IRRIGATED GUAYULE — PLANT GROWTH AND PRODUCTION

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ABSTRACT


Guayule (\textit{Parthenium argentatum} Gray) has the potential to alleviate future natural rubber shortages and to provide economic benefits to people in arid lands. A study was initiated to obtain information on guayule plant growth and rubber production as influenced by water management and water use. Annual guayule rubber yields from 2-year-old plants were as high as 500 kg/ha for a whole plant harvest and 300 kg/ha for clipped plants cut 100 mm above the ground using present cultivars under a wet irrigation regime in central Arizona. The clipped plants, when allowed to continue growing, will provide another harvest in 1 or 2 years with a cumulative yield that could be greater than a single harvest of 4-year-old plants. Rubber yield from the wet was twice that of the dry irrigation treatment. Plant height, volume and weight, leaf area, and resin yield were also higher on the wet treatment and decreased in a uniform manner from the wet to dry. Conversely, rubber concentration was higher in the drier than in the wetter treatments. Rubber concentration was also higher in the branches than in the roots of the plant. Plant biomass was observed to be closely related to plant height, plant volume, or crown diameter in young plants so that biomass production can be predicted from these plant parameters. Seasonal growth and production patterns also indicated optimum whole plant harvest dates would be from February to March or October to November of each calendar year.

INTRODUCTION

A significant plant growth behavior observed in earlier research on the guayule plant (\textit{Parthenium argentatum} Gray) was that little natural rubber was formed when the plant was actively growing (Hammond and Polhamus, 1965). A possible reason was that the cortical tissue, which is the main rubber bearing area, would expand only during periods of active growth and rubber synthesis would occur when the plant was stressed (soil moisture, plant nutrients, etc.). There appeared to be a seasonal cycle between functions


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of growth and rubber synthesis where the plants grew during the early part and rubber produced in the latter part of the season (McCallum, 1941). Benedict et al. (1947) noted that guayule grown under alternate low and high moisture stress of 2 to 4-month duration each had higher rubber content during high than low moisture stress. Unfortunately, this experiment was conducted for only 15 months and the plants were not at an age when harvest would normally be made.

Olson (1944) and Rotty (1944) observed similar yields in the 2 to 3-year-old guayule shrubs grown with and without irrigation. Bullard (1946a) noted that the highest rubber yields were obtained from 3-year-old plants irrigated for the first 2 years only. Hunter and Kelley (1946) obtained three harvests within the second growing season and showed: (a) that the highest rubber content (percentage) over the whole season was from the treatments given one or no irrigations; (b) that the rubber yield increased throughout the year; and (c) that the main differences in rubber yield between the stressed and unstressed treatments occurred in the months when the shrub growth was most rapid.

Tingey's (1952) study with seven different crop densities and three irrigation treatments showed that rubber yields were largest for the highest plant populations of over 92,000 plants per ha and the highest number of irrigations, although the rubber content was higher (8–11%) for no irrigation compared with a lower rubber content (5–6%) for the high irrigation. The guayule was harvested at 21 and 33 months of age, but unfortunately the amount of irrigation water applied was not measured. Bullard (1946b) indicated, on the other hand, that plant populations of 27,000 to 35,000 plants per ha for irrigated guayule might be too dense for adequate growth in a field rotation of more than 3 years.

Predicting resin and rubber yields have been subject to errors because data from previous production experiences do not provide a reliable base for projections. The Intercontinental Rubber Company gave up their 2,400 ha irrigated plantation in Arizona because, according to McCallum (1941), "the rubber was slow in forming in the plant because of irrigation and because the rains came in the summer and promoted plant growth just when the plants should be drying out." In contrast to this experience, Hilgeman (1946) found that with irrigated 3 to 4-year-old plants annual yields of 330–450 kg/ha were produced with 27,000 plants per ha, and that 560 kg/ha were produced under a closer direct-seeded spacing. In New Mexico, a direct-seeded plot produced 300–450 kg/ha of rubber annually (Davis, 1945). In California, Bullard (1946a, b) sampled three irrigated plantings and obtained annual rubber yields from 285 to 670 kg/ha depending upon the harvesting of the shrub from 2 to 5 years of age, while the two dryland plantings ranged from 145 to 345 kg/ha.

Past experiments have not provided adequate answers to the many questions on how rubber production changes occur during the plant growth
cycle, on when or how often guayule should be harvested, and on what would be the projected rubber yields for present-day guayule cultivars, particularly in respect to the amount and frequency of irrigations. The objective of this paper is to describe guayule growth patterns and production with time for a wide range of irrigation regimes on a medium water-holding capacity soil.

METHODS AND MATERIALS

Seedlings of three guayule cultivars (593, N565-II and 11591) were transplanted on a 0.5-ha site during the 1st week of April 1981 in central Arizona. Planting density was 54,000 plants per ha, and better than 95% transplant survival was achieved. Details on greenhouse seedling production, transplanting methods, experimental design and irrigation practices were described in a previous paper (Bucks et al., 1985).

Six different irrigation treatments replicated four times were begun during the 1st week of July 1981. These irrigation treatments were based on applying water when a preselected percentage of the soil water was depleted in the effective rooting depths of 0–1.2 m for the last 6 months of 1981, and 0–1.8 m for the entire 1982 season. Soil type and irrigation water quality as well as methods used to measure the volumetric water content with time were also discussed previously (Bucks et al., 1985). The six irrigation treatments were as follows:

$I_1$, irrigate at 60% depletion (wet);
$I_2$, irrigate at 70% depletion (wet);
$I_3$, irrigate at 80% depletion (medium);
$I_4$, irrigate at 90% depletion (medium);
$I_5$, irrigate at 90% depletion, plus 2 weeks delay (dry);
$I_6$, irrigate at 90% depletion, plus delay to give only three irrigations per year (dry).

Plant height was measured at least monthly for all cultivars and irrigation treatments. Also, two whole plants were sampled for each cultivar—irrigation—replicate treatment combination starting in August 1981, 4 months after transplanting, giving a total of 144 plants per harvest. Four to five periodic whole plant harvests per year were made. Leaf area, crown diameter, plant height, volume and weight, and resin and rubber contents were measured for the individual plants. In addition, each plant was divided into upper branches (above a 100-mm plant height), lower branches (soil surface to a 100-mm height), and roots (soil surface to a 150-mm depth). The leaves were removed from the guayule plant because they contain negligible amounts of rubber and possible substances that could deteriorate rubber quality (Foster et al., 1979). Resin and rubber contents were determined using the gravimetric acetone-cyclohexane extraction technique (Black et al., 1983).
RESULTS AND DISCUSSION

Data on water applied, soil water content, evapotranspiration, and plant water stress were presented in the previous paper (Bucks et al., 1985). Plant growth was significantly reduced between the wet and medium (I₃ through I₅) irrigation treatments, while little differences were noted between the two drier (I₄ and I₆) treatments. Plant heights decreased consistently with reduced irrigation amounts for the I₁, I₂, and I₆ treatments of the three guayule cultivars as shown in Fig. 1. After 3 months of plant establishment (April to June 1981), cv. 11591 was taller than N565-II, followed by cv. 593 for the I₁ through I₄ treatments; and cv. 11591 and N565-II were nearly the same height in I₅ and I₆ treatments, with both being taller than cv. 593. During the 1st year, plant height increased by over 30 mm/month on the wettest (I₁) treatment compared with less than 20 mm/month on the driest (I₆) treatment; and for the 2nd 1982 year, plant height increased by 20 mm/month on the wet treatment compared with 12.5 mm/month on the dry treatment.

Plant harvests were made in August and December 1981, followed by February, May, July, September 1982 and January 1983. Table 1 presents the whole plant harvest data from 15 January 1983 for the six irrigation treatments and three cultivars. The 1982 date represented the final produc-

Fig. 1. Average plant heights for three guayule cultivars under I₁, I₃, and I₆ irrigation treatments at Mesa, AZ, 1981–1982.
tion obtained after 21 months or two seasons of guayule growth. Significant differences in crown diameter, above-ground harvested plant volume, leaf area index, dry matter, resin content, resin yield, rubber content, and rubber yield resulted from the six irrigations. Crown diameter, plant volume, leaf area, dry weight, resin concentration, resin yield, and rubber yield decreased from the wet \((t_1)\) to dry \((t_6)\) treatment. In contrast, rubber content (percentage) was about 1.0% higher on the dry \((t_6)\) treatment than on the other five \((t_1\) through \(t_5)\) treatments. This trend of increased rubber percentage with greater water stress was not large enough to compensate for more than a two-fold increase in plant dry weight from the dry \((180 \text{ g per plant, } t_1)\) to wet \((400 \text{ g per plant, } t_1)\) treatments. The highest yield occurred on the wet treatment which averaged 1610 kg/ha resin and 1090 kg/ha rubber after two seasons of plant growth, representing about a 170% increase in resin and a 80% increase in rubber production for the wet over the dry treatment.

In terms of the three guayule cultivars (Table 1), no significant differences in above-ground plant volume, leaf area index, dry matter and resin yields were found for the January 1983 whole plant harvest. The largest crown diameter, rubber content and rubber yield were obtained with cv. 508, whereas N565-II had the highest resin content; 11591 had the largest harvested plant volume. Although some variation occurred between the three guayule cultivars, the differences in resin and rubber production due to cultivars were small.

For the 21-month-old plants, the average rubber concentration was 5.6% in the upper branches (above a 100-mm height), 5.4% in the lower branches (soil surface to 100-mm height), and 4.2% in the roots (soil surface to a 150-mm depth) (data not shown). The average resin concentration in the upper branches was 6.1%, in the lower branches 6.8%, and in the roots 6.1%. Thus, the upper and lower branches tended to have a greater percentage of rubber than the roots, whereas the resin content was similar throughout the plant. Artschwager (1945) found that branches had a higher rubber concentration than either roots or crowns and that rubber content in the roots were higher in secondary than in main roots for native plants. However, the portion of production obtained from the roots in cultivated guayule has not been reported.

Similar plant development patterns were demonstrated for all six irrigation treatments based on the seven whole plant harvests. Leaf area index versus time remained nearly constant in the fall of 1981, declined slightly during the winter dormancy period, increased rapidly in the spring until mid-summer, and decreased again in the early fall of 1982 so that the leaf area at the end of the year was nearly the same as at the start of 1982 for the six treatments. Plant height (Fig. 1), harvested plant volume, and crown diameter (data not shown) were nearly the same as leaf area in terms of seasonal developmental patterns. They increased steadily during the fall of 1981; stayed the same during the winter of 1981–1982 (possible dor-
### TABLE 1

Whole plant harvest data from 15 January 1983 for six irrigation treatments and three guayule cultivars at Mesa, AZ

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>Cultivars</th>
<th>Crown diameter (mm)</th>
<th>Above-ground plant volume (m³)</th>
<th>Leaf area index</th>
<th>Dry matter (g/plant)</th>
<th>Resin content (%)</th>
<th>Total resin yield (kg/ha)</th>
<th>Rubber content (%)</th>
<th>Total rubber yield (kg/ha)</th>
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<tbody>
<tr>
<td></td>
<td>593</td>
<td>37 a²</td>
<td>0.151 a</td>
<td>2.1c</td>
<td>534 ±</td>
<td>6.6 ±</td>
<td>1391 ±</td>
<td>5.4 ±</td>
<td>1567 ±</td>
</tr>
<tr>
<td></td>
<td></td>
<td>29 b</td>
<td>0.098 b</td>
<td>0.7</td>
<td>300 b</td>
<td>6.7 ±</td>
<td>1091 b</td>
<td>5.7 ±</td>
<td>928 b</td>
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<tr>
<td></td>
<td></td>
<td>25 bc</td>
<td>0.077 bc</td>
<td>0.4</td>
<td>276 bc</td>
<td>5.0 ±</td>
<td>743 ab</td>
<td>4.5 ±</td>
<td>672 bc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 bc</td>
<td>0.067 bc</td>
<td>0.5</td>
<td>191 bc</td>
<td>4.5 ±</td>
<td>466 c</td>
<td>4.7 ±</td>
<td>482 c</td>
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<td></td>
<td></td>
<td>25 bc</td>
<td>0.055 c</td>
<td>0.5</td>
<td>181 bc</td>
<td>6.0 ±</td>
<td>585 bc</td>
<td>5.4 ±</td>
<td>527 c</td>
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<td></td>
<td></td>
<td>24 c</td>
<td>0.039 c</td>
<td>0.6</td>
<td>154 c</td>
<td>6.7 ±</td>
<td>497 c</td>
<td>6.7 ±</td>
<td>559 bc</td>
</tr>
<tr>
<td></td>
<td>N565-II</td>
<td>28 a</td>
<td>0.108 a</td>
<td>0.8</td>
<td>363 a</td>
<td>8.4 ±</td>
<td>1652 a</td>
<td>4.5 b</td>
<td>878 a</td>
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<td></td>
<td></td>
<td>26 ab</td>
<td>0.098 ab</td>
<td>0.6</td>
<td>284 ab</td>
<td>7.5 ±</td>
<td>1142 b</td>
<td>5.0 ±</td>
<td>773 a</td>
</tr>
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<td></td>
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<td>24 ab</td>
<td>0.058 c</td>
<td>1.2</td>
<td>206 b</td>
<td>7.4 abc</td>
<td>821 b</td>
<td>4.8 ±</td>
<td>536 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 ab</td>
<td>0.054 ab</td>
<td>1.0</td>
<td>233 b</td>
<td>6.1 c</td>
<td>763 b</td>
<td>4.3 b</td>
<td>535 a</td>
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<td></td>
<td></td>
<td>24 ab</td>
<td>0.061 bc</td>
<td>0.5</td>
<td>177 b</td>
<td>7.2 abc</td>
<td>687 b</td>
<td>5.1 ±</td>
<td>483 a</td>
</tr>
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<td></td>
<td></td>
<td>23 b</td>
<td>0.059 c</td>
<td>0.9</td>
<td>182 b</td>
<td>6.4 bc</td>
<td>627 b</td>
<td>5.8 ±</td>
<td>572 a</td>
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<td>I_1</td>
<td>11591</td>
<td>29 ab</td>
<td>0.135 a</td>
<td>1.2</td>
<td>312 ab</td>
<td>7.7 a</td>
<td>1299 ab</td>
<td>4.9 b</td>
<td>832 ab</td>
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<td>I_2</td>
<td>30 a</td>
<td>0.148 a</td>
<td>0.6</td>
<td>403 a</td>
<td>7.0 ab</td>
<td>1523 a</td>
<td>5.2 ab</td>
<td>1123 a</td>
<td></td>
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<tr>
<td>I_3</td>
<td>26 abc</td>
<td>0.082 b</td>
<td>0.6</td>
<td>242 bc</td>
<td>6.56 b</td>
<td>853 bc</td>
<td>5.3 ab</td>
<td>690 b</td>
<td></td>
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<tr>
<td>I_4</td>
<td>24 bc</td>
<td>0.074 b</td>
<td>0.4</td>
<td>220 bc</td>
<td>6.4 ab</td>
<td>757 c</td>
<td>5.5 ab</td>
<td>660 b</td>
<td></td>
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<tr>
<td>I_5</td>
<td>23 c</td>
<td>0.063 b</td>
<td>0.5</td>
<td>178 c</td>
<td>6.4 ab</td>
<td>612 c</td>
<td>5.0 ab</td>
<td>481 b</td>
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<td>0.8</td>
<td>199 bc</td>
<td>6.1 b</td>
<td>657 c</td>
<td>6.1 a</td>
<td>660 b</td>
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<table>
<thead>
<tr>
<th></th>
<th>Average three cultivars</th>
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<tbody>
<tr>
<td>I_1</td>
<td>31 a</td>
<td>1.4</td>
<td>403 a</td>
<td>7.6 a</td>
<td>1614 a</td>
<td>5.0 b</td>
<td>1092 a</td>
<td></td>
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<td>I_2</td>
<td>28 ab</td>
<td>0.7</td>
<td>329 a</td>
<td>7.1 ab</td>
<td>1282 b</td>
<td>5.3 b</td>
<td>941 a</td>
<td></td>
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<tr>
<td>I_3</td>
<td>25 bc</td>
<td>0.7</td>
<td>241 b</td>
<td>6.3 bc</td>
<td>806 c</td>
<td>4.9 b</td>
<td>632 b</td>
<td></td>
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<tr>
<td>I_4</td>
<td>24 c</td>
<td>0.7</td>
<td>215 bc</td>
<td>5.7 c</td>
<td>662 c</td>
<td>4.8 b</td>
<td>556 b</td>
<td></td>
</tr>
<tr>
<td>I_5</td>
<td>24 c</td>
<td>0.5</td>
<td>178 c</td>
<td>6.5 bc</td>
<td>628 c</td>
<td>5.2 b</td>
<td>497 b</td>
<td></td>
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<tr>
<td>I_6</td>
<td>24 c</td>
<td>0.6</td>
<td>178 c</td>
<td>6.2 c</td>
<td>594 c</td>
<td>6.2 a</td>
<td>596 b</td>
<td></td>
</tr>
</tbody>
</table>

Average six irrigations N565-II 28 a 0.081 N.S. b 0.8 273 N.S. 5.8 c 879 N.S. 5.4 a 789 a
Average six treatments 11591 28 b 0.094 0.7 259 6.7 b 950 5.3 ab 739 ab

a In each group, means followed by the same letter belong to the same population at the 5% level of significance according to Duncan's Multiple Range Test.
b Analysis of variance showed no significant difference.
c Analysis of variance not included for leaf area index because sample size was smaller; however, irrigation treatments appear to be significantly different.
mancy period); increased during the spring, summer and fall of 1982; and stayed constant by the end of 1982.

Average total harvested dry matter (branches plus roots minus leaves) continued to increase from August 1981 through January 1983, although dry weights remained nearly constant during the possible dormancy period of late November through mid-February for 1981–1982 in a pattern similar to the plant height (Fig. 1), harvested plant volume, and crown diameter. However, one period of rapid increase in dry weight occurred from late summer to early fall (approximately July through September 1982). This is the same period of peak evapotranspiration (ET) after an abrupt mid-summer decline in water use that was discussed in the previous paper (Bucks et al., 1985).

A non-destructive method for determining biomass production, which in turn can be used for estimating resin and rubber yields would be helpful. The following three linear regression equations were developed for predicting dry matter (branches plus roots minus leaves) from three types of field plant measurements:

\[
\text{DMW} = -10.3 + 0.048 \text{PH} \quad S_a = 0.67, \quad S_b = 0.002, \quad R^2 = 0.96 \quad (1)
\]

\[
\text{DMW} = 2.15 + 150 \text{PV} \quad S_a = 0.32, \quad S_b = 6.0, \quad R^2 = 0.95 \quad (2)
\]

\[
\text{DMW} = -14.4 + 1.09 \text{CD}, \quad S_a = 1.02, \quad S_b = 0.046, \quad R^2 = 0.93 \quad (3)
\]

where DMW is the dry matter from a whole plant to include branches and roots, but not leaves (t/ha), PH the plant height from the soil surface to the top of the highest growth, but not including the inflorescence or seedhead, (mm), PV the plant volume (m³), computed from PH (plant height) and PW (plant width), CD the crown diameter, the diameter at the plant base near the soil surface (mm), S_a standard error of intercept, S_b standard error of slope, and $R^2$ coefficient of determination.

These equations were developed for a plant population of 54,000 plants per ha, and could be different for other plant spacings or climatic conditions. Each datum point in Fig. 2 represents 24 harvested plants averaged for the three cultivars and a single irrigation treatment. A minimum of six to eight plants should be measured before a reasonable estimate of dry matter can be made based on numbers obtained for the harvest of a single cultivar. Although the highest coefficient of determination was obtained from the plant height, both crown diameter and plant volume measurements provided accurate estimates of dry weights.

Similar seasonal patterns of resin and rubber contents (percentages) occurred for all guayule cultivars and irrigation treatments. Both resin and rubber concentrations increased slightly during the fall of 1981, followed by a substantial increase during the winter of 1981–1982 (possible dormancy period); later in the spring and summer of 1982, the percentages actually declined when plant growth began to accelerate; and then, in the fall of 1982, the percentages began to increase slightly as plant growth
Fig. 2. Average dry matter yield versus plant height of seven whole plant harvests for three guayule cultivars under six irrigation treatments at Mesa, AZ, 1981—1982.

slowed. The highest resin and rubber contents along with the least amount of total dry matter occurred at the end of the guayule dormancy period somewhere between late February and March. On the other hand, both resin and rubber yields either increased with time or remained unchanged for short periods depending on the irrigation treatment. The greatest increase in resin and rubber yields for whole plants occurred between mid-July and mid-September harvest, particularly on the wetter irrigation treatments. This is shown in Fig. 3 where rubber yields increased significantly in the early fall on the wet (I1) and medium (I2) treatments compared to the dry (I3) treatment. Because the guayule plant grows rapidly in late summer and early fall, a second promising harvest date would be between early October through November.

Guayule plants can be harvested either by digging the plant to include portions of its roots or by clipping the plant above the soil surface. Limited studies were made with clipping during the 1940’s, although tops clipped from 5 to 7-year-old plants approached 68—75% of the rubber in the entire plant (Hammond and Polhamus, 1965). Possible advantages of clipping include obtaining an earlier economic return, eliminating re-establishment costs, and a higher cumulative production compared with harvesting an older guayule plant. More recently, Garrot et al. (1983) found that the
clipping of cv. 593 guayule (above a 100-mm height) at 2 years of age followed by digging entire plants at 3 years of age, yielded 64% more total rubber than with a single harvest of 3-year-old whole plants.

In order to determine the earliest possible date as well as a yield potential for clipping, Fig. 4 depicts the proportion of rubber production, respectively, from large branches, small branches, and roots for the seven harvest dates. Regardless of the harvest dates, the portion obtained from the upper branches ranged from 51 to 70%, the lower branches from 14 to 32%, and the roots from 9 to 39% of the total yield. In terms of resin production, the percentage of the resin yield coming from the upper branches (above a 100-mm plant height) varied from 52 to 72%, the lower branches (soil surface to a 100-mm height) from 19 to 32%, and the roots (soil surface to a 150-mm depth) from 11 to 21% of the total whole plant yield.

Seasonal cycles, plant age, and irrigation treatments appear to cause the variations in the percentages of resin and rubber production from different plant parts. In respect to optimum time periods for a clipping harvest, the higher portion of rubber production from the upper branches was obtained
for late February (end of possible dormancy) through late March. Also, the period from early October up to February appears to be promising for clipping guayule plants; however, the extent of rubber production and plant survival during a late fall and winter clipping harvest will require further study. The poorest time for a clipping would be from June through September in central Arizona.

![Graph](image)

Fig. 4. Percentage of rubber yield with time from large branches, small branches, and roots of seven whole plant harvests for three guayule cultivars under I₁, I₂, and I₃ irrigation treatments at Mesa, AZ, 1981–1982.

**SUMMARY AND CONCLUSIONS**

Results from 2 years of research on three guayule cultivars at Mesa, AZ, showed that plant height, plant volume, plant biomass, leaf area, resin yield and rubber yield decreased progressively from the wet to dry for six irrigation treatments at seven harvest dates. Rubber yields of 21-month-old plants averaged 1090 kg/ha on the wet compared with 595 kg/ha on the dry treatment. Although rubber concentrations were higher under the drier than the wetter irrigation regimes, yields were significantly higher in the wetter treatments because of the larger biomass. Large differences in resin
and rubber yields did not occur between the cultivars, except that cv. 593 had a slightly higher rubber content and yield than cvs. N565-II and 11591.

Linear regression equations can be used to estimate plant biomass from non-destructive measurements of plant height, plant volume, or crown diameter ($R^2$ better than 0.93). Two periods were optimum for whole plant harvesting — between February and March or October and November — in central Arizona, where rapid increases in rubber content or plant biomass occurred. If guayule plants were clipped after two seasons and allowed to regrow rather than be harvested as whole plants, rubber yields of approximately 65% of whole plants could be expected, with 20% remaining in the lower branches and 15% in the roots. Only on the wettest irrigation could present guayule cultivars be expected to obtain annual rubber yields of more than 500 kg/ha on whole plants and 300 kg/ha on clipped plants in central Arizona after two seasons of growth. Preliminary indications are that sequential clipping for several times will possibly increase yields compared with a single whole plant harvest at an older age.

REFERENCES


