THE EFFECT OF ECOLOGICAL FACTORS ON GROWTH OF *Sterculia foetida* L. IN BUON DON AND EA SUP DISTRICTS, DAK LAK PROVINCE

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Abstract

Accurate and reliable assessment of site suitability for the growth of selected plant species is critical for afforestation projects and programs to improve rural livelihoods. This research examines the relationship between growth of Sterculia foetida L. and six ecological factors in Buon Don and Ea Sup districts, Dak Lak Province. The purpose of the research is to predict the growth in average height and trunk diameter of the trees using ecological factors that are easy to measure and observe. These include topography (slope) and soil characteristics (clay ratio, depth of soil layer, surface and subsurface rock concentrations, and agglomeration ratio). The ecological factors were evaluated by multivariable regression analysis of growth data from 31 experimental plots, 16 in Buon Don district and 15 in Ea Sup district. The results show that four of the six factors affect average growth in tree height and that five factors affect average trunk diameter growth. The findings are of practical value for households and agricultural extension officers to consider before planting Sterculia foetida L. in the two areas.

Keywords: Ecological factors; Growth; Height; *Sterculia foetida* L.; Trunk diameter.

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1. INTRODUCTION

Currently, the Department of Agriculture and Rural Development of Dak Lak Province and local authorities are interested in selecting and setting up a forestry tree planting model for economic development in Buon Don and Ea Sup districts. Other plant species such as cashew, hybrid acacia, and rubber have not brought high economic efficiency in trials due to the lack of crucial ecological factors for their growth. Research on forest trees in this area has only been conducted on experimental planting of *Tectona grandis* in the enrichment model of dipterocarp forests at different sites (Bao et al., 2017). Therefore, accurate and reliable assessment of crop suitability and high economic efficiency plays an important role in the two border districts of Dak Lak Province.

Sterculia foetida L. is a plant species in the genus Sterculia. In the wild, *Sterculia foetida* L. commonly grows in the Central Highlands provinces of Kon Tum, Gia Lai, Dak Lak, and Lam Dong and in the Southern Central coastal provinces of Khanh Hoa, Ninh Thuan, and Binh Thuan (Nguyễn & Vũ, 2014). *Sterculia foetida* L. has many different applications. The seeds can be used for food, the leaves can be used as fodder, and flour from the seeds can be used to make cakes. The oil from the seeds can be used to treat fungal skin diseases or as fuel. Extracts from the leaves can be used as plant protection pesticides. Fiber can be obtained from the bark, and the wood can be used for furniture, packaging, pulp, particle board, fiberboard, and in industry (Aued-Pimentel et al., 2004; Nguyễn & Vũ, 2014; Prakash et al., 2012; Vipunngeun & Palanuvej, 2009; Vital et al., 2010). The *Sterculia foetida* L. product of greatest value is latex, an important material used in the beverage processing industry. Latex contributes to improving blood fat, increasing satiety, and regulating blood sugar in people who are overweight, obese, or diabetic. *Sterculia foetida* L. latex is now also used as a skin cream (Nguyễn et al., 2016; Prakash et al., 2012).

Sterculia foetida L. is a woody plant of arid regions, tolerant of hot climate, low rainfall, and poor soil nutrients (Nguyễn & Vũ, 2014). The border area of Dak Lak Province is a dry area characterized by a hot dry season and inundation in the rainy season. Therefore, only the dipterocarp forest ecosystem exists and develops in this harsh climate. In general, the hot dry climate in the border area has conditions similar to the dry coastal areas of Ninh Thuan and Binh Thuan. However, the severity of the site-specific conditions is different in each region. The aim of this study is to meet the needs of growers by measuring the growth of *Sterculia foetida* L. to assess the potential of the target area for *Sterculia foetida* L. cultivation. The study was carried out on agricultural land to examine the relationship between growth indicators and ecological factors in the two districts.

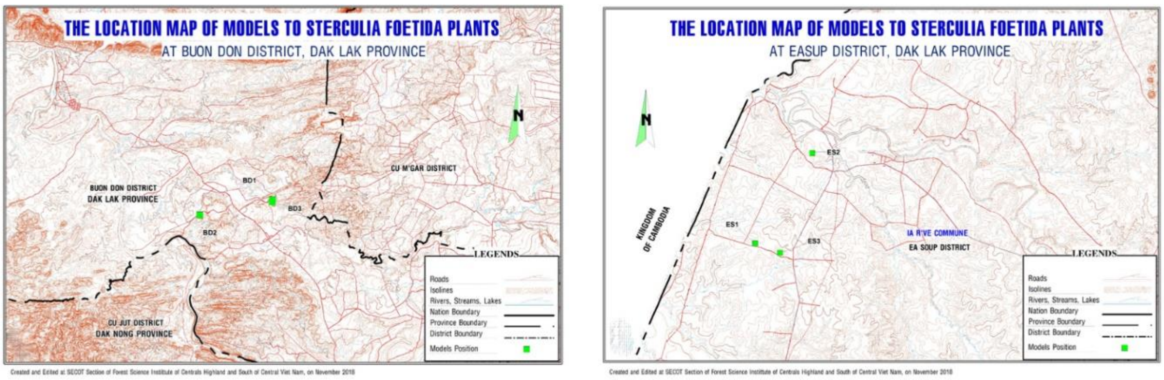
2. MATERIALS AND METHODS

2.1. Soil characteristics in the study areas

Much of the land in Buon Don and Ea Sup districts has a thin layer of poor soil and inert gravel that is poor in nutrients. The topsoil often hardens in the dry season. Some places are without the A layer (topsoil), in other places there is no B layer (subsoil), and the C layer (parent material) is gradually being exposed. The soil structure is broken and waterlogged in the rainy season due to the short distance (0.5-1.0 m) to the parent rock layer. In some places, the soil layer is 20-30 cm thick and unable to retain moisture. The soil has a high percentage of sand and with large size structure, making it less able to retain moisture so that water is easily lost in the dry season. In addition, humus and other nutrients are easily washed away in the rainy season (Phạm et al., 2018; Phung & Trinh, 2019).

2.2. Study areas

Sterculia foetida L. plants (29 and 41 months old) were planted in the Buon Don and Ea Sup districts of Dak Lak province in 2015 and 2016 (Figure 1). The study areas include 31 experimental plots, 16 plots in Buon Don district and 15 plots in Ea Sup district (Table 1). Each plot is 2,000 m^2.



(a) (b)

Figure 1. Study areas in Dak Lak Province

Notes: a) Buon Don district; b) Ea Sup district.

Table 1. *Sterculia foetida* L. study areas in Buon Don and Ea Sup districts

Symbol	Density (trees/ha)	The number of experimental plots	Growth Year
BD1	830	6	2015
BD2	830	5	2016
BD3	830	5	2016
ES1	830	5	2015
ES2	830	5	2016
ES3	830	5	2016

Notes: BD (Buon Don) and ES (Ea Sup).

2.3. Methods

2.3.1. Assessment and analysis of ecological factors in the experimental plots

The assessment and analysis methods are based on previous studies of *Sterculia foetida* L., site characteristics in the study areas, and the research method of Bao et al. (2017) on the assessment of suitable sites for teak trees. Six hypothetical factors were selected to evaluate the average growth rate of *Sterculia foetida* L.: clay ratio, soil layer depth, slope, surface rock concentration, subsurface rock concentration, and agglomeration ratio.

In each experimental plot of 2,000 m^2 (50 × 40 m), subplots of size 10 × 10 m were established to collect data on the six ecological factors (Table 2).

Table 2. Ecological factor variables and collection methods

Factor	Assessment method	Value
Ratio of clay	Using soil drilling tools, drill on two levels at three locations on the diagonal of the 10 × 10 m plots, mix together, collect 0.5 kg of soil sample, and bring it back for laboratory analysis to determine the ratio of clay.	(1) < 20% (2) 20-30% (3) > 30%
Soil depth	Use a soil drill to determine soil depth at three locations on the diagonal of the 10 × 10 m plots, calculate the average, and rank the result.	(1) > 60 cm (2) 30-60 cm (3) < 30 cm
Slope	Measure with an inclinometer at three locations on the diagonal of the 10 × 10 m plots, calculate the average, and rank the result.	(1) < 3° (2) 3-15° (3) ≥ 15°
Surface rock concentration	Measure the total length of the surface rocks on two diagonals of the 10 × 10 m plots, divide by the total length of the two diagonals, and rank the result.	(1) < 10% (2) 10-30% (3) > 30%
Subsurface rock concentration	Dig and collect soil samples at three locations on the diagonal of the 10 × 10 m plots at two levels, determine rock content by volume.	(1) < 10% (2) 10-30% (3) > 30%
Ratio of agglomeration	Measure the total length of the agglomeration on two diagonals of the 10 × 10 m plots, divide by the total length of the two diagonals, and rank the result.	(1) < 10% (2) 10-30% (3) > 30%

2.3.2. Evaluation of average growth of tree height and trunk diameter based on ecological factors

Data (29 or 41 months old) were collected from 31 primary plots, each 2000 m^2 in area. In each primary plot, five secondary 10 × 10 m plots were established with a plot in the center and each corner. Tree heights and trunk diameters of six representative trees were measured in each secondary plot. The total number of samples in each primary plot to monitor the average growth in height (△H) and trunk diameter (△Do) was 30 trees. Tree heights (H) were measured in meters with a height gauge and base diameters (Do) were measured in centimeters with a micrometer caliper.

Average growth in height/year: $\triangle H = H/A$

In which $\triangle H$: Average growth in height/year (m/year); H: Average height (m); A: Age (number of months/12).

Average growth of trunk diameter/year: $\triangle Do = Do/A$

In which $\triangle Do$: Average growth of trunk diameter/year (cm/year); Do: Average trunk diameter (cm); A: Age (number of months/12).

2.3.3. Model building and model selection criteria

The database includes y_i, the average growth values, $\triangle H$ and $\triangle Do$ of *Sterculia foetida* L., and x_i, the values of the ecological factors that affect its growth and were collected in the experimental plots.

On the basis of the data set in the experimental plots $y_i – x_i$, we conducted the analysis and set up the model in Statgraphics. We tested the standardization of the variables and selected the variables x_i that affect y with Statgraphics commands in the following order: Improve/ Regression Analysis/ Multiple Factors/ Multiple Variable Analysis. We built the model in the order: Improve/ Regression Analysis/ Multiple Factors/ Multiple Regression.

On that basis, we explored many different types of multivariable functions, including transformations of variables or combinations of variables, such as log (x), sqrt (x), 1/x, and exp(x). We selected the optimal multivariable model according to the following conditions.

The variables were tested for the existence of a relationship with the dependent variable by the Student-t standard with the error *p*-value < 0.05.

Testing the existence of the coefficient of determination R^2 shows that if the existence between y and the variable x_i equals the standard F-test with *p*-value < 0.05 and $R^2 > 50\%$, then the model is accepted.

The observed points and predicted values of the function follow the diagonal of the observed/predicted graph. The residual variability of the studentized residuals/predicted graph is in the range of ± 2.

The purpose of detecting factors that affect the growth of *Sterculia foetida* L. is to have appropriate technical data to improve the survival rate and growth of *Sterculia foetida* L. at different stages and to contribute to the selection of suitable sites.

Multivariable regression analysis model is used in the form: $y = f(x_i)$, where y is the average growth in tree height or trunk diameter in the 31 primary plots, and the x_i consist of the values of the ecological factors: soil depth, clay ratio, slope, surface rock concentration, subsurface rock concentration, and agglomeration ratio.

2.4. Statistical analysis

Collected data were processed with Excel and Statgraphics Centurion XV software.

3. RESULTS AND DISCUSSION

3.1. The analysis results of ecological factors

Table 3. The ecological factors of study areas

Study areas	Factors					
	TLS	DSTD	DD	DN	DL	TLKV
ES1	1	1	2	1	1	1
ES2	2	1	1	1	1	2
ES3	2	1	1	1	1	2
BD1	3	2	2	3	3	3
BD2	3	2	1	3	3	3
BD3	3	2	2	2	2	3

Notes: ES (Ea Sup), BD (Buon Don), TLS (Ratio of clay), DSTD (Soil depth), DD (Slope), DN (Surface rock concentration), DL (Subsurface rock concentration), and TLKV (Agglomeration ratio).

The results of coding ecological factors in the models (Table 3) show that soil characteristics in the study areas vary by a relatively large amount. Specifically, the clay ratio (factor TLS) is below 20% in 5 plots, between 20-30% in 10 plots, and above 30% in 16 plots (Table 4). Soil depths (DSTD factor) at two levels are relatively equal with depths > 60 cm in 15 plots and depths from 30-60 cm in 16 plots (Table 5). Similar to soil depth, the slope (factor DD) is below 3 degrees in 15 plots and ranges from 3-8 degrees in 16 plots. Rock concentrations (factors DN and DL) are above 30% in 11 plots. The agglomeration ratio (TLKV) is above 30% in 16 plots.

3.2. Evaluation of average growth in height and trunk diameter of *Sterculia foetida* L. by individual factors

The evaluation of tree growth at the time of data collection includes six factors: soil depth, clay ratio, slope, surface rock concentration, subsurface rock concentration, and agglomeration. The soil depth factor has two levels (> 60 cm and 30-60 cm), and the slope factor has two levels (below 3 degrees and 3-15 degrees). These two factors have one less level than the others due to the decrease in the number of experimental plots for many reasons, including poor growth and households changing the purpose of crops.

3.2.1. Clay ratio

Soil texture has an impact on plant growth. However, for different plants, growth requirements depend on different proportions of nutrients, sand, and clay. The average growth in height and trunk diameter of *Sterculia foetida* L. was influenced by the clay ratio (*p*-value below 0.05), as shown in Table 4. The average height and trunk diameter growth rates were highest at 1.05 m/year and 2.43 cm/year, respectively, at a clay ratio of 20-30%. At clay ratios below 20% and over 30%, there was no difference in the average growth rate in height, but there was a difference in the average trunk diameter growth rate (2.05 cm/year compared to 1.41 cm/year).

Table 4. Average growth in height and trunk diameter of *Sterculia foetida* L. by clay ratio factor

No	Criterion	*p*-value	Growth rates for different clay ratios		
			< 20%	20-30%	> 30%
1	Plots (plot)	/	5	10	16
2	△H (m/year)	< 0.05	0.48 ± 0.05	1.05 ± 0.04	0.42 ± 0.03
3	△Do (cm/year)	< 0.05	2.05 ± 0.12	2.43 ± 0.09	1.41 ± 0.07

3.2.2. Soil depth

Table 5. Average growth in height and trunk diameter of *Sterculia foetida* L. by soil depth factor

No	Criterion	*p*-value	Growth rates for different soil depths		
			> 60 cm	30-60 cm	< 30 cm
1	Plots (plot)	/	15	16	/
2	△H (m/year)	<0.05	0.86 ± 0.06	0.42 ± 0.06	/
3	△Do (cm/year)	<0.05	2.31 ± 0.08	1.41 ± 0.07	/

The analysis results show that there is a statistically significant difference at the 95% confidence level between the two levels of soil depth in the average growth criteria of height and trunk diameter at 29 and 41 months of age (Table 5). For experimental plots with a soil depth over 60 cm, the average growth in height and trunk diameter were superior to those of the experimental plots with a soil depth of 30-60 cm. The height growth rate is 0.86 m/year for the larger soil depths compared to 0.42 m/year for the smaller soil depths. The trunk diameter growth rate is 2.31 cm/year for the larger soil depths compared to 1.41 cm/year for the smaller soil depths.

3.2.3. Slope

Table 6. Average growth in height and trunk diameter of *Sterculia foetida* L. by slope factor

No	Criterion	*p*-value	Growth rates for different soil slopes		
			< 3 degrees	3-15 degrees	> 15 degrees
1	Plots (plot)	/	15	16	/
2	△H (m/year)	> 0.05	0.79 ± 0.07	0.49 ± 0.07	/
3	△Do (cm/year)	< 0.05	2.06 ± 0.13	1.64 ± 0.13	/

There is no significant difference in the average growth rate in tree height due to the slope factor, as shown by the *p*-value in Table 6. However, the average trunk diameter growth rate differs between the two slope levels (*p*-value below 0.05) and is more than 0.4 cm/year greater for slopes below 3 degrees (△Do = 2.06 cm/year) compared to slopes over 15 degrees (△Do = 1.64 cm/year).

3.2.4. Surface rock/subsurface rock concentration

The results show that the surface rock and subsurface rock concentration factors have the same number of corresponding plots. The analysis results of average growth in height and trunk diameter showed that the surface/subsurface rock concentration factor had a clear influence. The *p*-value at three levels of surface/subsurface rock concentration and two small growth parameters is less than 0.05. A low percentage of surface rocks (below 10%) gave better growth of *Sterculia foetida* L. (with △H = 0.86 m/year and △Do = 2.31 cm/year), while the differences in average growth of height and trunk diameter in the remaining two levels are not large (Table 7).

Table 7. Average growth in height and trunk diameter of *Sterculia foetida* L. by surface rock/ subsurface rock concentration

No	Criterion	*p*-value	Growth rates for different surface rock/subsurface rock concentrations		
			< 10%	10-30%	> 30%
1	Number of plots	/	15	5	11
2	△H (m/year)	< 0.05	0.86 ± 0.06	0.50 ± 0.10	0.38 ± 0.07
3	△Do (cm/year)	< 0.05	2.31 ± 0.07	1.61 ± 0.13	1.32 ± 0.09

3.2.5. Agglomeration ratio

The average growth in height and trunk diameter was different at all levels of the agglomeration ratio (*p*-value below 0.05). The agglomeration ratio at 10-30% gave the best result, with average height and trunk diameter growing at 1.05 m/year and 2.43 cm/year, respectively (Table 8). In the other two levels, there is no significant difference in the average growth in height, but there is a significant difference in the average growth in trunk diameter.

Table 8. Average growth in height and trunk diameter of *Sterculia foetida* L. by agglomeration ratio

No	Criterion	*p*-value	Growth rates for different agglomeration ratios		
			< 10%	10-30%	> 30%
1	Number of plots	/	5	10	16
2	△H (m/year)	< 0.05	0.48 ± 0.05	1.05 ± 0.04	0.42 ± 0.03
3	△Do (cm/year)	< 0.05	2.05 ± 0.12	2.43 ± 0.09	1.41 ± 0.07

3.3. Multivariable regression equations

The results of changing variables, combinations of variables, and types of variables have identified two models of ecological factors that affect the growth of *Sterculia foetida* L..

3.3.1. Model of height growth according to factors

$$\triangle H = 1.8828 + 0.2356*DD - 2.1373*DSTD + 0.2680*TLKV*TLS \quad (1)$$

N = 31; R^2 adjusted = 94.08%; p-value < 0.05.

In Equation (1), four factors were determined to affect average height growth, namely slope (DD), depth of soil layer (DSTD), agglomeration ratio (TLKV), and clay ratio (TLS). The 31 experimental plots have a p-value below 0.05 and an adjusted R^2 = 94.08%. The two factors excluded from the model are the surface and subsurface rock concentration factors.

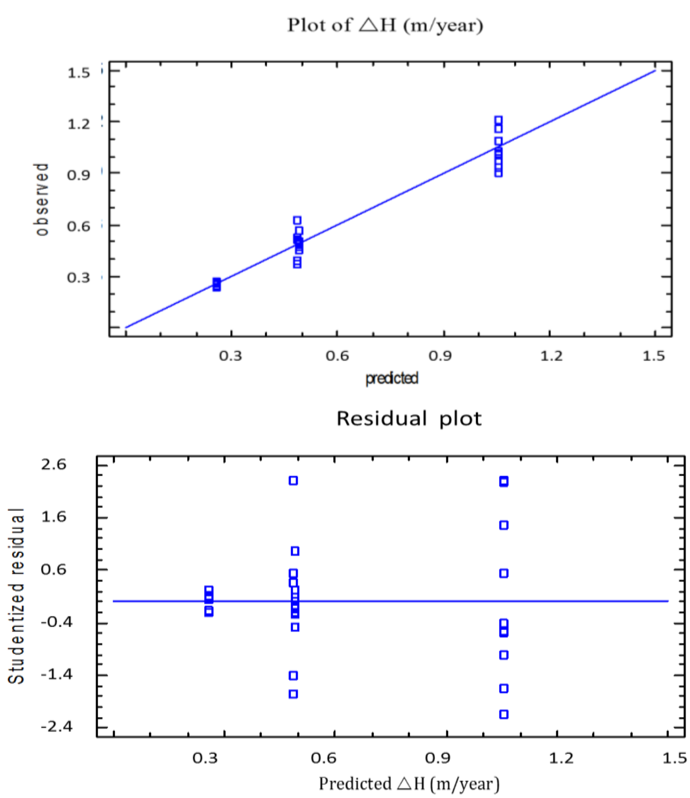


Figure 2. Model of tree height growth (△H) according to ecological factors

3.3.2. Model of trunk diameter growth according to ecological factors

$$\triangle Do = 3.2711 - 1.2930*DSTD - 0.0588*DN*DL + 0.1288*TLKV*TLS \quad (2)$$

N = 31; R^2 adjusted = 77.74%; p-value < 0.05.

For Equation (2), five factors were determined to affect the average growth of trunk diameter, namely soil depth (DSTD), surface rock concentration (DN), subsurface rock concentration (DL), agglomeration ratio (TLKV), and clay ratio (TLS) with 31 experimental plots, *p*-value below 0.05, and adjusted R^2 = 77.74%. The factor removed from the model is the slope factor.

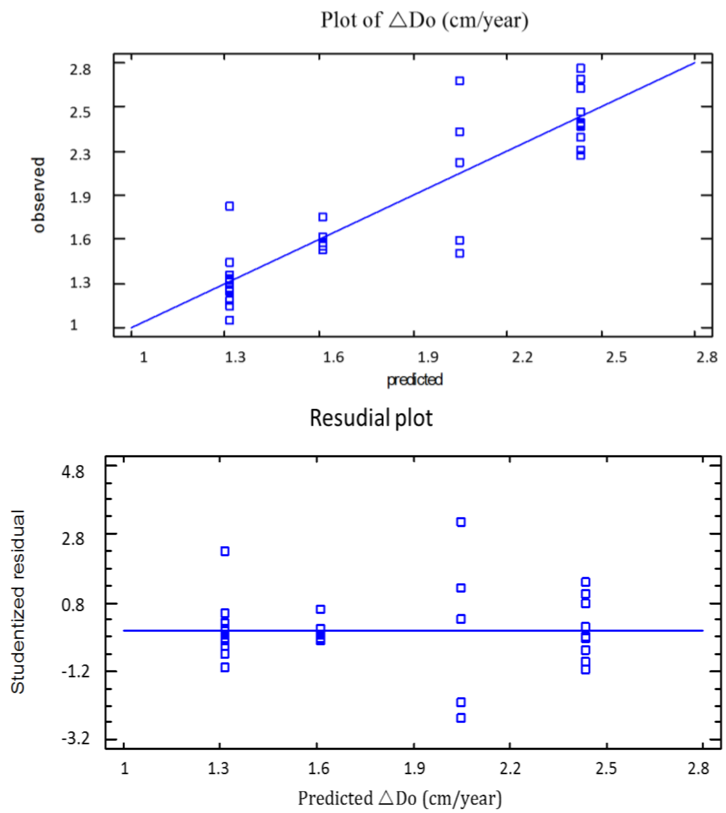


Figure 3. Model of trunk diameter growth (△Do) according to ecological factors

As a result, a model for predicting height growth (1) and trunk diameter growth (2) was created from the observed values and the residual was shown in Figure 2 and Figure 3.

Figure 4. A 29-month-old *Sterculia foetida* L. tree in Ea Sup district

Figure 5. A 29-month-old *Sterculia foetida* L. tree in Buon Don district

Both model (1) and model (2) show that ecological factors affect the growth of *Sterculia foetida* L.. Tree growth was a response to ecological factors in the study sites (Figure 4, Figure 5).

4. CONCLUSION

From the multivariable regression model, it has been determined that four of the six survey factors affect the average tree height growth rate: soil depth, clay ratio, slope, and agglomeration ratio. Likewise, five of the six factors affect the average growth rate in trunk diameter: soil depth, clay ratio, surface rock concentration, subsurface rock concentration, and agglomeration ratio. The single-factor analysis of variance only shows the influence of each individual factor on the growth of *Sterculia foetida* L.. This analytical result is only completely true when the other ecological factors are the same. However, in reality, these ecological factors affect the overall growth of *Sterculia foetida* L. in the experimental plots, so it is necessary to use a multivariable approach to detect the combined influence of ecological factors on the growth of *Sterculia foetida* L.. The ability of the soil to absorb and hold moisture in such dry areas is to be examined in further studies.

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