altitude of 800–2,600 m, such as in Doi Inthanon National Park in Chiang Mai province, Phu Kradueng National Park in Loei province, and Namnao National Park in Phetchabun province (Thiangburanatham, 1999) These trees are considered potential landscape plants that can be domesticated and cultivated as one of several species for use as a resilient tree urban planting (Dirr, 2009). Nonetheless, although a small number of these trees have been recorded in forests or national parks in Thailand, in general, this species represents a resource that is currently relatively unused.

MATERIALS AND METHODS

Study function and implementation of SIBYLA program

The main use of the SIBYLA growth simulation software in forest management and thinning model is for empirical forest modeling, using functions and features such as lecturer, generator, medium, cultivator, prophet, calculator, explorer, analyst, and expert (Fabrika, 2003) as shown in Figure 1.

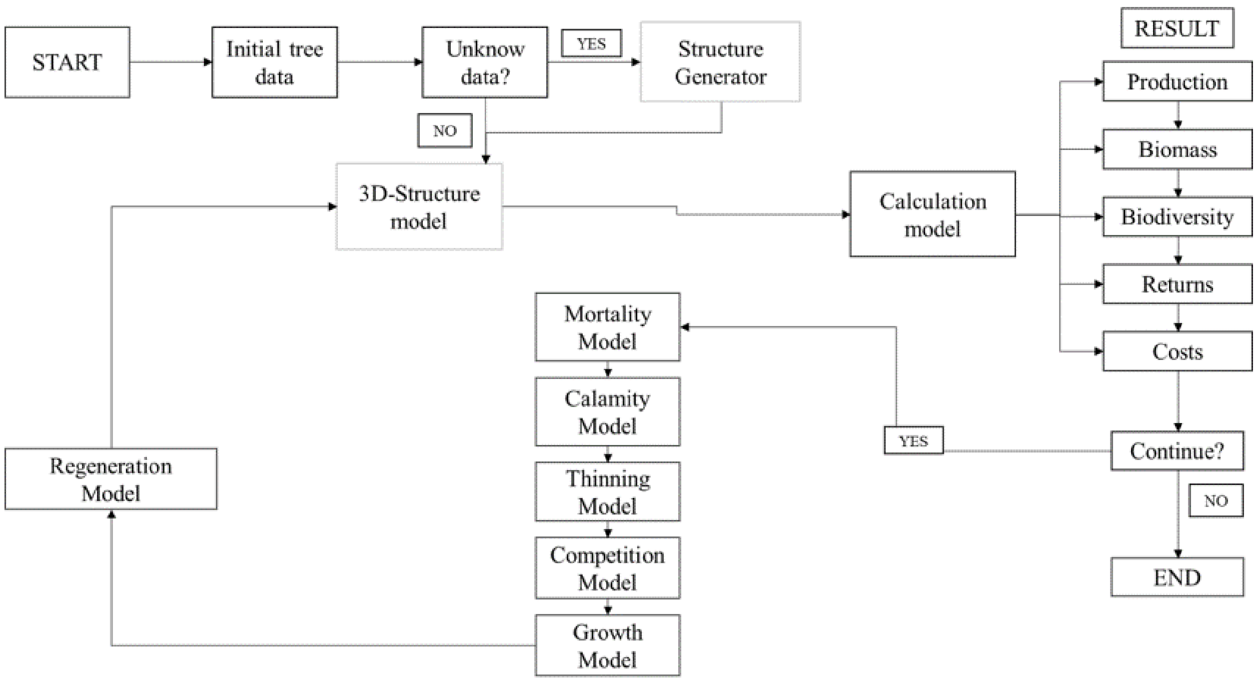


Figure 1 The SIBYLA growth simulator workflow chart

Input data from practical section and set up program

As shown in Figure 1, the initial tree data (DBH, height, tree coordinates from GPS) collected in Nam Nao National Park were entered into the generator function. Next, the type of forest and desired forest area were defined for the model. Then, program simulates tree growth by generating simulations after specifying the length of period and number of periods. The results are automatically processed using the prophet features (Figure 2). The current study used 8 periods each being 5 years in the generation of the simulation, with thinning occurring 8 times 5 years apart, with a mean age range of 24–59 years.

Figure 2 3D-Structure simulation plot model of *Carpinus viminea*

Simulation and analysis of thinned forest

After processing the 3D-Structure, the next step used the calculator model to process various results from the simulated plots such as production, costs, biomass, biodiversity, and returns. Then, applying the cultivator sets the parameters for various thinning practices of interest. The current study applied the TB, TA, and NT options based on thinning 20% of the standing volume to study the implementation of the program. The results from cultivator were run through the prophet function to simulate and estimate the growth, mortality, competition, and other forest dynamics parameters for each plot. Next, the results from the simulated plots were displayed in the explorer function using characteristics, such as mean age, diameter, and height, for each thinning period (Figure 3).

(a) (b)

Figure 3 3D-Structure of *Carpinus viminea* for no thinning plot (a) and thinning plot (b)

Data analysis

The outputs from the explorer function were exported into a Microsoft Excel spreadsheet and sorted and managed as group data. Then, options were applied to provide trendlines and graphs for the different options simulated. Next, data were analyzed for relationships between mean age and other variables using ANOVA and the least significant difference (LSD) as a *post hoc* test, with pairwise comparisons used to evaluate thinning relationships between each thinning practice based on significant differences in the data, calculated using the IBM SPSS Statistics program.

RESULTS AND DISCUSSION

Results

Mean diameter

The NT option produced the biggest mean diameter (38 cm) at a mean age of 59 years, while TB produced a mean diameter of 42 cm at a mean age of 59 years. Lastly, TA produced a mean diameter of 42 cm at a mean age of 59 years. There were high coefficients of determination (R^2) values for TB and TA with the mean diameter (R^2 = 0.937 and R^2 = 0.931, respectively), as shown in Figure 4.

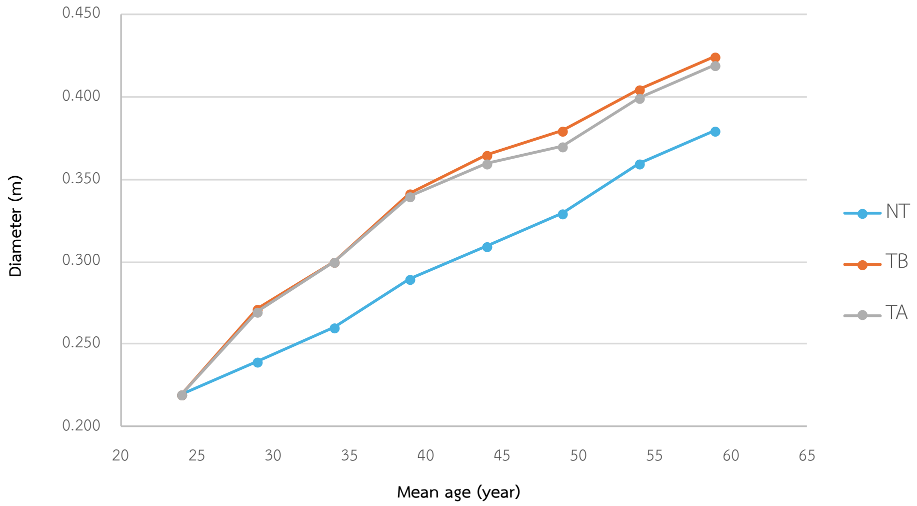


Figure 4 Mean diameter of each thinning practice with age

Mean height

At age 59 years, the mean heights for the NT, TB, and TA options were 18.30 m, 18.33 m, and 18.16 m, respectively. TA and TB had high coefficient of determination values (R^2= 0.937 and R^2 = 0.945, respectively) with the mean height (Figure 5). Therefore, all three simulated practices could produce an increase in tree height with time.

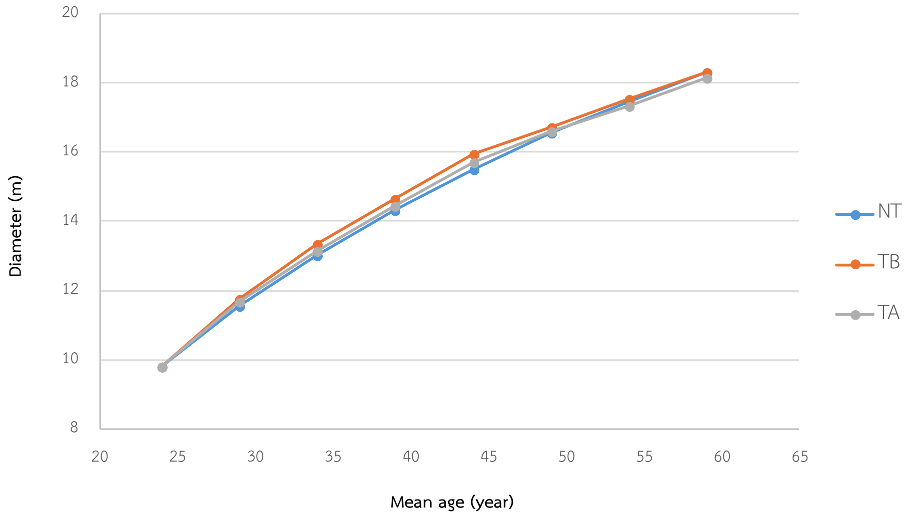
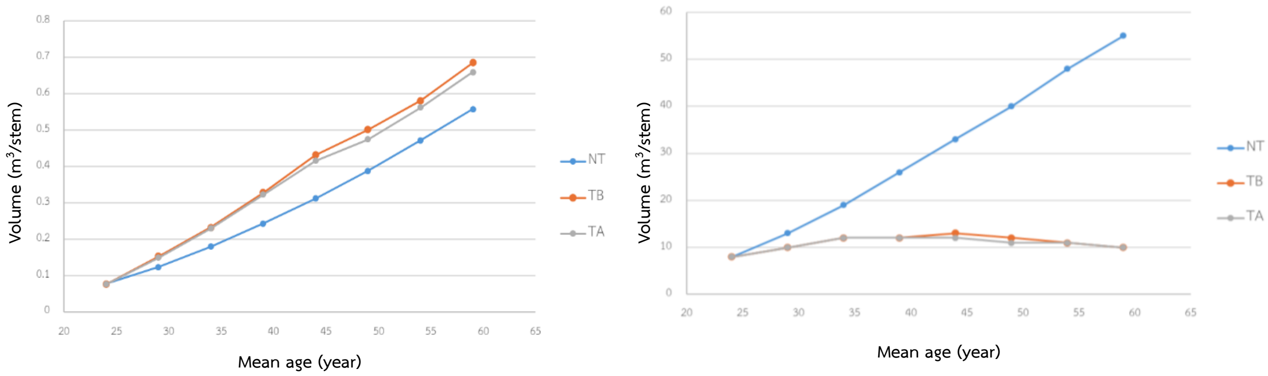


Figure 5 Mean height of each thinning practices

Mean volume per stem and per unit area

The mean volume after thinning can be separated into two parts: mean volume per stem and mean volume per hectare. The values for the mean volume per stem (Figure 6a) were 0.558 m^3 0.686 m^3, and 0.660 m^3, for NT, TB, and TA, respectively, with the age and stem volume for TB and TA both having high coefficient determination values (R^2 = 0.926 and R^2 = 0.929, respectively). The values for the volume per hectare (Figure 6b), at the mean age of 59 years for NT, TA, and TB were 55 m^3/ha, 10 m^3/ha, and 10 m^3/ha, respectively. However, the coefficient determination values for TA and TB were very weak (R^2= 0.116 and R^2 = 0.101, respectively), indicating that TB and TA were not correlated to NT.



(a) (b)

Figure 6 Mean volume per stem (a) and Mean volume per hectare (b) for each thinning practice

Biomass

The total biomass in kilogram dry matter per hectare was analyzed, which included the root and stump with bark, wood, bark, branches with bark, and foliage. The highest biomass values were 55.800 t/ha, 13.066 t/ha, and 13.062 t/ha for NT, TB, and TA, respectively. Figure 7 illustrates that biomass had a weak coefficient of determination with TB and TA (R^2 = 0.014 and R^2 = 0.063, respectively).

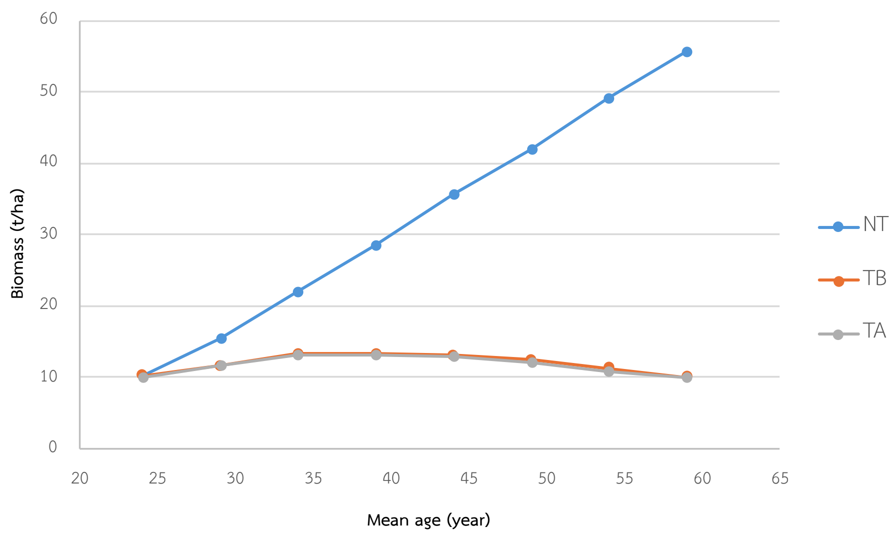


Figure 7 Biomass of each thinning practice

Biodiversity

The forest biodiversity was calculated using the calculation of total diversity from Jaehne and Dohrenbusch (1997), using the aggregation of the partial components of diversity such as diversity of vertical structure, tree spatial structure, tree spatial distribution, and crown differentiation. Figure 8 shows that NT had the highest summary index of biodiversity (2.778) at a mean age of 24 years. TB and TA had the same highest value for the summary index of biodiversity (2.778) at a mean age 24 of years.

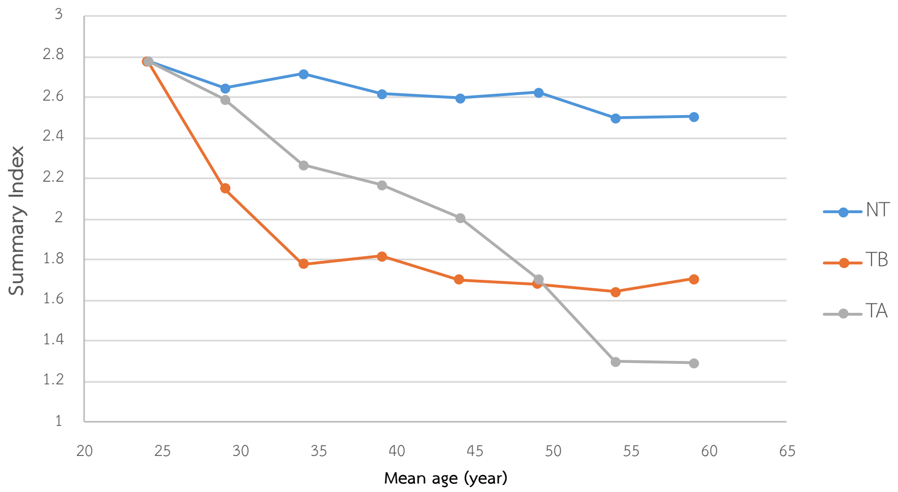


Figure 8 Biodiversity of each thinning practice

Discussion

Comparing the thinning practices, TB had slightly higher production than NT and TA based on the values for mean diameter and mean height. Hence, after thinning, TB offered larger and taller trees compared to TA. TB reduced competition for resources among the remaining trees, leading to improved growth and quality. This thinning practice would favor more vigorous and commercially valuable trees. In contrast, while heavy crown thinning promotes faster growth for some trees, it ultimately reduces overall tree quality. Therefore, TB would be more effective in maintaining a balance between growth and quality, making it more suitable for some commercial purposes. Even though there were no significant differences between thinning practices (Novosadova *et al*, 2024), hence, both thinning practices promoted similar growth for *Carpinus viminea* according to the SIBYLA growth simulation program. Mcdowell *et al*. (2003) reported that a stand density reduction resulted in increased growth of individual trees via increased stomatal conductance, with a strong relationship between basal area increment and the modelled ratio of photosynthesis, suggesting that changes in water availability and stomatal conductance have a significant effect on carbon assimilation and growth of these trees.

TB produced the highest mean volume per stem of the three practices simulated, whereas NT had the greatest mean volume per hectare. The thinning reduced the number of trees resulting in an immediate reduction in the mean tree volume for the plot area. Therefore, NT had a greater mean volume per area. For the same reason, NT produced the greatest amount of biomass among the thinning practices. This was consistent with Simon and Ameztegui (2023), who reported increasing biomass extraction through harvesting reduced carbon storage in forests, leading to increased nitrogen and carbon leaching. Similarly, intensifying thinning and shortening the rotation period decreased the carbon stored in trees; while this might increase wood availability for products, it may not fully compensate for the overall carbon loss within the forest ecosystem (Zanchi *et al*., 2014).

NT had the highest summary index, indicating greater biodiversity. Conversely, TA showed a notable trend of a decrease in the summary index, signifying intensified artificial management. The impacts of TB and TA on the mean diameter, mean height, and mean volume per stem, contributed to consecutive increases in tree growth over time. However, the mean volume per hectare and the biomass decreased if either of the two thinning practices were applied (Zhao *et al*., 2022).

Table 1 shows that there were no significant differences ($p > 0.05$) in diameter, height, and volume per stem between the thinning practices, while there were significant differences ($p < 0.05$) in mean volume per ha, biomass, and biodiversity. Thinning practices influenced the overall structure, density, and composition of the forest stand, leading to notable changes in these variables. These findings underscored the importance of considering the broader ecological impacts of thinning practices on forest ecosystems. For example, the highest mushroom production resulted when from the simulated heaviest thinning intensity, with a strong interaction with thinning frequency; if frequent and heavy thinning operations were carried out, the basal area would drop below the optimal, resulting in a decline in mushroom production (Simon and Ameztegui, 2023).

Table 1 Significance differences in relationships between thinning practices

Variable	NT–TA	NT–TB	TA–TB
Mean diameter	0.288	0.251	0.929
Mean height	0.978	0.894	0.916
Mean volume per stem	0.501	0.429	0.903
Mean volume per hectare	0.001	0.001	0.960
Biomass	0.000	0.000	0.959
Biodiversity	0.005	0.001	0.589

The simulation program did not allow full access to features for external users; consequently, only a limited variety of tree species were available and it was not possible accurately specify topographical and climatic conditions for use in Thailand. Therefore, full access to allow specific Thai conditions (species, topography and climate) would facilitate simulating the growth of trees in natural forests and in plantations for broader use by organizations in the future.

CONCLUSION

Based on the statistical analysis, there were no significant ($p > 0.05$) differences between TA and TB for the growth parameters modeled (mean diameter, mean height, and mean volume per stem), indicating that both practices could increase productivity yields. However, the mean volume per hectare, biomass, and biodiversity for TA and TB were all significantly ($p<0.05$) lower than for NT. The removal of some trees in either TA or TB resulted in reductions in productivity, while NT resulted in continuous growth in productivity, leading to a proportional increase in biomass values corresponding to tree sizes. Additionally, both mean volume per hectare and biodiversity increased in tandem with tree growth.

In conclusion, both TB and TA can be used as thinning practices in *Carpinus viminea* (Himalayan Hornbeam) to increase productivity yields and the growth response of the trees. Nevertheless, considering other productivity factors, such as volume per hectare, biomass, and biodiversity, NT may be the more suitable alternative.

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