

Relationship Between Guayule Biomass Production, Rubber Synthesis, and Climatic Conditions

José Luis Angulo-Sánchez, Diana Jasso de Rodríguez, and Raúl Rodríguez-García

INTRODUCTION

A knowledge of the growing characteristics of guayule (*Parthenium argentatum* Gray, Asteraceae) shrubs, with details of rubber and coproducts production and response to management practices is important for the selection of high yielding plants (Macrae et al. 1986; Dierig et al. 1989a,b; Foster and Moore 1991; Foster et al. 1991; Nakayama 1991; Nakayama et al. 1991; Jasso de Rodríguez et al. 1996), as well as to define the best time for harvesting. This information would be useful to maximize commercial rubber and coproducts production. Several studies have been carried out looking for rubber content variation throughout the year and the possibility to increase rubber yield. There are reports suggesting a relationship between rubber synthesis and environmental factors or agronomic practices (Appleton and Van Staden 1989; Benedict 1991; Estilai 1991; Foster and Moore 1991; Nakayama 1991; Nakayama et al. 1991; Ray et al. 1992; Jasso-Cantú et al. 1997). However, these reports did not present explicit relationship among the variables.

Other authors have reported that rubber percentage in guayule decreases throughout the growth cycle (Hammond and Polhamus 1965; Downes and Tonnott 1985; Appleton and Van Staden 1989; Macrae et al. 1986; Nakayama 1991; Jasso-Cantú et al. 1997). There has been speculation about the causes promoting this reduction but no evidence has been presented. We proposed the existence of rubber synthesis periods (Jasso-Cantú et al. 1997) with a multimodal molecular weight distribution curve (Angulo-Sánchez et al. 1995), but there are no reports confirming the relationship between the growth and yield variables and rubber production cycles. This paper reports results from a three-year investigation relating rubber and resin content and biomass production to temperature and rainfall in two Mexican guayule accessions and one check cultivar developed at Universidad Autónoma Agraria Antonio Narro in Saltillo, Coahuila, México.

METHODOLOGY

Three high rubber yielding accessions were used for the study: BG1123 and BG1132 from the state of Durango and BG11605 with rubber contents of 11.07%, 10.97%, and 8.8% respectively (Lopez and Kuruvadi 1985; Kuruvadi 1988; Angulo-Sánchez et al. 1995).

Details on the experimental procedures for the seeding and cultivation for these accessions were reported by Jasso-Cantú et al. (1997). The three genotypes were seeded during May 1992 in a greenhouse, transplanted to an experimental field in October in a randomized block design with three replications (the plant density was 15,625 plants/ha) and grown under rainfed conditions, with no supplemental irrigation. Three different plants from each accession were sampled every month for dry weight, rubber, and resin content. Analyses for rubber and resin followed procedure described by Jasso de Rodríguez et al. (1993). Rainfall and temperature were recorded during the study period. The thermal units (TU) were calculated according to Jaafar et al. (1993). They were accumulated during the experiment period as cumulative TU (Σ TU).

The relationship among dry weight, rubber, and resin content as a function of time, were analyzed and their function defined according to the following equations.

$$\phi_{Dw} = (Dw / 10) / (Dw / 10 + Rb + Rs) \quad [1]$$

$$\phi_{Rb} = Rb / (Dw / 10 + Rb + Rs) \quad [2]$$

$$\phi_{Rs} = Rs / (Dw / 10 + Rb + Rs) \quad [3]$$

where:

ϕ_{Dw} = dry weight; ϕ_{Rb} = rubber content fraction; ϕ_{Rs} = resin content fraction. These fractions are defined to fulfill the condition

$$\phi_{Dw} + \phi_{Rb} + \phi_{Rs} = 1 \quad [4]$$

Dry weight was divided by a weight factor of 10 to handle quantities of similar magnitude. The fractions are presented in a plot to evaluate their relative dependence.

Cumulative thermal units (Σ TU), rainfall (Rf), and rubber yield (Rby) relative variables were defined to construct ternary diagrams allowing for relationship between the three monitored variables. Normalized variables and their fraction were calculated according to the following equations:

$$\phi_{\Sigma TU} = (\Sigma TU / 100) / (\Sigma TU / 100 + Rf / 10 + Rby) \quad [5]$$

$$\phi_{Rf} = (Rf / 10) / (\Sigma TU / 100 + Rf / 10 + Rby) \quad [6]$$

$$\phi_{Rby} = Rby / (\Sigma TU / 100 + Rf / 10 + Rby) \quad [7]$$

where

$$Rby = Dw * Rubber\ content\ (\%) \quad [8]$$

The fractions fulfill the condition stated in Eq. 4. In these equations Σ TU and Rf were divided by weight factors of 100 and 10, respectively, to obtain good point spacing.

Relationship among the measured variables were estimated using the equation proposed by Miller et al. (1958) with a statistics software MStat (MStat-C 1990). The T-test (Manly 1990) was used to determine differences among the variables mean values.

Accession BG1123 is used as an example to evaluate the relationship among rubber content and dry weight as a function of climatic conditions as well as for relative variables relationship versus time. The data for the three accessions was used to construct ternary diagrams, relating temperature, rainfall, and rubber content.

RESULTS AND DISCUSSION

Climatic Data

Temperatures recorded during the experiment period are presented in Fig. 1. Less variation occurred in the maximum temperature values compared with the mean and minimum values. The maximum temperature occurred in July and the minimum between December–February. The minimum temperatures were below 0°C for all three years.

Rainfall was plotted as a function of the experiment elapsed time (Fig. 2). During the first 13 months, rainfall was lower than 30 mm/month, which is common for this arid region. From months 14 (June) to 17 (September) the highest rainfall (405 mm) occurred. In the following months little rainfall occurred until month 23 (March 1994). From April to October 1994, rainfall was 268 mm. Finally, there was no precipita-

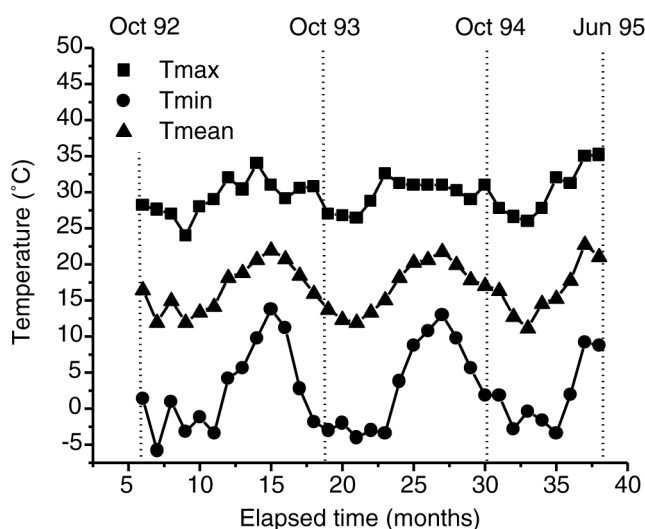


Fig. 1. Temperatures recorded during three years for the guayule study.

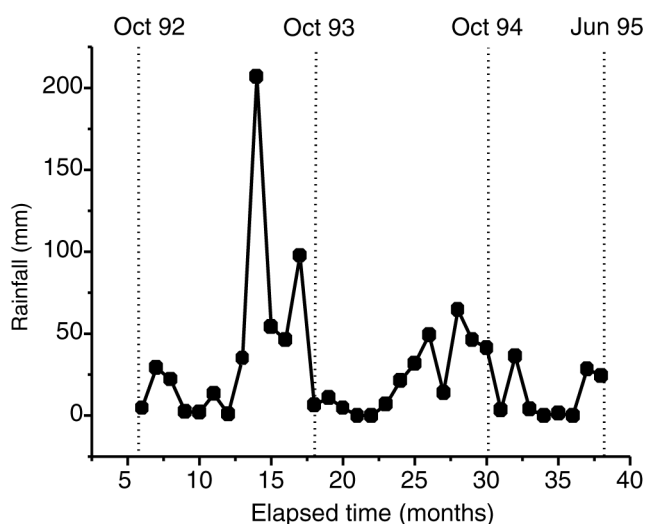


Fig. 2. Rainfall recorded during three years for the guayule study.

tion from November to April 1995, except for December when it was 36 mm. During May and June 1995, rainfall was 53 mm.

Relationship Between Dry Weight, Rubber Content, and Climatic Conditions. The dry weight, rubber and resin content for the accessions, as a function of age has been published by Jasso-Cantú et al. (1997). These results were analyzed further to determine whether a correlation existed among the three variables and climatic conditions.

The rubber content for accession BG1123 is plotted as a function of dry weight in Fig. 3. Dry weight increased (or at least remained constant) whereas the rubber percentage increased or decreased. These changes are season dependent. The correlation for these variables was positive and highly significant ($r = 0.687^{**}$). This correlation shows that rubber increases take place mainly during the autumn-winter periods (September 1993–March 1994, and October 1994–January 1995). This supports our earlier study (Jasso-Cantú et al. 1997) regarding the existence of rubber synthesis cycles depending on environmental conditions. The rubber contents were around 4% for the first 16 months, rising to 8% by the end of the study period. However, values up to 12% were found during January 1995.

The rubber content and dry weight as a function of cumulative rainfall are shown in Fig. 4 for accession BG1123. The other accessions showed similar behavior.

The October 1992 to September 1993 period showed a slight decrease in rubber content from 4.1% to 3.2%; the T-test reported a highly significant difference ($P < 0.01$) between these values. During this period the biomass increased from 4.5 to 45 g per plant. Accordingly, the biomass increased 10 times whereas the rubber content decreased by 22%. Based on Fig. 1 and 2, we can divide this growth period into two stages: one covering six months with minimum temperatures, near and below 0°C and rainfall accounting for 73.3 mm. During this stage the biomass and rubber remained constant. The second stage had minimum temperatures between 3°C to 12°C and cumulative precipitation of 440.7 mm; during this stage biomass increased and rubber decreased.

In the second stage, from September 1993 to March 1994, rubber content increased from 3.1% to 9.7% and biomass accumulation from 45.1 to 88.8 g/plant. Rubber increased 300% and biomass 196%. In this stage, the minimum temperature was between 2°C and 3°C in September and March, and consistently below 0°C in the remaining months, reaching -5°C in January. Rainfall was 97.7 mm during September and 28.8 mm for the rest of this stage. It should be noted that there was high rainfall previous to this stage, which promoted biomass accumulation. On the other hand, the low temperatures combined with the low rainfall promoted an active rubber biosynthesis raising the average value to almost 10% in March 1994. The importance of the low temperature and dry conditions for rubber synthesis (Benedict et al. 1947; Macrae et al. 1986; Appleton and Van Staden 1989) is evident when the plants were 22 months old.

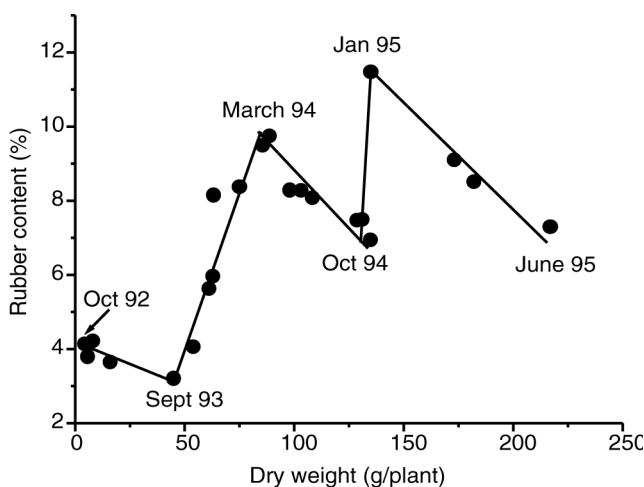


Fig. 3. Rubber content in guayule accession BG1123, as a function of dry weight during the three years study.

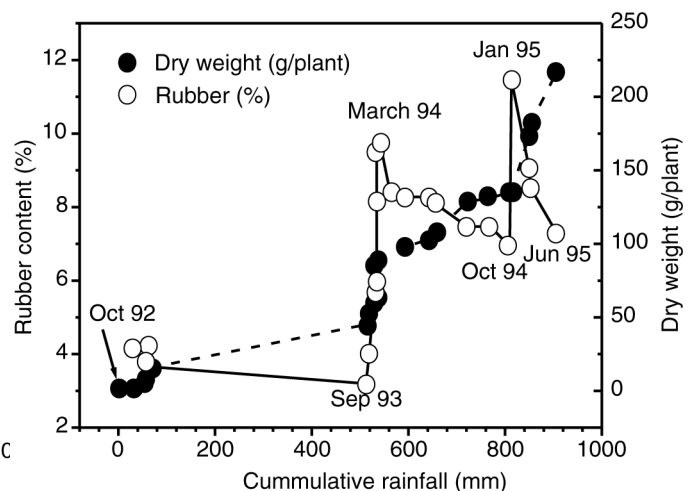


Fig. 4. Rubber content and dry weight in guayule accession BG 1123, as a function of cumulative rainfall during a three-year period study.

The third stage covered the March to October 1994 when rubber decreased (9.7% to 6.9%), and biomass increased (from 88.7 to 135 g). Rubber content reduction was 28.9% and the biomass increase was 152%. The minimum temperature rose from 3°C (March) to 10°C (June) and then decreased to 5°C in October; rainfall was 275.3 mm. The relatively high water supply and temperature favored biomass accumulation, but no rubber synthesis. Thus, the rubber content decreased. This behavior is similar to that of the first stage.

The fourth stage lasted four months (October 1994–January 1995) where the rubber increased from 6.9% to 11.5% (164% increment), but biomass remained constant. The minimum temperatures decreased from 2°C to –2°C. Rainfall was 43.3 mm during the stage. The low temperature and precipitation again promoted rubber synthesis, with no increase in biomass as discussed in the second stage.

The last stage covers January to June 1995, where biomass accumulation increased (135 to 220 g per plant) and rubber content diminished (11.5% to 7%) as in the first and third stages. Changes were 155% for biomass and 31% for rubber. The minimum temperatures were below or near 0°C for the first four months and rose to 8°C by the third stage. Rainfall was 58 mm.

Biomass increased mostly during spring–summer, whereas the rubber increased during autumn–winter season (Fig. 4). Correlations among cumulative rainfall with rubber content and with dry weight were positive and highly significant ($r = 0.698^{**}$ and $r = 0.928^{**}$ respectively). The results indicate that rubber percent reduction in the plant is not due to degradation of rubber or its consumption when water stress is severe. Rubber reduction was observed during plant growth (when temperature and rainfall are high).

Correlation Between Relative Variables

The relation of the fractions defined by Eqs. 1–3 with time, is presented in Fig. 5 for accession BG1123. The dry weight relative fraction (ϕ_{Dw}) always increased, due to the constant weight gain of the plant discussed in the previous section. As this variable increased its relative fraction the other two (rubber and resin) must decrease according to Eq. 4. The rubber fraction (ϕ_{Rb}) share does not present significant variations with time, suggesting that it may be a constant for each accession. This variable presents a negative and significant relationship with dry weight ($r = -0.478^*$), possibly due to the season changes shown in Fig. 4. The resin fraction ϕ_{Rs} always decreases. The relationship between resin with biomass is negative and highly significant ($r = -0.936^*$). In young plants, the resin fraction is greater than the rubber and dry weight fractions. As time elapses, the three fractions reach similar values at approximately 24 months. When the plants were 32 months old, the dry weight relative fraction dominated the other two. This indicates that biomass increase reflects increases in cortex tissue. These results help define the best time for harvesting, when looking for optimum quantities of the three products (biomass, rubber, and resin). In this case it was approximately two years. No defined relationship was found for rubber with resin relative fractions during the study ($r = 0.142$).

The data obtained with Eqs. 5–7 for the three accessions (BG1123, BG1132, and BG11605) were used to construct Fig. 6. Most of the points fall on one line. The areas around apex corresponded to different conditions of temperature and moisture. The area close to ϕ_{Rf} corresponded to cold/humid conditions, the area near ϕ_{Rby} represents cold/dry conditions and the area around $\phi_{\Sigma TU}$ to warm/dry. The area in the middle of the triangle base corresponded to warm/humid conditions. It is apparent that increasing the temperature (moving from the left side towards the $\phi_{\Sigma TU}$ apex) caused a reduction of rubber yield (shifts the points away from the ϕ_{Rby} apex). The combined effect of temperature and moisture is illustrated by dividing the diagram into two parts, one corresponding to $\phi_{\Sigma TU}$ from 0 to 0.5, where a displacement on the rainfall fraction (ϕ_{Rf}) axis from 0.5 to

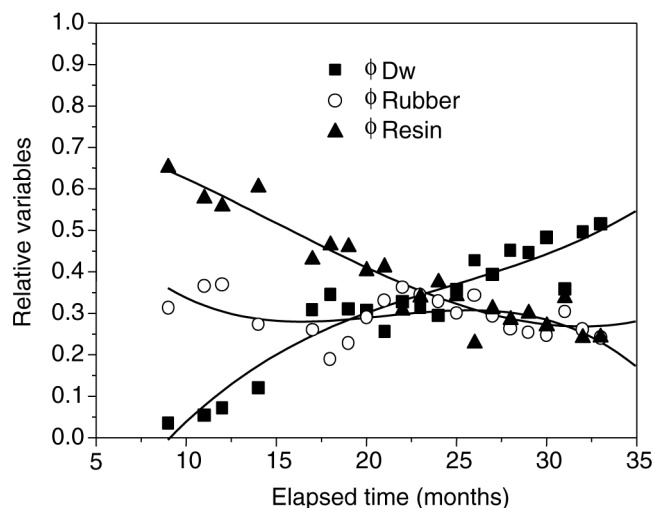


Fig. 5. Relative variables for dry weight, rubber and resin content as a function of elapsed time in guayule accession BG1123.

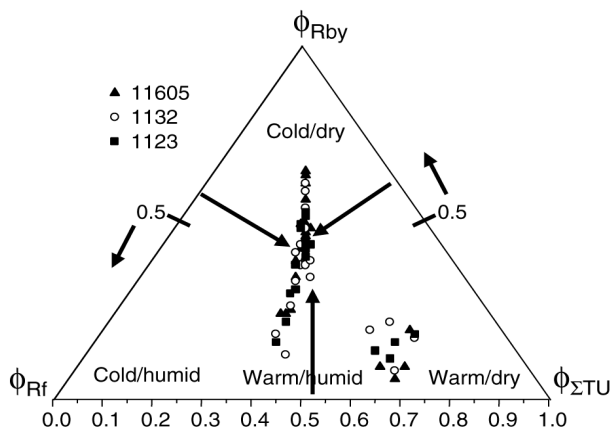


Fig. 6. Ternary diagram of relative fractions of rubber yielding, rainfall and cumulative thermal units for guayule accessions BG1123, BG1132 and BG11605 study.

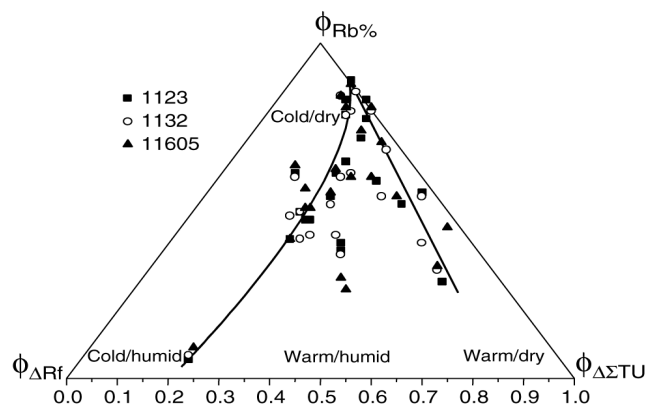


Fig. 7. Ternary diagram of relative fractions increments of rubber content, rainfall and cumulative thermal units for guayule accessions BG1123, BG1132 and BG11605 study.

0.1, leads to high rubber yield. The second part of the diagram corresponded to young plants (less than 14 months) with $\phi_{\Sigma TU}$ values between 0.5 to 1.0. In this section it is apparent that high values of thermal units show low rubber yielding values, although no clear trend is shown with rainfall. This is due to low rainfall during a prolonged period. Rubber yield is high only for cold/dry conditions, decreasing if temperature or rainfall increases (Fig. 6). This behavior was confirmed by negative correlations among rubber yield with the cumulative thermal units and with the cumulative rainfall for the accessions: BG1123, $r = -0.0601^{**}$ and $r = -0.945^{**}$ respectively; BG1132, $r = -0.455^{*}$ and $r = -0.954^{**}$; and BG11605, $r = -0.106$ and $r = -0.948^{**}$.

Rubber content, as a response to climatic conditions, is shown in Fig. 7. This diagram indicated that high rubber content is only found under cold/dry conditions. This is important because rubber yield production in guayule is based partly on the rubber content. Correlations among rubber content ($\phi_{Rb\%}$) with cumulative thermal units ($\phi_{\Delta \Sigma TU}$) have negative values: BG1123 $r = -0.533^{*}$; BG1132 $r = -0.0527^{*}$; and BG11605 $r = -0.574^{**}$. Correlations among rubber content ($\phi_{Rb\%}$) with cumulative rainfall ($\phi_{\Delta Rf}$) were also negative with higher “r” values: BG1123 $r = -0.825^{*}$; BG1132 $r = -0.802^{**}$; and BG11605 $r = -0.797^{**}$.

CONCLUSIONS

The relationships among the different characteristics show the importance of temperature and rainfall in rubber synthesis. Temperature was the most important variable found in defining rubber content. Exposure of shrubs to long periods with temperatures between 2°C and -4°C promotes rubber synthesis. The rainfall effect was reflected in the following way: low rainfall levels improved rubber accumulation, whereas high rain levels did not. However, high precipitation also improved the biomass production.

The results confirm the existence of rubber synthesis cycles triggered during the autumn–winter, and rubber content decreased during the spring–summer season. In contrast, plant dry weight increased mainly during the spring–summer seasons, particularly when rainfall occurred. These results indicate that biomass increased both structural and rubber producing cells, which initially do not contain rubber and later accumulate rubber during the cold/dry season.

According to the results, better agronomic management is possible to optimize high solid rubber and latex yields for commercial exploitation. Shrub harvesting may be carried out by the end of the winter when plants are around two-years-old due to a higher quantities of rubber, latex, and co-products.

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