Quantification of Growth and Economically Important Yield Components of Rubber Plantations in Wet and Intermediate Zones of Sri Lanka

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Abstract

Although rubber is traditionally grown in the wet zone of Sri Lanka, its cultivation now has been expanded to the intermediate zone of the country. Further, demand for rubber has been extended beyond the latex with new emerging market for rubber timber and carbon. In order to discover these prospects under different growth conditions, quantification of growth and important yield components such as latex yield, timber and carbon is quite important under commercial conditions. Therefore, this study was aimed to quantify those using the commercially grown rubber plantations in both wet and intermediate zones of the country. Data required for the study were collected through the destructive and nondestructive assessments in existing rubber plantations and from the records of previous experiments. Empirical growth models were developed for both wet and intermediate zones and based on the growth parameters several other models were developed to predict yield components. Growth and yield differences under the two climatic regimes are discussed.

Key words: *rubber, climatic conditions, growth, yield, models*

Introduction

Rubber constitutes ca. 8% of agricultural land use in Sri Lanka and is grown on 118,000 hectares of land (Anon, 2007), covering 15 administrative districts representing two major agroclimatic zones, *viz*. Low country Wet Zone (WZ) and Intermediate Zone (IZ). Though the agroclimatic conditions of the Wet Zone is more favorable for rubber cultivation, having high land per capita, the IZ has now been targeted for the expansion of rubber cultivation in the country.

Rubber is mainly cultivated for latex production though other benefits such as timber and amount of carbon stored in the biomass are also of economic importance (Rodrigo *et al.*, 2005). With the economic lifespan of 30 years, rubber in the country has the potential of supplying ca. 4300 hectares annually for timber. National production of dry rubber is ca. 109.2 Mn kg, with the productivity level of 1150 kg per hectare (Anon, 2007). Within the country, over 90% of natural rubber production is converted to value added products (Anon, 2007) and those industries are further expanding. Also, the local demand for rubber wood is likely to increase further with newly set up factories for medium density fibre (MDF) and plywood boards. All this emphasize the need for expansion of the rubber cultivation in the country. New cultivations of rubber would be qualified for carbon trading as it is directly involved in mitigating the greenhouse effect with sequestering atmospheric CO_2.

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In order to explore the prospects of rubber cultivation, it is required to predict the growth and its benefits under different environmental conditions. However, such details are lacking and where available, those have been confined only to growth and based on on-station experiments (Rodrigo *et al.,* 2005, Silva, 2007). In particular, no records on growth and yield are available on rubber cultivation in the drier areas of the country. Therefore, the objective of this study was to quantify the growth and other benefits such as latex, timber and carbon in commercially grown rubber plantations in two major climatic zones, i.e. wet and intermediate zones of the country.

METHODOLOGY

Quantification of growth of rubber

Being a perennial crop, data collection is impossible within a reasonable time frame by planting rubber in a traditional experimental design. Therefore, quantification of the growth of rubber in the wet and intermediate zones had to be confined to the existing rubber plantations of different growth stages. In the wet zone, eight commercial estates in Kalutara and Ratnapura districts were selected for this purpose. With the limited number of rubber fields in the intermediate zone, sites selected for the intermediate zone were from two commercial estates in Moneragala and Kurunegala districts and some smallholdings in Moneragala district. From each zone, sixty sites were selected from the most widely grown genotype, RRIC 100 and at different stages of growth i.e. 1-30 years after planting (YAP). Tree diameter was measured at 1.5m height of the trunk in 25 trees with a measuring tape and the total height with an altimeter (Hohenmesser BL6) in five trees in each site. However, the measurements on total height had to be limited to 50 sites in the wet zone and 40 sites in the intermediate zone due to unavailability of the altimeter for a short period. Data were plotted against the age of the rubber crop and logistic growth functions were fitted to both diameter and height development using statistical package (GenStat, Tenth Edition, UK).

Quantification of latex yield of rubber

Yield records of rubber in terms of kg per hectare per annum (YPH) were collected from 33 rubber fields of RRIC 100 in four commercial estates in the wet zone representing the full tapping cycle of rubber, i.e. 6 – 30 years. The function of Quadratic by Quadratic (Equation 1) was fitted to explain the average ontogenetic variation of the rubber yield.

$$\text{YPH (kg)} = \frac{395 + (-165.6+39.5*\text{YAP})}{(1-0.13*\text{YAP}+0.006*\text{YAP}*\text{YAP})} \quad (1)$$

where, YPH and YAP refer to yield per hectare per annum and years after planting, respectively.

It was not possible to collect yield records in the intermediate zone for the full lifespan of rubber. However, in a genotype x environment interaction experiment, yield records for both wet (Miriswatta estate, Kalutara) and dry (Bibile estate) were found for four years (Jayasekera *et al.,* 1983, 1984, 1985, 1987). It comprised of 10 clones with mean yield per tree per harvest. The mean yield for the four year period was calculated and the difference between the wet and intermediate zones was obtained (14% less in the intermediate zone). Thereafter, with the knowledge of number of tapping days per year in the intermediate zone and assuming that a similar stand per hectare as in the wet zone would exist in the intermediate zone, the equation 1 was modified to derive the YPH for the intermediate zone.

Quantification of timber yield of rubber

Direct *in situ* measurements on timber volume of the tree is rather difficult, hence a simple model was developed to estimate the log volume (unsawn timber volume) of the rubber tree.

Rubber trees in four sites comprising three genotypes, i.e. RRIC100 in two sites, RRIC121 and RRIM600, were selected from Kalutara and

Ratnapura districts of the wet zone of Sri Lanka. Sites of RRIC100 were in 28 and 30 years after planting (YAP) whilst the age of clones RRIC121 and RRIM600 was 11 and 30 years, respectively. Number of trees sampled for the detailed assessment on timber volumes in each site was 21 and 13 in RRIC100, 19 in RRIC121 and 11 in RRIM600 making a total of 64 trees. Tree diameter at the height of 1.5 m was measured. The main trunk of the tree and branches up to the girth of 20cm of uprooted trees were separated into sections and timber volume was measured using Smalian's formula (Equation 2) with the information on length and diameter of logs (Philip, 1994).

$$\text{Volume } (m^3) = \frac{\pi\,(d1^2 + d2^2)}{80000 * H} \quad \text{(Smalian's formula)} \quad (2)$$

where, d1 and d2 were the diameters at two ends of the log in centimeters whilst H was the length in meters.

Since the timber volume is a function of the diameter and length, simple linear regression analysis was performed to build up a model to estimate the total log (unsawn timber) volume of a rubber tree as a function of the square diameter at 1.5m height and the total height of the tree (Equation 3). Then, in combination with the logistic functions developed to explain the ontogenetic changes in tree diameter and total height, the equation 2 was used to estimate the timber log volume at different age categories in both wet and intermediate zones.

$$\text{Total timber log volume } (m^3) = -0.02 + 0.39 * D^2 * H \quad (3)$$

where, D and H refer to tree diameter at 1.5m height and the total height of the tree in meters, respectively.

Quantification of carbon yield of rubber

In trees used for the analyses of timber log volume, the dry weights of different tree components were measured to assess the total biomass of the trees. Also, sub samples of those tree components were taken for organic carbon analyses. As per the model developed to assess the timber log volume, another model (Equation 4) was developed to estimate the total carbon content in the rubber tree using the square diameter at 1.5m height and the total height of the tree. Then, in combination with the logistic functions developed to explain the ontogenetic changes in tree diameter and total height, the equation 4 was used to estimate the carbon content in the rubber tree at different age categories in both wet and intermediate zones.

$$\text{Total organic carbon (kg)} = -5.1 + 144.9 * D^2 * H \quad (4)$$

where, D and H refer to tree diameter at 1.5m height and the total height of the tree in meters, respectively.

RESULTS

Logistic functions fitted to the values of tree diameter and total height have been able to explain the ontogenetic variations. Models were statistically significant ($p < 0.001$) and explained ca. 90% of the variation as shown by the r^2 values (Table 1).

Table 1: *Estimated parameters of statistical analysis of the logistic growth curves fitted to explain the ontogenetic variation of tree diameter at 1.5m height and total height of the rubber tree. The equation of the logistic functions was Diameter (cm) /Total height (m) = a + c / (1+ exp (-b (YAP – m), where a, b, c and m are constants while YAP refers to years after planting.*

	Diameter		Total height	
Age	WZ	IZ	WZ	IZ
a	-463.6	-442.5	-15.13	-342.9
b	0.07	0.09	0.13	0.24
c	495.5	472.6	40.28	363.7
m	39.74	29.82	1.03	9.87
r^2	0.91	0.93	0.89	0.86
S.E.	1.48	1.62	1.41	1.32

Tree trunk expansion of the rubber tree in terms of diameter at 1.5m height was more or less same in both wet and intermediate zone (Fig. 1). Nevertheless, as shown by the parameter 'm' the fitted logistic functions, the maximum growth rate was achieved quicker in the intermediate zone (Table 1). Also, the highest diameter achieved (as given by upper asymptote, parameter 'c') was slightly higher in the wet zone.

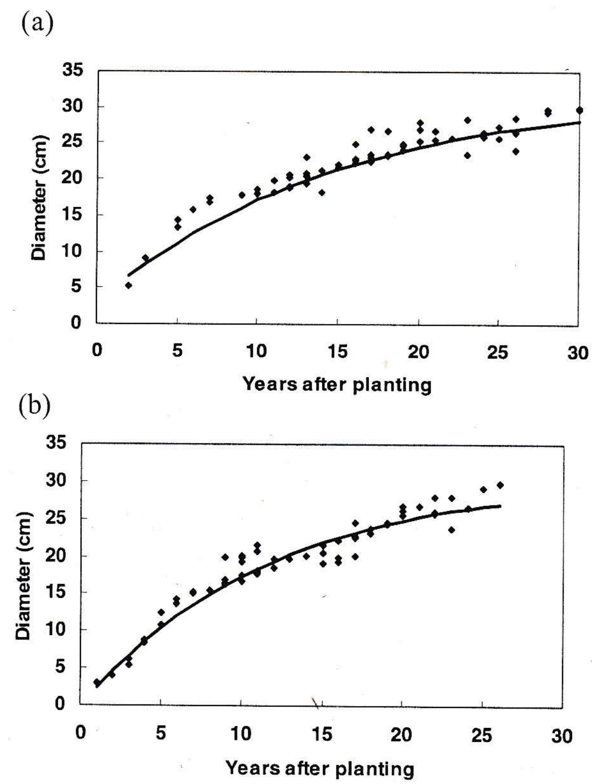

Fig. 1. *Diameter development of rubber tree in the wet (a) and intermediate (b) zones of Sri Lanka (genotype RRIC 100). The best fitted line was obtained using the logistic function; Diameter (cm) = a + c / (1+ exp (-b (YAP – m) where a, b, c and m are constants (values are given in Table 1) while YAP refers to years after planting.*

Ultimate height of the tree was greater in the wet zone than that of the intermediate zone and was indicated by the parameters 'a' and 'c' which represent upper asymptote of the logistic curves. However, the diameter expansion was more rapid in the intermediate zone where it achieved the highest diameter, quicker than that of the wet zone (Table 1, Figure 2). Assuming that growth is linear during the first 10 years, total height in the intermediate zone, increased at a rate of 1.6 m per year whilst that of the wet zone was 1 m.

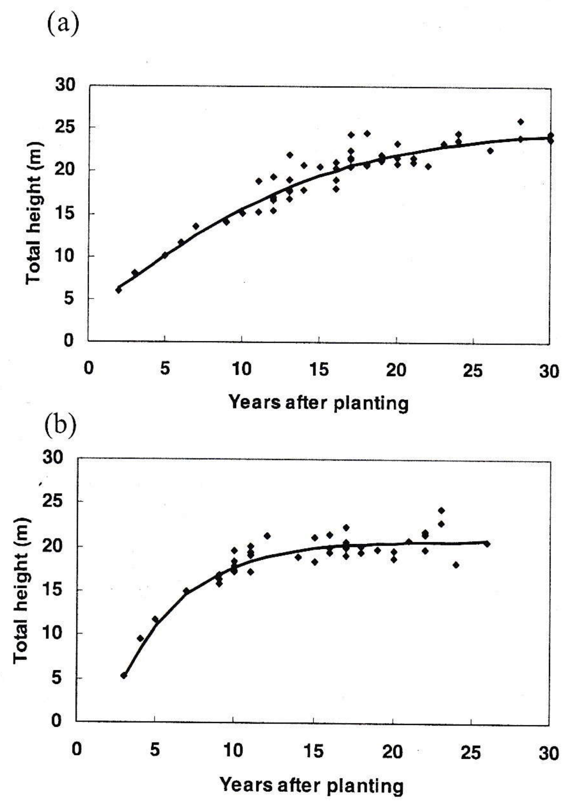

Fig. 2. *Total height development of rubber tree in the wet (a) and intermediate (b) zones of Sri Lanka (genotype RRIC 100). The best fitted line was obtained using the logistic function; Total height (m) = a + c / (1+ exp (-b (YAP – m) where a, b, c and m are constants (values are given in Table 1) whilst YAP refers to years after planting.*

Yield in terms of kg per hectare per annum (YPH) in the wet zone increased with the age and reached the maximum level of 1325 kg at 13 years after planting, i.e. seven years after the commencement of tapping. Then the latex production tended to decrease and reached to a plateau of 800 kg towards the end of the lifecycle. With a 6% yield reduction, the highest YPH expected from the intermediate zone was 1245 kg (Fig. 3).

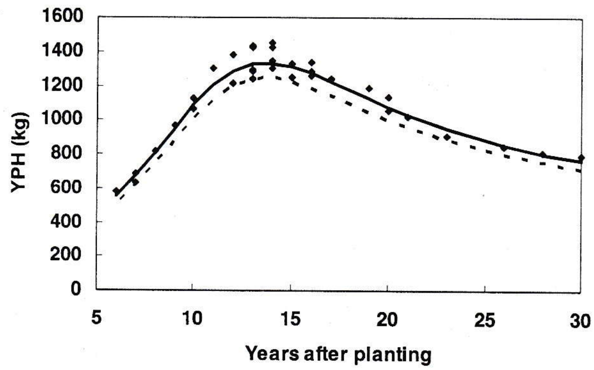

Fig. 3. *Yield profile of rubber tree in wet zone of Sri Lanka (genotype RRIC 100). The fitted solid line represents equation 1 as;*
*YPH (kg) = 395 + (-165.6+39.5*YAP) / (1-0.13*YAP+0.006*YAP*YAP)*
where YPH and YAP refer to yield per hectare per annum and years after planting, respectively. The expected variation of the function for the intermediate zone is shown with the dotted line.

Timber log volume and total carbon content in the tree could be estimated with simple linear functions using the parameters of tree diameter and the total height. Direct use of tree diameter and the total height was not successful to build up linear relationships and those had to be established with the combination of diameter squared and total height (Fig. 4 & 5). As per the functions fitted, the rate of timber log volume and carbon content increase per increase in 1cm tree diameter was in the range of 0.02-0.09 m^3 and 7-33 kg, respectively. Similarly, the sensitivity for unit change in total height (m) was in the range of 0.01-0.09 m^3 and 4-33 kg for timber log volume and carbon content, respectively.

Ultimate timber volume per tree at the end of 30 year lifespan of the rubber tree was 0.73 m^3 in the wet zone and there was ca. 16 % reduction of it in the intermediate zone. Similarly, carbon content in a 30 year old tree was 274 kg in the wet zone and 230 kg in the intermediate zone. Timber volume per hectare of rubber was 208 m^3 in the wet zone and 175 m^3 in the intermediate zone at 30 years, assuming similar stands for both climatic zones. Also, the carbon content in the above was 78 and 66 kg for the wet and intermediate zones, respectively (Table 2). Assuming a linear rate of development over the period of 30 year lifespan, rubber tree is capable of fixing ca. 10 kg carbon per year.

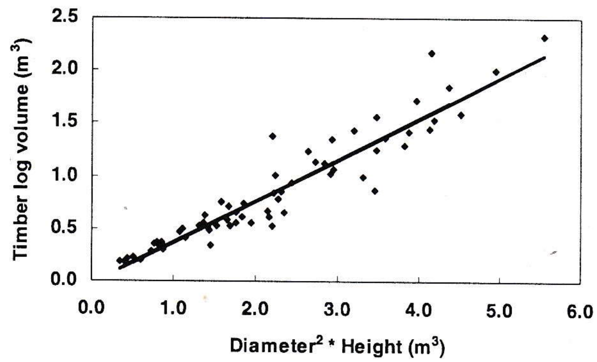

Fig. 4. *Relationship of timber log volume (per tree) with the tree diameter (at 1.5 m height) and total height. The fitted line represents equation 3 as;*
*Total timber log volume (m^3) = -0.02 + 0.39 * Diameter^2 * Height (m^3)*

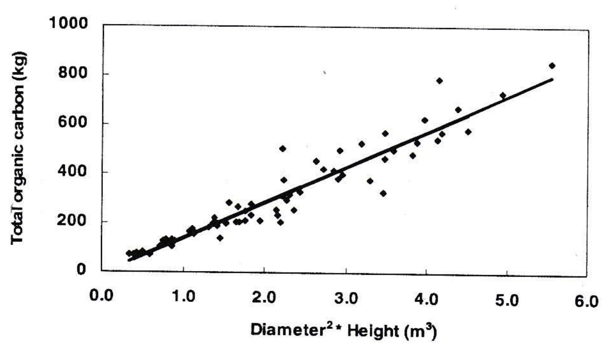

Fig. 5. *Relationship of total organic carbon content (per tree) with the tree diameter (at 1.5 m height) and total height. The fitted line represents equation 4 as;*
*Total organic carbon (kg) = -5.1+ 144.9 * Diameter^2 * Height (m^3)*

Table 2: *Estimated values of timber log volume and total carbon content in the rubber crop for the wet and intermediate zones; (a) on tree basis and (b) on hectare basis. (WZ-wet zone; IZ-intermediate zone)*

(a)

	Timber log volume(m^3/tree)		Total carbon (kg/tree)	
Age	WZ	IZ	WZ	IZ
5	0.029	0.026	13.19	11.90
10	0.158	0.188	61.05	72.19
15	0.328	0.351	124.28	132.76
20	0.493	0.473	185.40	178.14
25	0.628	0.557	235.67	209.25
30	0.730	0.613	273.63	229.90

(b)

	Timber log volume(m^3/ha)		Total carbon (MT/ha)	
Age	WZ	IZ	WZ	IZ
5	12.07	10.64	5.45	4.92
10	56.58	67.32	21.86	25.84
15	107.33	114.80	40.64	43.41
20	151.76	145.74	57.10	54.87
25	185.27	164.29	69.52	61.73
30	208.11	174.57	77.98	65.52

DISCUSSION

Quantification of growth and important yield components such as latex yield, timber and carbon under commercial conditions is quite important to explore the benefits of rubber cultivation and for financial planning under different growth conditions. The study was able to quantify those components and further develop empirical models. This makes the task easier for policy makers to plan and assess the prospects on rubber cultivations. With the models developed, the average growth and the yield of latex, timber and carbon can successfully be predicted for both wet and drier (i.e. intermediate zone) areas of the country. Experimental values reported by Seneviratne *et al.* (2006) for the growth and latex yields are quite higher than the values reported here due to the fact that plants in those sites are maintained with maximum care under optimum management conditions. Sites from which most of data were collected in the present study, were maintained extensively as per the case in most of rubber plantations in the country and so, there would be little or no room for over estimation. Therefore, any project can make successful use of the findings of this study, with respect to estimated yields, and in most cases, higher levels of yields could be obtained with proper management efforts.

Logistic functions are suitable and generally used to build up growth curves as it is capable of showing classic 'S' type of growth. In order to model the tree growth with respect to tree trunk expansion and height increase, logistic functions were used. Though it was fitted well, the classic 'S' type could not be observed due to the fact that growth values were collected from different sites which were managed for commercial exploitation. Further, rubber plantations are established with budgrafted plants and therefore, its growth pattern would be slightly different from that originated directly from seeds. Nevertheless, the logistic function fitted to the continuous data collection from a single site in a rubber/banana experiment showed the classic 'S' type curve (Rodrigo *et al.,* 2005) proving the suitability of this function to predict the growth of rubber.

Despite of similar growth patterns, tree diameter at a given time point in the wet zone was slightly higher than that of the intermediate zone. Therefore, the ultimate tree diameter was greater in the wet zone. This could be expected due to the suboptimal growth conditions with respect to rainfall and soil water prevailed in this zone. Nevertheless, as per the logistic function fitted, the maximum growth rate was achieved quicker in the intermediate zone. Although this was quite unexpected, Rodrigo *et al.* (2005) in a study on rubber based intercropping systems, have concluded that rubber plants grown with intercrops like banana achieve the highest growth rate earlier than the sole cropped rubber. Unlike in the wet zone, the rubber in the intermediate zone is grown by traditional farmers who always tend to grow some other crop with rubber. This is particularly important to protect the rubber plants from the additional solar radiation (Rodrigo *et al.,* 2008) and would have been the reason for reaching the highest growth rate quicker in the intermediate zone.

Rubber plants are expected to be at 16 cm diameter by the end of 6 years of growth and that is the standard girth for commencement of rubber tapping. As per the fitted line, plants in the wet zone could reach this level in seven years, i.e. one year before the plants in intermediate zone.

For a particular genotype, latex yield is determined by such factors as the growth stage of the tree, environmental conditions, and quality of tapping at present and past. In line with previous reports, the highest latex yield is given at ca. 7 years after the commencement of tapping. This is due to the increase in tree diameter resulting in more latex vessels being opened with continued tapping. However, the yield declined thereafter and came to a plateau towards the end of life cycle. Though this is quite unexpected, it could be attributed to two factors, 1) decline in tree stand and 2) poor quality tapping. Due to the natural deaths, actual tree density tends to decline with time and even in existing trees, some are not capable of providing latex due to the syndrome of Tapping Panel Dryness. This would mask any growth related yield increase in rubber trees. High rate of bark consumption in tapping and too deep tapping injuring cambium were also observed. High rate of bark consumption results in completing the tapping on original (virgin) bark quicker. Then, tapping should be done on the renewed bark which has not been properly grown due to deep tapping in the virgin bark and also had no sufficient time for bark renewal due to high rate of bark consumption in the virgin bark. Ultimate result is less yields even on tree basis despite of tree growth.

Yield difference in the intermediate zone could be attributed to two contrasting factors. Obviously, drier conditions diminish the water status in the tree lowering turgur pressure inside the latex vessels and then resulting in low yields. This is quite common even in the wet zone if tapping is delayed by a few hours, instead of early morning tapping (ca.25% yield drop). Tapping operation is also disturbed by the rains in the wet zone limiting the number of days tapped in a particular year. Although rainguards have been introduced by the RRISL to overcome this problem, it is yet to be popularized. Loss of tapping days due to rains is not a problem in the intermediate zone hence any yield decline at individual tapping is overcome by increase in tapping days. Therefore, ultimate yield difference was only 6% between the two climatic zones.

Timber log volume could successfully be estimated using the tree diameter and the total height. The function resembles simple mathematical equation used to estimate the volume of the cylinder hence this could rather be considered as a mechanistic than an empirical model. Therefore, the model developed here has an advantage of using over the range tested in the present study. The model estimate for the timber log volume at the end of the 30 year life cycle was 0.73 m^3 per tree and 208 m^3 per hectare for the wet zone. The values recorded for the intermediate zone was 16 % less than those for the wet zone reflecting the growth difference between the two climatic regimes. When compared with other timber species, rubber could produce timber more than that of teak but less than that of mahogany at the same age (Munasinghe and Rodrigo, 2006).

In the wet zone, the rubber tree is capable of sequestering 274 kg of carbon which is equal to 1000 kg of CO_2. The values given here is comparable with those reported by Sivakumaran *et al.* (2000). The amount for the intermediate zone was 16% less than that in the wet zone again reflecting the growth difference. With fewer clouds, one would expect to have high level of carbon sequestering in the intermediate zone; however soil moisture and the vapour pressure deficit seem to limit the photosynthetic rates. This has particularly been evident during the mid day time and in the afternoon (Rodrigo *et.al*, 2000).

On a hectare basis, the total amount of carbon sequestered in the wet and intermediate zones was 78 MT and 66 MT, respectively. These amounts are equal to 286 MT and 242 MT of CO_2 and a significant amount could be claimed, should carbon trading be undertaken. If rubber is grown in new areas, particularly in the intermediate zone, there is a potential to explore such carbon credits. No records to date are available on rubber cultivation projects with a view to carbon trading, although there are some forestry projects in the business. Therefore, it is worth exploring such avenues which will ultimately benefit the country and the people involved in rubber cultivation.

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