GUAYULE RUBBER PRODUCTION
THE WORLD WAR II EMERGENCY RUBBER PROJECT
A Guide to Future Development

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University of Arizona
Tucson, USA
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PREFACE

This publication presents research findings and practical applications generated by the World War II Emergency Rubber Project as well as those findings and applications produced by various postwar programs. Topics addressed include criteria for suitable planting areas, planting, cultivation, harvesting, milling and processing guayule.

This publication is designed to be a reference work for persons who:

1. Are interested in learning more about the Emergency Rubber Project;
2. Want to obtain an overview of guayule production;
3. Are engaged in various aspects of guayule production research; or
4. Have an interest in developing guayule programs.

An extensive bibliography supports this document. Those citations noted with a double asterisk (**) in the bibliography were the principal sources of information to the authors. Most of the references cited are available in the Guayule Special Collection, Office of Arid Lands Studies, University of Arizona, Tucson, Arizona 85719 USA. Persons interested in borrowing or securing reproductions of documents should write first for information concerning availability and cost.
INTRODUCTION

In 1930, an investigation was made by the War Department. Two officers were detailed to make a study of the possibility or desirability of guayule production (390). After exhaustive investigation these two officers, Major Dwight D. Eisenhower and Major Gilbert Van Wilkes, made their report, dated June 6, 1930, including the following points.

1) It would appear that the Government might be interested in encouraging development of the guayule industry in the United States in the view of:

   a) the opportunity to build up a domestic source of rubber supply so that in a grave emergency we would not be wholly dependent on Southeast Asia and the adjoining islands for this important raw material;

   b) the opportunity to build up a domestic source of rubber supply so that the American consumers would have some protection against possible commercial combines between the greater rubber producing companies of Southeast Asia;

   c) the possibility of building up an industry in the United States that would give profitable employment to some thousands of American farmers, mechanics and laborers; and

   d) the precarious position in the United States in depending entirely on the continued rubber supply from Hevea trees in Southeast Asia that now produce 96 percent of the world's supply of rubber.

-3-
2) At present no one believes that the United States in this or the next generation will produce annually the major part of the rubber that we consume. But if the guayule industry could develop to the point where approximately 400,000 acres were devoted to the growth of guayule, we would produce annually almost 160 million pounds of rubber, have in reserve at all times not less than 250 million pounds....

Twelve years passed before the U.S. Government became involved in producing natural rubber on a large-scale in this country. The enactment of Public Law 473 established the World War II Emergency Rubber Project.

After the war the program was dropped. No more commercial plantings were made and it was not until 1975 that guayule again came under consideration for development in the United States.
Early History of Rubber Production

The rubber-producing guayule shrub has a long, varied and interesting history. The aboriginal peoples of north-central Mexico probably were acquainted with guayule's rubber-producing characteristics long before European explorers appeared on the North American continent. These explorers reported seeing North American Indians playing with rubber balls in the 18th century. The rubber balls reportedly were produced by communal chewing of guayule bark.

The first commercial extraction of rubber from guayule was made by the New York Belting and Packing Company. The company imported 100,000 pounds of the shrub from Mexico and extracted rubber by immersing the plants in hot water. But in 1902 William A. Lawrence began a series of experiments that led to development of the pebble mill method. The mechanical method was first used to extract rubber from guayule in 1904 and was still in use at the end of World War II.

The Continental Rubber Company was organized in 1903 in New York. A subsidiary, the Continental-Mexican Company, was incorporated in 1904. Continental-Mexican built a small mill at Torreón, Coahuila, Mexico, and subsequently acquired four more mills, plus a small batch mill. These two companies and another Mexican subsidiary corporation constituted the entire wild guayule rubber production industry at the outbreak of World War II.

The amount of guayule rubber produced varied widely because exploitation was not followed by replanting and many native stands of guayule were exhausted. Starting with a rubber production of 150,000 pounds in 1905, a maximum production of about 21.5 million pounds was reached in 1910. A production low of 65,000 pounds occurred in 1921. But about 12 million pounds of guayule rubber were produced in 1927. From 1931 to 1933, no rubber was shipped because of low prices. In 1934, however, 9 million pounds were produced. Shipments increased steadily to a peak of almost 20 million pounds in 1944. Nearly all of this rubber was shipped to the United States (240, 390).

Intercontinental Rubber Company

Dr. W.B. McCallum joined the Intercontinental Rubber Company when it was still known as the Continental-Mexican Rubber Company in 1910. McCallum began his experimental guayule studies in Torreón. When the Mexican Revolution began in 1912, he moved his studies to Valley Center, near San Diego, California, where the company bought 440 acres of undisturbed land to establish a nursery and field test plots.

At McCallum's suggestion, research activities were moved to Arizona where the company purchased a large tract of land 25 miles south of Tucson. Most of this land was undeveloped, but it was suitable for irrigation agriculture and the Intercontinental Rubber Company developed a comprehensive irrigation system. McCallum was not satisfied with the
research and production results obtained in Arizona. He experienced difficulty in regulating irrigation, and believed that the very hot summers and cold winter nights were detrimental to guayule production.

Because of McCallum's dissatisfaction, operations were moved to Salinas, California, in 1925. Intercontinental planted about 8,000 acres with guayule there, principally in the Salinas Valley. Nearly half the area was plowed under by contract farmers during the period of low rubber prices in the 1930s. Nevertheless, the Intercontinental mill at Salinas processed the harvest from approximately 4,400 acres of guayule during 1931-1941 to produce more than 3 million pounds of rubber. Throughout this period McCallum continued his agricultural practice and plant breeding studies in an effort to develop improved strains of guayule (390).

In 1942 the U.S. Government purchased Intercontinental Rubber Company holdings in California to ensure the nation a wartime supply of natural rubber. This purchase included 1,483 acres of land (674 acres of which were planted with guayule), 22,867 pounds of seed, and 14 million seedlings in a small nursery. Also purchased were the Spence Rubber Extraction Mill, and miscellaneous buildings, equipment and supplies (390). When the U.S. Government purchased Intercontinental, the company was the only guayule rubber producer in the United States.

McCallum, who became a consultant to the government, had developed several strains of guayule by this time. Because of the erratic reproductive behavior of the plant, however, these varieties did not always produce seeds that would reproduce themselves exactly. The best cultivated varieties at an optimum age yielded 20 percent crude rubber based on dry weight of the plant, whereas the average yield from wild plants in native habitats was 15 percent or less.

World War II Guayule Program

The Emergency Rubber Project (ERP) was established March 5, 1942, by an act of Congress. As a result of the earlier government purchase of Intercontinental holdings, a small staff was able to begin operations the day the ERP Act was signed by President Franklin D. Roosevelt (390).

The Forest Service, U.S. Department of Agriculture (USDA), was designated to undertake land acquisition, planting, cultivation, harvesting and milling activities. Research was conducted by the Bureau of Plant Industry, Soils and Agricultural Engineering (which later became the Agricultural Research Service, Crops Research Division), the Bureau of Agricultural and Industrial Chemistry (which later became the Agricultural Research Service, Utilization Research and Development Divisions), and the Bureau of Entomology and Plant Quarantine (which later became the Agricultural Research Service, Entomology Research Division (140)).

The project existed 3.5 years. During that period 60,000 acres of land were leased. Government leased land included 31,689 acres of
cultivated guayule and 2,900 acres of nurseries equipped with overhead sprinkling systems that produced more than one million seedlings. In Texas, 6,048 acres of guayule plantations were developed. These plantations and harvests of 2,540 acres of native stands of guayule produced nearly 3 million pounds of rubber for the Reconstruction Finance Corporation Office of Rubber Reserve.

At the peak of the ERP more than 800 classified technical, supervisory and clerical persons were employed by the USDA Forest Service along with approximately 125 researchers working in other participating USDA agencies. A work force of about 4,500 was involved in planting, cultivating, harvesting and milling guayule.

The ERP was terminated in 1946. All land leases were canceled by June 30, 1946; subsequently 30,000 acres of guayule were destroyed. The destroyed guayule contained an estimated 21 million pounds of rubber (390).

Postwar Research Program

The Natural Rubber Extraction and Processing Investigations Project, a postwar guayule research program, was established August 1, 1947, at Salinas. The project was conducted jointly by the USDA Bureau of Agricultural and Industrial Chemistry and the Bureau of Plant Industry, Soils and Agricultural Engineering, which was responsible for the cultural and breeding portions of the program.

In December 1950 an emergency guayule seed and seedling stockpiling program was initiated by the USDA and administered by the Production and Marketing Administration with the Bureau of Plant Industry, Soils and Agricultural Engineering, providing technical guidance. The Bureau established seedling programs in California and Texas. Seedlings were transplanted to 357 acres in the Salinas Valley and 529 acres of nurseries were established in Texas (140).

The Texas guayule seedling stockpiling program closed December 31, 1951, and the California program ceased operations one year later. A total of 15,801 pounds of threshed seed had been harvested. Added to previously harvested seed, the U.S. stockpile amounted to 26,334 pounds of variety 593 guayule seed, dried and stored in airtight metal containers.

On June 30, 1953, the Natural Rubber Extraction and Processing Investigations Project was terminated, although the cultural and breeding program continued until June 30, 1959 (140).
CHAPTER 1

AN OVERVIEW

DESCRIPTION

Guayule (Parthenium argentatum Gray) is the only species of Parthenium known to produce commercial amounts of rubber. It is a bushy shrub with narrow leaves covered by white wax and white hairs (trichomes) that act as protection from drought. The guayule (pronounced wy-oo-lee) plant normally reaches a height of about 2 feet and in its native habitat may live for 30 years or 40 years. (See Figure 1.)

The gray-green leaves are first marked by a single tooth near the middle of one margin, but later more teeth appear until the leaf has a more or less lobate form. During the dormant period the lower leaves shrivel and eventually are shed leaving only compact terminal clusters of small leaves. Both surfaces of the leaves are densely covered with T-shaped hairs parallel to the leaf surface. An abscission layer is imperfectly formed and the leaves do not fall until the leaf dies. This is important in the defoliation of the shrubs before extracting rubber.

Guayule stems develop rapidly, forming many branches even during the first year of growth when they are still in an herbaceous state. The terminal branches end growth with the formation of an inflorescence; then two or three upper buds begin to elongate (140).

The root system of guayule includes a tap root that may reach a depth of 20 feet under cultivation but does not usually penetrate more than 2 feet in wild stands. The greatest concentration of fibrous roots is in the upper 6 inches of soil. These roots may attain a lateral spread of 10 feet or more, enabling the plant to use the moisture from brief, sporadic rains.
Wild guayule growing in its native habitat may develop adventitious shoots, called retonos, from the shallow roots of a parent plant. A stem rises from the retoño and eventually develops into a new plant a foot or more away. In native guayule, retonos often outnumber seedlings and are important elements in the continuing survival of the stand, particularly in areas where the seedling survival rate is low or where the wild plants are harvested by pulling (190).

The inflorescence terminating the growth of the primary shoot and subsequent branches is a compound, one-sided cyme with flowers borne in heads within a common receptacle. Each head contains five fertile ray-florets, each with two attached, subjacent, sterile disc-florets. The ray-florets are unisexual with no visible remnants of stamens. The disc-florets contain an abortive pistil in addition to the functioning fertile stamens and are attached to each other at the base. The ray-floret with attached disc-florets falls from the flower head as a unit.

The achene complex, when shed, consists of the achene, the two subjacent sterile disc-florets and a subtending bract, together with a persistent ligule and a withered two-lobed stigma. The mature achene usually contains an embryo invested by two seed coats; both are thin and white and the inner one is hard (140).

The flowering period in the native habitat is normally during summer, but it may occur at any time of year when growth is active, depending on the amount of rainfall. Under irrigated conditions the plant may continue to flower from early spring to late fall.

Guayule is pollinated by both wind and insects. Pollen may be carried more than 2,000 feet by the wind. Many insects including ladybird beetles, lygus bugs and cucumber beetles, are known to carry guayule pollen. Honey bees are probably also effective pollinating agents (241).

NATIVE HABITAT

Guayule is a shrub native to the Chihuahuan Desert of north-central Mexico, particularly the states of Coahuila, Chihuahua, Durango, Zacatecas, San Luis Potosí and Nuevo León and the adjacent Big Bend area of Texas. Its habitat is confined to the northern portion of the central plateau, an area of approximately 130,000 square miles. Guayule grows in scattered patches ranging in size from less than one acre to several hundred acres. (See Figure 2.) It is restricted mainly to outwash slopes and calcareous soils in regions with an annual rainfall of 5 inches, most of which falls in late spring and early autumn.

Lloyd (190) gives the northern limit of guayule in southwestern Texas as Presidio, Brewster and Pecos counties, a region contiguous with its distribution in Mexico. Only a small proportion of the total guayule habitat is in Texas, but this stand is important because it is the only native one in the United States and marks the northern limit of the plant's range. This northern boundary falls along an irregular east-west line.
FIGURE 2. GUAYULE PLANTS IN NATURAL HABITAT (Guayule plants are identified by an "x")
from about 20 miles east of Balmorhea in Reeves County to Fort Stockton and then along a northward-bulging arc to the vicinity of Bakersfield in southeastern Pecos County. A stand to the south in Terrell County near Dryden appears to mark the eastern limit of the guayule range in Texas. Although the plant was reported near Langtry in southwestern Val Verde County, this stand has never been verified. It may have disappeared due to grazing.

Guayule occurs at elevations between 2,000 feet and 10,000 feet with comparatively few large stands above 6,500 feet. In Texas the elevation range is 2,800 feet to 4,200 feet, but most stands are between 2,800 feet and 3,800 feet. The most extensive guayule area in Texas is on and near the O-Two Ranch about 30 miles south of Alpine, where the average elevation is about 3,700 feet.

Along its northern habitat boundary in Reeves and Pecos counties, guayule is confined mainly to the stony, steep slopes of the buttes and escarpments on the higher levels of the Edwards Plateau. Here, as elsewhere, it does not penetrate the wide intervening plains and valleys (190).

CLIMATIC LIMITATIONS

Because climate has a considerable effect on the development of guayule under any given set of conditions, it is often the determining factor in selecting production areas. Certain soils may be suited to guayule only under specific climatic circumstances. One guayule variety may be better suited to a given climate than another. The type of culture in plantations, as well as many other operations, is often completely dependent on climate. Field curing of the harvested shrub before milling must follow day-to-day dictates of weather.

A brief picture of how the climate affects guayule in its native range may help show the importance of this factor in commercial guayule production. The plant is native to a region with an arid or semiarid climate where the mean annual rainfall varies from 5 inches to 15 inches. Recorded extremes range up to 25 inches. Rainless periods of four months are common, and many droughts are recorded. Rainfall is generally biseasonal, with peaks in the spring and fall, although in some areas most of the rain occurs during late summer and fall and very little in the winter and spring (190).

Seasonal and diurnal temperatures vary greatly; maximums of 115 °F and minimums of 5 °F have been recorded. But the overall climate of the region is comparatively moderate, and there is no very cold season in much of the area. The warm season is wet, and cloudiness tends to hold temperatures down. Winter and early spring are drier and sunny. Guayule growing on slopes often is not exposed to extreme cold. Dry winds occur during the winter, but in the growing season humidity is rather high.
Unless dormant, guayule is not cold tolerant, but can stand droughts. Climates in which cold or dry periods come on gradually produce the healthiest shrub and greatest yields. In California, where guayule was grown under cultivation, the moderate growing season temperatures and cool but not cold winters of the coastal areas produced fair growth and high rubber content. Dry periods late in the growing season stimulated rubber increment (342).

Precipitation

Rainfall in the California production area was important in two ways: first as a source of water on the dry-farmed plantations; and second as a factor affecting soil preparation for planting and other cultural operations. In the lower San Joaquin and Sacramento valleys, efficient use of machinery on the plantations often depended on a narrow range of moisture conditions.

Annual rainfall in the native guayule range is from 5 inches to 15 inches, but the plant's usual location on slopes provides it with an extra moisture supply. Runoff and percolation from higher areas may supplement rainfall moisture by as much as 50 percent. For this reason, and because guayule does not make rapid growth in its native habitat, more moisture is required for commercial production where tonnage must be made in fewer years. Guayule roots can descend 20 feet or more and ultimately may deplete soil moisture nearly to that depth (235).

Bullard (45) conducted a study to determine possible guayule production areas that included seasonal distribution of precipitation and drought frequency. (See Figure 3.) At the beginning of the ERP the minimum normal precipitation suitable for dryland culture was believed to be 11 inches per year; 9 inches to 11 inches were considered doubtful, and below 9 inches unsuitable.

Bullard suggested that the level of precipitation considered suitable for dryland culture be raised to about 15 inches except in areas with cool, foggy summers. About 10 percent of the time rainfall in these areas is close to the mean; the rest of the time it is split between years below normal and years above normal. Growers using the previously established suitable level of 11 inches planted in areas that were often too dry and shrub growth was retarded after available soil moisture was withdrawn. The 11 inch limit is satisfactory at sites such as the California coast. At the upper limit, the old assumption of 25 inches of precipitation apparently is still good. Where guayule has been grown under more than 25 inches of rainfall during the year-long distribution, shrubs have reached a large size but have not developed a high rubber content.

Day length and sunshine intensity are assumed to be important but have not yet been found to influence growth or rubber production. Fog is helpful in certain areas because it furnishes additional moisture and keeps temperatures and growth rates down. Humidity is not important except that it may increase the incidence of disease,
FIGURE 3. AREAS IN THE UNITED STATES WITH CLIMATE CONSIDERED SUITABLE FOR THE CULTIVATION OF GUAYULE (after Swensen and Bullard)
The ideal climate for cultivating guayule would provide a rainy season during late winter, spring and early summer, and the last half of the growing season would be dry. Early rains would replenish soil moisture. Then, when temperatures became favorable in the spring growth could begin. Subsequent rains would promote continued vigorous growth for three or four months. At the end of the rainy season growth would taper off according to available residual soil moisture and the guayule would begin drought dormancy. The climate in some of the California production areas approached this ideal, except that rains did not extend into the summer and the moisture received during the winter was exhausted in some cases too early in the season.

In other areas where guayule was cultivated, rainfall occurred in a biseasonal pattern. Peaks occurred during spring and fall, as in Texas, or during summer and winter, as in Arizona. The biseasonal pattern promotes good yields of rubber where total precipitation is only enough to produce a gradually developing xeric type shrub.

In the high rainfall belt at the lower end of the Rio Grande Plain in Texas, guayule grows year round since there are no marked drought periods and temperatures are high enough to permit plant growth. In this area the rubber content is usually low except where moisture competition is increased by closer spacing of the plants.

In certain areas insufficient rainfall is augmented by other sources of moisture. On agricultural lands along the California coast, rainfall varies between 10 inches and 15 inches, somewhat low for guayule, but summer fogs and night condensation help maintain soil moisture and keep down daytime temperatures. Guayule does not grow as vigorously under these conditions as in hotter areas, but rubber production is very good. Guayule apparently has no pronounced seasonal growth mechanisms and seems well suited to this moderate environment.

Precipitation distribution, particularly storm frequency, affects plant establishment and survival in new plantations. Where drainage is poor, storm frequency and intensity correlate with seedling mortality. Planting cannot be successful when the soil is either too wet or too dry because of mechanical difficulties with planting equipment and because plants fail to become established when moisture is inadequate. Sufficient rainfall after planting is a necessity with dryland culture.

Bullard (45) pointed out that guayule shows some accommodation to climate. When water is made available during the growing season, the plant responds and begins growth immediately. As the water supply is reduced, growth slows and then stops. When the cool, dry, winter dormant season approaches, the larger summer leaves are shed and only the small leaves on the terminal clusters are retained. At this time the rate of rubber and hydrocarbon formation in the plant is highest.

Dormancy in guayule appears to be a function of moisture availability and temperature. In the native range the dry period usually coincides with the cool period and the plants are more or less dormant from
October to April. There is considerable variation in local conditions. If soil moisture is available some growth will occur during warm periods of winter. Guayule does not seem to have a definite seasonal growth rhythm; it grows, flowers and fruits whenever, and as long as conditions are favorable. This characteristic makes it especially susceptible to changes in the weather.

Guayule was cultivated in several areas having dry summers and winter rains. It was grown experimentally in totally different climates in Arizona, New Mexico and Texas. Arizona has some of the same climatic influences as California. Both have a winter rainy season, but Arizona has an additional late summer rainy season. In New Mexico and western Texas the principal wet season is from July to October with the heaviest rainfall in September. The winter is quite dry. In southern Texas there may be considerable rain in every month of the year, but the peak amounts occur in May and September. New Mexico and Texas (except the extreme southern part) have colder winters than Arizona and California and more wind. Humidity is high in southern Texas and along the California coast during the growing season but low in the other areas described.

The largest shrub was grown in south Texas under dryland culture. Under irrigation, the largest shrubs were grown in central Arizona and in the hot central valley of California. The shrub richest in rubber was grown on a dryland plantation on the California coast. High rubber content per shrub does not necessarily produce the highest rubber yield per acre; larger shrubs lower in rubber content still could produce more total rubber yield per shrub. In the southern end of the Rio Grande Plain, guayule produces vegetative growth almost year round but has relatively poor rubber production. Where the shrub grows slowly in the foggy and relatively cool climates of the California coast it attains fair size and excellent rubber production.

**Temperature**

_Growth and Mean Annual Temperatures._ Guayule grows best where temperatures are between 90 F and 100 F. Growth slows markedly when the temperature is below 60 F. Plants are not damaged when temperatures reach a maximum of 120 F but are injured when temperatures fall below 15 F. Therefore, the most suitable climate for dryland cultivation of guayule would have mean annual temperature between 56 F and 62 F, with a minimum temperature not below 15 F. Mean annual temperatures up to 70 F would be satisfactory in irrigated cultivation (45).

_Temperature, Dormancy and Cold Injury._ Conditions that prevent rapid growth such as moderate temperatures appear to be desirable. The climate should permit plant growth to taper off because of water deficiency in conjunction with gradually lowering temperatures to bring the guayule into dormancy slowly. When growing temperatures prevail much of the time in irrigated cultivation areas, the soil environment must allow manipulation of irrigation waters to maintain a moderate rate of vegetative growth. A slow lowering of temperatures during the onset
of winter produces the greatest rubber increment and safety from cold
damage.

Cold injury to guayule is related to available soil moisture and
growth activity in the plant. In Texas, dormant plants on certain
test plots withstood temperatures from 1 F to 4 F without appreciable
injury, while on other plots considerable damage occurred at temperatures
of 14 F and 15 F. The effects of cold include defoliation, killing of
small twigs, of the bark and cambium near the ground surface, and injury
to root crown tissues to a depth of 2 inches below the surface. Severe
injury killed the plants outright, but recovery from moderate cold injury
was usually rapid. Minor injury did not seem to impair the vigor of the
shrub. When defoliation was caused by cold, new leaves were produced
earlier and in greater abundance than on undamaged plants (45, 158, 278).

Diurnal Fluctuations. Warm, dry summers are conducive to growing
guayule with a high rubber content, although maximum rubber development
requires relatively low night temperatures. Daytime temperatures from
65 F to 80 F, with nighttime temperatures from 35 F to 45 F promote
satisfactory rubber accumulation in young shrubs. Diurnal temperature
fluctuations seem to affect rubber deposition more or less without regard
to vegetative growth, although cool nights tend to reduce growth rates.

Disease, Insects and Temperature. The incidence of disease also
was affected by temperature. Cotton root rot was most severe in hot,
humid weather, or after irrigation in hot weather. Verticillium wilt
became serious during spring and fall when temperatures were near 70 F.
Crown root rot in the nurseries was most common during cooler, foggy
weather with high humidity. While insect epidemics were known to be
correlated generally with climate, the few local outbreaks experienced
by the ERP could not be correlated with specific temperature or moisture
conditions.

Cold Tolerance. During World War II, ERP personnel attempted to
determine the cold tolerance of guayule in two ways. Test plots were
established in California, Arizona, New Mexico and Texas where plants
might be subject to cold temperatures. The other was to observe
guayule in its native habitat (155, 278).

The ERP indicator plots were planned to be permanent. There were
146 plots established in the northern portion of the Sacramento Valley
in California, in southern Arizona and New Mexico and in central and
southern Texas. (See Appendix A for a more detailed discussion of
indicator plots.)

In addition to these ERP plots, many small plantations were
established by private investigators or experimental stations throughout
a much larger area. There were plantings as far north as Pullman,
Washington, Corvallis, Oregon; and Albuquerque, New Mexico; and eastward
to Woodward, Oklahoma; Lincoln, Nebraska; and Fort Collins, Colorado.

During the period of observation from 1942 to 1945, the 31st
parallel of latitude appeared to represent a boundary above which the
plants were injured by cold. Generally speaking, the farther north of
the boundary the plots, the more severe the injury. Conversely, the
farther south from the 31st parallel, the less the injury, if any, to
the plant occurred. The 31st parallel also marks the northern boundary
of the natural range of guayule.

The degree of injury was observed to be seldom in direct ratio
to the degree of cold. Rather, injury appeared to be influenced by
the amount of soil moisture. This was not always true, however, and
other factors may be important in cold tolerance, including soil texture,
air, drainage and wind, as well as the pattern of low temperatures and
the degree of plant dormancy at the time low temperatures prevailed
(45, 158, 280).

The conclusions drawn from studying indicator plots are as
follows:

1) The degree of injury is in an inverse ratio to the degree of
dormancy;

2) When quite dormant, plants can withstand zero F with little or
no injury;

3) High soil moisture does not appear to be a primary hazard if
the plant is dormant;

4) An important factor in winter survival appears to be the tempe­
ratu re pattern in late fall and early winter. A gradual onset
of decreasing temperatures provides a high degree of protection
regardless of the amount of soil moisture;

5) Especially hazardous areas are those subject to winter warm
spells with temperatures high enough to induce plant growth but
followed by freezing temperatures;

6) The greatest insurance against winter injury seems to be a dry
fall season that concides with gradual temperature declines;
and

7) With comparable temperatures and variable soil moisture, the
degree of injury appears to be in direct ratio to the amount
of moisture.

In irrigated areas where little or no rain falls during the late
summer or fall, withholding irrigation to induce drought dormancy protects
the plants from cold injury. Where temperatures fluctuate rapidly
between growing temperatures and those as low as 15 F, some injury may be
anticipated; where fluctuation is from high temperatures to 15 F or lower,
heavy to total loss may occur.

The Mesilla valley in New Mexico and the Middle Pecos valley in
Texas, characterized by fall drought, experience short intervals when
moisture is present to promote guayule growth. When temperatures drop abruptly to freezing—a normal occurrence—plant injury occurs.

A fall drought usually occurs in the southern but not in the northern part of the plains between Fort Stockton and Lubbock, Texas. But the normal fall and winter temperature pattern is similar throughout the area. Gradually declining fall temperatures and winter temperatures are seldom high enough to induce active vegetative growth (158).

A Central Plains pattern of climate exists in the eastern area where guayule test plots were established. Abundant moisture is present during the fall and winter months. Temperatures are usually high enough to activate plant growth. But there are frequent short intervals of freezing temperatures that can cause severe plant injury.

TOPOGRAPHY AND SOILS

In its native habitat guayule is confined to slopes and grows only where the ground is stony. The closely related mariola, however, grows abundantly on alluvial plains as well as on slopes.

Guayule is native to the Cretaceous region of the central plateau and therefore to highly calcareous soils. The edaphic habitat of the plant suggests that the mechanical conditions of alluvial soils are unfavorable for its growth (190).

Within its native range guayule tends to be limited to well-drained and aerated soils. Under cultivation it did best on similar soils. Native guayule is not found on impervious caliche or poorly drained valley soils. Plantation survival was poor on heavy soils or where subsoils were very coarse.

ERP experience with field plantings of guayule bore out the validity of the initial recommendations used in selecting planting areas. Good growth was obtained on soils ranging from loamy fine sand to silty clay loam. However, guayule is very sensitive to soil conditions. The shrub varies in size, weight and rubber content according to minor changes in soil moisture retention and availability. Soil is the dominant factor in rubber production because of its relation to moisture stresses (390). Controlling moisture to stress the shrub without injuring it is possible only with a soil type that makes water available to the plants rather slowly (see Chapter 6).

Soil Texture

The largest plants in both irrigated and dryland plantings occurred on light- and medium-textured soils. With the same cultural treatment and planting stock on a single plantation, larger shrubs were developed on loam and sandy loam than on other textures. But the highest percentage of rubber was found in smaller plants that had been
grown on other soil textures. Plants grown on clay soils showed a higher concentration of rubber than those on light soils (44, 93).

**Hardpans and Claypans**

Hardpans and claypans, including plowsole, tend to restrict guayule growth in inverse relation to their depth below surface. Where pans are shallow and drainage poor due to heavy soils, guayule is small and apparently lacks vigor. Under such conditions it is susceptible to disease and drowning out. In lighter soils the pans restrict growth, but have a much less adverse effect on survival.

It is difficult for guayule roots to penetrate pans. If the pans are within 30 inches of the surface, shrub growth is never satisfactory. Root extension is limited and the feeding area small. Extremely stunted plants, of which there were relatively few in the ERP test plantings, showed low rubber production, but those that were less retarded showed higher rubber production. Per-acre yields, however, always were decreased by restrictions on growth.

**Soil Moisture**

Soil moisture availability, the principal factor affecting guayule growth, varies with soil texture. For best growth, guayule requires permeable, well-drained, well-aerated soils that have a reasonably good supply of soil moisture most of the year. Optimum vegetative growth, however, usually is not combined with maximum rubber increment or content in the shrub. Those soils that slowly make water available to the plants promote the highest rubber content per unit shrub weight and, if other growing conditions are favorable, produce the highest yields of rubber per acre (44, 93).

Unsatisfactory growth and rubber yield result when soil conditions make moisture easily available for short periods that are followed by extremely dry periods. This occurs on both light and heavy soils with very coarse substrata at shallow depths. Under such conditions guayule experiences spurts of luxuriant growth and then dies back a little under heavy stress. The succulent "growing" leaves are rapidly lost and photosynthetic activity is reduced greatly during the dormant stress period. Little rubber accumulates. When available moisture is reduced slowly the shrub has time to "prepare" for the dry dormant period. A xeric type of leaf develops and rubber deposition increases markedly.

Water tables at or below 5 feet provide conditions similar to continuous irrigation and promote continuous shrub growth. But those at 2.5 feet produce smaller plants that are subject to severe stress when the water level recedes. Waterlogging destroys parts of the root systems when water tables are high, but plant death does not occur when the shallow lateral roots are well aerated and still able to function. Poorly aerated, water-soaked soils will cause drowning out of a considerable number of plants. The extent of cold damage is usually related inversely to the moisture content of the soil and the plant.
Soil moisture also is important in relation to disease. Attacks by various fungi often coincide with the presence of excess moisture, especially in heavier soils with slow drainage (393).

Soil moisture capacity has a considerable effect on cultural practice. Competition between plants is strongly affected by spacing and soil moisture availability. Furthermore, moisture-plant relations change under cultivation, especially with respect to aeration. On newly cleared brushlands with fine sandy loam soil, the soil is loose at first and shows a moisture deficiency similar to that caused by high evaporation. Clays, usually considered to heavy and poorly aerated for guayule, are suitable if they are friable. Dryland production on problem soils is impractical, as is irrigated production on very loose sandy or gravelly soils, because of the impossibility of high cost of meeting water requirements for best growth. On soils of very poor structure, a low plant survival rate often occurs because of poor contact between the soil and the plant.

Soil Fertility

Like other plants, guayule grows best on more fertile soils, but it does not respond noticeably to most fertilizers. While native to calcareous soils, guayule grows very well on non-calcareous soils of granitic or sedimentary origin. Required fertility levels, like moisture capacities, seem related more to spacing and competition between plants than to general needs. Low fertility may be a limiting growth factor in a few instances, but if so, the soil moisture relations are so far from optimum that they obliterate any measurement of this fertility factor (164).

Salinity

The salt content of the soil is important to guayule. Plants grow well in a soil pH from 6.0 to 8.5 and are stunted at pH 4.5 or 10.5. Optimum growth occurs from pH 7.2 to 8.3.

Guayule tolerates up to 0.3 percent alkali anywhere in the soil profile, but alkali content from 0.3 to 0.6 percent in the upper 2 feet of soil greatly retards growth. More than 0.6 percent alkali in the surface soil kills the plants. The number of lower leaves on the shrub actually increases with alkali concentration in the soil up to the limits of tolerance, but shrub weight and survival decrease. The physiological drought produced by increased soil moisture tensions apparently causes reactions in the plant similar to those caused by natural drought (168, 273, 276, 277, 406, 407).

REPRODUCTION AND GENETICS

Guayule plants initiate seed formation in several ways. In some groups the female reproductive cell is fertilized in the usual way by the male pollen cell. Both cells carry genes that transmit characteristics.
to the offspring. In other groups the pollen acts only as a stimulator to the female cell without actually fertilizing it. Since the seed is developed through a multiplication of the female cell, progeny from such a seed inherits the characteristics of the mother plant only. This latter type of reproduction has two classes: in the first, and most common type, the female cell with a non-reduced number of chromosomes receives only "stimulation" from the pollen; in the second, which is rare, the female cell with a reduced number of chromosomes is similarly induced to grow without fertilization. In the first case the offspring's cells and overall character duplicate the female parent characteristics; in the second case, each offspring is slightly different from the parent and all such offspring are genetically different from one another although the biological differences may be minor (140).

Studies by Powers (262, 264), Rollins (284) and others (103, 104) have revealed the occurrence of apomixis in guayule. In apomictic reproduction, unlike sexual reproduction, there is no orderly sequence of stages in embryo-sac formation. The progeny reproduced by apomixis should duplicate all the characteristics of the mother plant. This was not always true, however, in guayule. A few individuals deviated to some degree from the mother plant. There has been much study of the inheritance of apomictic lines as well as the mechanism whereby plants may be opened up to cross-fertilization.

Breeding studies showed that certain strains were only facultatively apomictic and that it was possible to develop strains that will cross even when apomixis predominates. As a result, it is possible to open up plants for breeding and then close them so that they become fully apomictic. In this way it is possible to fix a hybrid so that it will be uniform from the first generation onward (103, 140, 373). Thus the long process of selection to obtain true breeding hybrid strains is avoided.

Various other irregularities occur in guayule chromosome complements, including aneuploidy, polyploidy, chromatic bridges, and fragmentation that produce sterile pollen and other cytological irregularities.

Plants collected from Mexico and from the Trans-Pecos region of Texas had approximately 36, 54, 72, and, rarely, 108 chromosomes. Those in the 36-chromosome group were all, or nearly all, normal sexual plants in which both reduction and fertilization took place. This group also was predominantly self-incompatible. With one exception, no predominantly normal sexual plants were found among the 54-, 72-, and 108-chromosome groups. They were apomictic and self-incompatible (137, 140, 261).

The chromosome groups of 54, 72, and 108 are multiples or half-multiples of the basis number 36. Abnormal sexuality among plants with 36 chromosomes sometimes yields offspring with 54 chromosomes; those having 54 chromosomes if they reproduce by non-reduction of the egg cell and were fertilized with an 18-chromosome gamete, would stabilize at the number 72. Random occurrence of the number 108 was associated with occasional abnormal sexuality of a 72-chromosome plant.
The principal strains used for commercial production during World War II and earlier were from 72-chromosome groups. Mariola (P. imccanum) plants with 72 chromosomes closely parallel the 72-chromosome guayule reproductive behavior.

**Guayule Strains or Varieties and Crosses**

Various strains or varieties of guayule have been recognized and several crosses have been identified since cultivation of guayule began in 1911, including stock from U.S. breeding programs and some foreign programs, most notably those developed in the Soviet Union, Spain, and Israel. (See Bibliography 216 for a fuller discussion.)

Several varieties or strains were selected and planted by the Intercontinental Rubber Company. The most promising of these were used by the ERP during its expansion program. Variety 593 appeared to be the best for general use. Most of the ERP plantings were of this strain. Other varieties used included 109, 130, 406 and 407. Variety III also was planted in indicator plots (46, 379, 390).

Individual guayule strains respond in their rubber yields differently to environmental conditions. For example, in the cool Salinas Valley of California, variety 593 produced high rubber concentrations; whereas in the warmer valleys of California and southwest Texas the plants were small and formed a number of relatively small branches. Rubber accumulation tended to level off after two or three years' growth. By contrast, variety III, a poor yielder in the Salinas Valley, consistently yielded as much as 50 percent more rubber in Texas than did 593.

Variety 593 established readily, had high survival rates, grew rapidly, was fairly resistant to drought and root rot, and produced high rubber yields when properly managed. Variety 406 was similar to 593 in shrub appearance and in its reactions, with the exception of its response to diurnal temperature fluctuation. The growth of 406 seedlings was retarded more by low night temperatures than that of 593 seedlings, but there was no significant difference in overall cold tolerance. Variety III was a good rubber producer. The plants were smaller but had higher rubber content than 593, however, it was sensitive to damping-off in nurseries and to root rot in fields. The viability of III seed was not very good. Variety 109 was nearly as good a rubber producer as 593, but it was less resistant to root rot and drought and was rather exacting with respect to soil requirements. It was, however, less susceptible to cold injury, possibly because it begins growing later in the spring than does 593. Establishment and survival of 109 seeds were poor, but it had the most rapid growth and attained a larger size than other strains. It had a fair rubber content and gave higher yields per plant because of its larger size. It was, however, highly susceptible to Verticillium wilt. Variety 130 had perhaps the highest rubber content of any of the older strains and was easy to grow. While Intercontinental found that 130 reached large size in Arizona, its growth in California was by no means exceptional. It did have relatively soft wood, which was important in crushing and milling operations. Variety 407
did very poorly under irrigation in California. While the shrub grew to tremendous size, the rubber content was so low that milling was barely worthwhile.

The strains used by the ERP varied considerably with respect to the time growth began, to general adaptability in hot or cool climates and wet or dry climates, and to disease resistance. One of the principal genetic experiments involved developing cold-hardy strains. Growth-rate differentials between varieties were considered with respect to growing season length in the various areas.

Where soil and cultural conditions were uniform, some differences between certain genetic strains could be easily determined. Strain 109 plants were usually larger and appeared more vigorous than other varieties. Strain 111 plants tended to have more compact crowns and rounded bluish-green leaves. Visual segregation of plant strains 130, 406 and 593 was more difficult. They were quite similar but their reactions to the environment caused much greater differences in appearance than those induced by heredity.

Seeds available from the National Seed Storage Laboratory, Colorado State University, Fort Collins, Colorado 80521, are listed in Table 1. Small amounts of these seeds have been furnished to interested growers. Plants of these varieties are being tested in the United States, Israel, Australia, Mexico and elsewhere.

In a two-year variety test beginning in 1957 at Shafter, California, selections 11701, 11693, N565, 11634, and 11635, respectively, were significantly higher in rubber yield than the control varieties 593 and 4265-X (140). Environmental conditions at Shafter were considered to be representative of southern Texas and the warmer California and Arizona valleys.

In Texas, variety 4265-X was greatly superior to 593, particularly in resisting charcoal rot.

Study findings indicate the need to determine milling characteristics of varieties or crosses that appear to have rubber production promise. Strains evaluated in limited post-World War II milling studies are listed in Table 2 and are summarized in the paragraphs that follow (110, 160, 282, 291, 341, 373).

**Strain D-65.** Wood fibers were very long. Small worms of rubber were observed after one hour of milling. When milling was completed the worms were bright olive-green and very buoyant in the flotation tanks, but difficult to recover because of their fineness.

**Strain D-118.** Wood fibers were long and stringy. Flower stems were profuse. No distinct worms of rubber were discernible after milling one hour. Rubber worms were very small, bright green and difficult to skim when milling ceased because of their small size. Buoyancy was only average.
# TABLE 1

SEED VARIETIES IN STORAGE AT FORT COLLINS, COLORADO

<table>
<thead>
<tr>
<th>Selection Number</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>11591</td>
<td>Hammond selection from 4254-I, better than 593 at Salinas</td>
</tr>
<tr>
<td>11600</td>
<td>&quot;</td>
</tr>
<tr>
<td>11604</td>
<td>&quot;</td>
</tr>
<tr>
<td>11605</td>
<td>&quot;</td>
</tr>
<tr>
<td>11609</td>
<td>&quot;</td>
</tr>
<tr>
<td>11619</td>
<td>&quot;</td>
</tr>
<tr>
<td>11633</td>
<td>Mexican introduction</td>
</tr>
<tr>
<td>11634</td>
<td>72 x 36 chromosome cross</td>
</tr>
<tr>
<td>11635</td>
<td>72 x 54 x 36 chromosome cross</td>
</tr>
<tr>
<td>11646</td>
<td>Hammond collection, superior performance at Salinas</td>
</tr>
<tr>
<td>11693</td>
<td>4265-I selection, 72 chromosomes</td>
</tr>
<tr>
<td>11701</td>
<td>4265-I x 36 chromosome cross</td>
</tr>
<tr>
<td>A48118</td>
<td>Hammond collection</td>
</tr>
<tr>
<td>A48143</td>
<td>Hammond collection from Zacatecas, good at Salinas</td>
</tr>
<tr>
<td>N396</td>
<td>Vigorous in Texas, resistant to charcoal rot</td>
</tr>
<tr>
<td>N565</td>
<td>Hammond collection</td>
</tr>
<tr>
<td>N566</td>
<td>Selection from 4265-I, higher than 593 or 4265-X</td>
</tr>
<tr>
<td>N575</td>
<td>Mexican introduction, better than 593 or 4665-X at Salinas</td>
</tr>
<tr>
<td>N576</td>
<td>Hammond selection, better than 593 and 4265-X at Salinas</td>
</tr>
<tr>
<td>N596</td>
<td>See 11635</td>
</tr>
<tr>
<td>12229</td>
<td>Cross with PP. tomentosum var. stramonium</td>
</tr>
<tr>
<td>12231</td>
<td>Hammond collection</td>
</tr>
<tr>
<td>593</td>
<td>Variety developed by Intercontinental Rubber Company</td>
</tr>
<tr>
<td>4265X</td>
<td>Selected from 4265-I, 72 chromosomes, higher yields</td>
</tr>
<tr>
<td>4265FX</td>
<td>Seed yield increase from 4265-X</td>
</tr>
</tbody>
</table>
TABLE 2
VARIETIES AND HYBRIDS TESTED

<table>
<thead>
<tr>
<th>Strain</th>
<th>Parentage</th>
<th>Chromosomes</th>
<th>Age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-65</td>
<td>Guayule 593 X Stramonium 43700</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>D-118</td>
<td>Guayule 42268 X Stramonium 43691</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>D-153</td>
<td>Stramonium 43691 X Guayule 4268</td>
<td>54</td>
<td>3</td>
</tr>
<tr>
<td>D-155</td>
<td>Stramonium 43691 X Guayule 4268</td>
<td>54</td>
<td>3</td>
</tr>
<tr>
<td>593</td>
<td>McCallum</td>
<td>72</td>
<td>3</td>
</tr>
<tr>
<td>4265-I</td>
<td>Feral, Durango, Mexico</td>
<td>54</td>
<td>3</td>
</tr>
<tr>
<td>4265X</td>
<td>Selection, 4265, Durango, Mexico</td>
<td>72</td>
<td>3</td>
</tr>
<tr>
<td>Mariola No. 1</td>
<td>(Guayule X Stramonium) X Mariola</td>
<td>90</td>
<td>2</td>
</tr>
<tr>
<td>Mariola No. 2</td>
<td>Guayule X Mariola</td>
<td>72</td>
<td>2</td>
</tr>
</tbody>
</table>

Strain D-153. Wood fibers were long. No worms of rubber appeared after milling one hour. When milling ceased, the rubber worms were exceedingly fine and dull olive-green in color.

Strain D-155. Wood was tough, fibrous and much more difficult to handle. Flower stems were profuse. Indistinct rubber worms were small, difficult to handle and dull olive-green in color. Dried deserialized rubber was not rubbery in texture, but more like dried putty.

Strain 593. Wood fibers were very much shorter than in any hybrid, but about the same as in the two 4265 varieties. Rubber worms formed after one hour of milling. At the end of the milling period, the worms exhibited normal characteristics.

Strain 4265-I. Defoliation was very difficult. Wood fibers were comparable to usual guayule. After milling, rubber worms were typical gray-green and normal size. Rubber was very buoyant and floated more readily than most.

Strain 4265-X. Defoliation was not difficult. Wood character was ordinary and worm characteristics were the same as 4265-I and 593.

Mariola hybrids. Little material was available. It was not possible to process in small, batch pebble mills. It was milled in the attritor. After milling, rubber aggregates were very fine, not worm-like, and could not be recovered by conventional skimming. However, back crosses
to guayule were not carried out and the full potential from interspecific crosses was never realized.

In conclusion: 1) Preparing shrubs was not unusually difficult. Strain 4265-I was difficult to defoliate. All hybrids that had one Parthenium stramonium parent had tough, long-fibered wood. 2) All hybrids produced very small worms that were difficult to recover in the flotation system. One hybrid, D-155, produced a dry, deserated crude that was not rubberlike in texture. 3) The highest yields per acre might be expected from strains 4265-I and 4265-X. All guayule hybrids produced less rubber per acre than any of the straight guayule strains; guayule X mariola hybrids were the least promising of all strains tested.

PHYSIOLOGY AND RUBBER FORMATION

The rubber in guayule exists as a colloidal suspension of latex confined to individual cells. Guayule has not organized latex tubes as does hevea. In general, plants older than one year carry the major portion of rubber in the vascular rays of phloem and xylem. Small quantities of rubber occur in the primary cortex, xylem parenchyma and epithelial cells of resin canals. Very small amounts occur in the leaf parenchyma. Rubber concentration in the roots is in the branch roots rather than in the main roots. The branch system above the ground contains more than two-thirds of the total rubber in the plant. It constitutes approximately two-thirds of the defoliate dry weight of the plant and has a higher rubber concentration than either the root or crown. The bark contains 75 percent to 80 percent of the total plant rubber. The proportion of bark to wood is low in the primary root but increases upward into the younger branches with smaller diameters. There is a strong tendency for uniform rubber concentration in the stem segment to correspond to successive annual elongation increments because of the greater proportion of bark in the younger stems.

There is a marked seasonal fluctuation in the overall concentration of rubber in the plant during the year. Concentration is highest during periods of moisture stress (see Chapter 7). The ratio of the radius of the wood to the bark is directly related to plant weight and water supply; lush growth increases the production of xylem tissue, which produces little rubber, at the expense of phloem tissue which has a higher rubber-producing potential.

The function of rubber in the plant is not known. The rubber is not a storage product that the plant can draw on for nutrition. It does not help resist drought, nor does it provide protection from grazing animals.

Resin canals occur in well-defined systems throughout the plant, but principally in the bark where they are distributed rather uniformly (131, 147). The resins include essential oils, parthenyl cinnamate and partheniol, betaine, fatty acids, an unidentified wax and other chemicals and constituents. Resin concentrations in the bark, green
stems and roots of plants vary from 7 percent to 10 percent on a dryweight basis. The concentration of resin is considerably less in the wood and even lower in the roots. Stems less than one year old have higher resin concentration than do older stems. When a branch dies under field conditions a considerable portion of the rubber is converted to acetone-soluble substances. The effect of dead plant parts on milling is to lower the rubber concentration and raise resin concentration (10, 13, 14, 110).
CHAPTER 2

SEEDS

The term "seed" is applied loosely to the achene complex including the remnants of the pistillate ray-floret, staminate disc-florets and a bract that remains attached when the seed falls from the plant. "Threshed seed" refers to the achenes from which the floral parts have been removed by threshing. A drawing of the flower and seed is shown in Figure 4 (140, 392).

SEED CHARACTERISTICS

Guayule seed has germination characteristics different from those of most other seeds. If the seeds are sown immediately after being collected from the plant, only a few will germinate because of two types of dormancy: embryo dormancy of short duration; and seedcoat dormancy that makes the inner seedcoat impermeable to the exchange of gases. The latter dormancy may persist for years under some conditions of storage (392).

Seedcoat dormancy can be eliminated by a chemical treatment or shortened to a few months by threshing and removing of the floral parts normally attached to the seed. Aeration and moisture content of the seed affect the persistence of seedcoat dormancy as well as the keeping qualities of the seed.
Flowering Stem

Remnants of Style & Stigma
Staminate flowers
Remnants of staminate flower

Guayule seed consisting of an achene with attached floral parts. x 12.
(inner and outer view.)

Seed with florets spread apart to show manner of attachment and position of the achene.

Achene, x13

FIGURE 4. BOTANY OF GUAYULE SEED
Time of Bloom

Nearly all varieties of quayule are prolific seed bearers. When soil moisture and air temperature are favorable, plants of all ages bloom and set seed profusely throughout the growing season. (See Figure 5.)

In native stands seedlings flower only infrequently before the third year. Subsequent flowering and seed bearing is highly variable and directly correlated with the occurrence of rains. In irrigated fields, however, plants can be made to blossom continuously throughout most of the growing season. Toward the end of an interval between irrigations seed ripens faster than new blooms are set. On gravelly streaks, or other "droughty" areas within the field, the seed may ripen prematurely, resulting in poor quality.

In the unirrigated fields of the ERP in California, plants grew slowly, and the main seed crop of the first growing season ripened about the first of September. In the following years the main crop ripened in late June or early July. Subsequent scant, spotty yields were confined to areas where sufficient soil moisture was available to enable the plants to continue active growth.

Fields

Quantities of seed produced per acre vary widely according to how many plants survive and their age and vigor. The flower stalk bears an average of seven composite flowers. A flower has five female florets, each of which contains an achene, or seed. When plants are in bloom, the potential seed crop from the stand can be estimated by a simple rule: Each flower stem per plant represents about one pound of clean seed per acre in a stand of 7,500 plants (346, 392).

In 1943, yields of clean, unthreshed seed ranged from 10 pounds to 300 pounds per acre, depending on the size of the plants and the length of the blooming season as influenced by moisture. In a few cases under especially favorable conditions, yields of 1,000 pounds of seed per acre were recorded. These yields, based on machine collection, should not be confused with total amounts of seed produced. Wind and hoeing crews dislodge up to half of the ripe seed. The picking machines get from one-third to two-thirds of what is left. On the average, collected yield is from 25 percent to 30 percent of all seed produced by the plants.

The largest quantities of seed are obtained from lush, vigorous and rapidly growing shrubs. High nitrogen fertility stimulates seed production by increasing vegetative growth. Irrigated shrubs, with a longer growing season, produce more seed than dry-farmed shrubs. In the San Joaquin Valley, 25 pounds to 40 pounds of clean (unthreshed) seed per acre were collected with a mechanical seed picker from irrigated plantings in the first growing season, and 500 pounds per acre was not uncommon in subsequent seasons. Unirrigated plantings in
the Salinas Valley yielded 10 pounds to 20 pounds of clean seed per acre the first season and 100 pounds to 200 pounds the second and subsequent years.

Effect of High Temperatures

Many seed quality differences were the result of environmental influences. For example, plants provided with ample moisture would grow vigorously at temperatures high enough to injure the pollen and thus prevent the formation of good seed. This was suspected from observations of seed collected during midsummer in Arizona. It was later borne out by tests in which potted plants were grown in a greenhouse where temperatures of 110 F to 120 F were maintained throughout the day and about 90 F during the night. Sufficient water to prevent wilting or severe growth check was supplied throughout the period of blooming and seed development. Seed produced under these conditions were uniformly unfilled (147).

SEED COLLECTION

Machine Collection

Since guayule seed loosens from the flowering stalk and shatters readily when ripe, it is easy to harvest by mechanical means. The Intercontinental Rubber Company developed a seed collector that used a vacuum produced by fans. The machine was complicated, heavy and not very efficient. After investigation and several trials by the ERP, the collector was discarded. Several types of harvesters employing revolving brushes or beaters that dislodge the seed into pan or trough receptacles proved successful and economical. One such machine has a shaft carrying four rotary brushes, one for each plant row, mounted in the chassis of a pull-type beet and bean cultivator and driven by a belt from the cultivator wheels. Torpedo-shaped pans, drawn along the ground between the plant rows, catch the seeds as they are brushed from the plants. A canvas cover prevents the seeds from being tossed into the air (343, 346).

Another collector model consists of a horizontal rotating brush long enough to span four rows and mounted across the front of a Ford-Ferguson tractor (208). The brush is partially enclosed in a metal box open at the front. The brush and the box move along the tops of the plants at a height controlled by the power lift of the tractor. Rotation is imparted by a shaft running forward from the power takeoff. The seed is brushed directly into the box where it is moved by a horizontal screw-conveyor to a vertical bucket elevator that discharges into sacks.

This machine is better adapted to collecting seed from plants of all sizes, because the brushes approach the plants ahead of the tractor, thus collecting the seed before it is knocked off by the wheels and frame of the tractor. Such a machine can cover from .8 acre to 20 acres in a 10-hour day, depending on the yield.
Hand Collection

Collecting seed by hand cannot compete with mechanical harvesters in speed or cost per pound. It is practical, however, when seed picking machines are not available, when quantities of seed are small or when it is important to obtain the highest possible percentage of the seed. A tray resembling an oversized dustpan, with a U-shaped opening in the forward edge, can be used to collect from small plants. The tray is slipped under the plant—the stem occupies the opening. Seed is brushed from the plant by tapping it gently with a paddle or by ruffling the flower stems between the palms of the hands. For larger plants, a shallow wooden box or tray is placed on the ground under the plant, and as the plant is bent over the box, the flower stems are ruffled by hand (392).

The quality of the seed is highly variable. Damage by lygus bugs reduces the seed crop, and high temperatures tend to inhibit the formation of good seed. Dry-farmed plantings produced better quality seed than irrigated plantings. With a few exceptions, the filled percentage of seed on nursery seedlings produced in the ERP plantings was too low for general use.

When to Collect

The proper time for seed harvesting can be determined by frequent inspection of the seed clusters. The clusters are tan to brown and shatter very readily when ripe. It is important to correlate the time of collection with irrigation and cultivation. Cultivation and furrowing immediately before cultivation may result in the loss of 50 percent of the ripe seed. Irrigation stimulates plant growth but retards ripening of the seed, making collection less effective and more difficult if it is delayed (343, 392).

Frequency of Collection

The number of times seed can be collected from the same plants in one season is influenced by several factors, including cultural operations, continuity of blooming stimulated by irrigation, uniformity of ripening and winds. On unirrigated plantations it is usually safe to plan on two collections and, in some cases, even a third may be economically feasible. The first collection should be made when 40 percent to 60 percent of the crop is ripe, and the second when the remainder of the crop is ready for collection. A third collection should not be made unless there is enough seed available from late blooming.

On irrigated plantations, frequency of water application is the main factor in determining the number of collections made. In fields where water is applied only once about the middle of the growing season, three to five collections may be possible—one or two before and two or three after irrigation. In fields irrigated four times during the growing season, it is possible to make five to seven collections—one or two before the final irrigation, one after each irrigation and one or two after the final irrigation (343).
Temporary Storage after Collection

When the seed is collected it should be air-dried to 6 percent to 10 percent moisture content to permit temporary storage without danger of molding or heating. No heating has been observed in sacked seed with less than 12 percent moisture. Reduction of the moisture content of sacked seed is accomplished most easily by sunning. Sacks should be stood vertically on tarps or boards to prevent absorption of moisture from the ground, and placed to provide air space on all sides. If the sacks are upended daily, the contents soon dry. In areas of high humidity, or where heavy dew or rain might occur, the sacked seed should be covered with tarpaulins at night.

During collection only the ripe, dry seeds shatter readily from the plants. Consequently, the principal moisture will be from collecting in the early morning when dew is heavy or when excessive beating of the plants removes some green seed (343).

Seed Cleaning and Handling

Cleaning consists of removing foreign matter such as stems, leaves, sand, clusters of sterile florets, insects and weed seeds. Separation and removal of empty seeds are also part of the cleaning operation. Standard commercial cleaning equipment is used.

The ERP fed the seed material over a power-driven shaker or scalping screen for quick removal of coarse trash gathered with the seed. The screen was of 1/4-inch mesh wire or of perforated plate with 1/4-inch holes. Some hand work was required to relieve clogging of trash on the screen. Seed fell into a hopper that fed an elevator delivering the seed to a Clipper Cleaner.

This cleaner, standard commercial equipment, had three screens in a vibrating riddle: A top screen of No. 10 round holes for removal of oversize material; a middle screen of 1/2-inch by 1/12-inch slots for separating the clusters of sterile florets from the seed; and a bottom screen of No. 7 round holes for removal of fine trash. Slightly different sizes were occasionally used, according to the average seed size of some lots. As a rule, unthreshed seed was cleaned satisfactorily by one run through the scalper and cleaner (343, 392).

Gravity Separation

Through a process of gravity separation it was possible to greatly improve the percentage of filled guayule seed retained. The process was fairly effective for unthreshed seed and very effective for threshed seed.

The gravity separator was equipped with casement cloth deck and 3/8-inch ruffles. A vibrating deck was so arranged that--as the seed flowed across it--the combined effects of vibration and the lift of air forced up through the cloth deck caused the seed stream to fan out on
the deck, segregating particles of like weight or density to different portions of the outgoing stream. Its sensitivity is indicated by the fact that it was used commercially to separate dust from snuff and to grade flour.

While the machine accurately graded unthreshed guayule seeds by their relative weights, the filled and empty seeds did not have separate weight ranges. Some of the empty seeds weighed as much as the heaviest filled seeds, and some of the filled seeds weighed as little as the lightest empty ones. Filled seeds are predominantly heavier, however, so considerable separation and discarding of empty seeds can usually occur without appreciable loss.

SEED THRESHING

Thresholding of guayule seed was not developed until after the seedling production program of the project had been drastically curtailed, and threshed seed was never used in a large-scale nursery seeding program. But threshed seed has been used in numerous experimental sowings. Results have been generally superior to those attained from unthreshed seed, and it is strongly believed that sowing threshed seed would permit use of a simpler type of nursery seeder; it should be adopted in future seedling production programs (343, 346, 392).

Extensive trials, both by the Forest Service and the Bureau of Plant Industry, Soils, and Agricultural Engineering, disclosed that threshing was beneficial. The natural dormancy of the seed, which requires special chemical treatment to secure short-term germination, persists in varying degrees for a number of years in unthreshed seed. Thresholding causes a substantial proportion to become viable at once, and the dormancy of the remainder disappears in a matter of months, thus eliminating the costly chemical treatment of stored seed. It was found that threshed seed germinated more quickly than unthreshed, and in most seeding trials, better stands of seedlings were obtained from threshed seed.

Various types of threshing machines were tried by the ERP, some of which proved ineffective for guayule or actually injured the seed. The Prater Hammermill with hammers of graduated length produced fair results, but the most successful type used on the project was a Forsberg Huller. It was originally designed for hulling bur clover and consisted of a conical, rubber-covered rotor turning inside a rubber-lined drum. It also had a suction device for removing dust from the hulled material. When properly adjusted it threshed about 400 pounds (unthreshed weight) of guayule seed per hour without injury to the seed. The drier the seed, the easier it was to thresh. A moisture content of 7 percent or less is conducive to good threshing; at higher moistures, the portion unthreshed may be salvaged from the gravity separator and rethreshed.

Threshed seed is more amenable to cleaning and gravity separation than unthreshed. While unthreshed seed is customarily 10 percent to
45 percent filled and weighs about 8 pounds to 10 pounds per bushel, threshed seed can be cleaned to 85 percent to 99 percent filled and weighs 25 pounds to 30 pounds per bushel. Threshing and recleaning ordinarily reduce the material to about one-fifth to one-eighth the weight and one-tenth the bulk. (See Figure 6.)

INSECTS AND PESTS

Insects of many kinds and sizes were present in freshly collected seed, but they died or left rapidly or were removed in the cleaning operation. None were observed feeding on the seed in storage.

Mice were attracted to the untreated seed but usually shunned seed treated with sodium hypochlorite (181, 343).

SEED DRYING

A dehydrator, similar in design to food dehydrators, proved successful in drying large quantities of seed. Small amounts can be dried in the sun, however, the trays of seed must be protected from wind, and from temperatures higher than 120 F (343).

STORAGE

Moisture and time, rather than temperature, have been demonstrated through experiment to be the principal determinants in guayule seed longevity. Dry seed will stand severe temperature changes for short periods and only moderate temperature changes for longer periods.

Metal drums with tight-fitting lids prevent changes in moisture levels as well as reduce water and fire hazards and rodent damage. The lids can be fitted with sponge rubber gaskets to create a practically airtight container. Sturdy enough for repeated use, the lock-rim 55-gallon drums, such as those used for shipping lard and vegetable shortening, are also low in cost. Sacks can be used instead of drums for short-term storage (343).

Effects of Moisture

In localities with high humidity, unthreshed guayule seed in open storage is likely to lose viability rapidly after the third year. But if sealed at 4 percent moisture immediately after cleaning, it will keep for more than 10 years. Data are lacking on longevity at intermediate moisture levels.

When short-term storage or two years to three years is planned, seed needs to be dried prior to storage in sacks or drums if the moisture content does not exceed 8 percent.
FIGURE 6. UNTHRESHED AND THRESHED GUAYULE SEED VOLUMES AND WEIGHTS
Prior to 1942 the Intercontinental Rubber Company lost seed after two years to three years of storage in cloth sacks at Salinas, while seed similarly stored at dry inland locations remained in good condition for many years. The company subsequently adopted the general practice of drying the seed to 4 percent moisture or less, promptly after collection and cleaning, then sealing it in airtight metal drums.

Investigations by the ERP indicated that this method was adequate for long-term storage but was not the best practice for seed stored only two years or three years. While very dry storage devoid of aeration keeps seed alive for a long time, it also causes seed to retain dormancy, necessitating expensive chemical treatment to ensure germination. If unthreshed seed is stored with allowance for aeration and atmospheric humidity, a steadily increasing percentage of the seeds lose their dormancy.

**Effects of Temperature**

While low temperatures are favorable for maintenance of most seed species, no evidence was found that this is true of guayule. Intercontinental Rubber Company seed kept in cloth sacks in the hot, dry climates of Valley Center, California and Phoenix, Arizona remained in good condition for four years or longer. Seed stored for one year in sealed drums at Indio, California and El Paso, Texas, germinated at slightly higher percentages than seeds not stored at all.

Guayule seed tolerance of temperature extremes for short periods was demonstrated by Taylor, who subjected seed containing about 5 percent moisture to temperatures of minus 112 F for three days and to baking at 195 F to 200 F for 40 hours to 80 hours with little, if any impairment of germination (343).

**Changes in Dormancy**

The disappearance of dormancy in untreated seed is most rapid when the moisture content is about 7 percent. After six months' storage under these conditions, practically all filled seeds of some lots germinated without hypochlorite treating. In other lots less than half the filled seeds lost dormancy within this period; the remainder were able to germinate during the ensuing year or two. When sealed at 4 percent moisture, residual dormancy was evident for five years.

Benedict reported on the changes in dormancy occurring in threshed seed during the first four months after collection. Seed threshed and recleaned immediately after collection in July germinated as shown in Table 3 (29).

Many seeds will germinate immediately after threshing and most of them need no treatment after six months of aerated storage at 6 percent to 10 percent moisture content. Storing threshed seed at 4 percent moisture content causes some retention of dormancy, but it is not as pronounced as with unthreshed seed.
TABLE 3
SEED GERMINATION PERCENTAGES

<table>
<thead>
<tr>
<th></th>
<th>Threshed Seed</th>
<th></th>
<th>Unthreshed and Untreated Seed*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untreated</td>
<td>Treated</td>
<td></td>
</tr>
<tr>
<td>July 19</td>
<td>12.25</td>
<td></td>
<td>3.0</td>
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<tr>
<td>August 28</td>
<td>27.5</td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>Sep 25</td>
<td>49.0</td>
<td>65.0</td>
<td>4.25</td>
</tr>
<tr>
<td>Oct 12</td>
<td>61.25</td>
<td>64.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Nov 15</td>
<td>81.25</td>
<td>80.75</td>
<td></td>
</tr>
</tbody>
</table>

*The unthreshed seed was 50 percent filled.

In general, it appears rapid breakdown of the impermeable seedcoat that causes dormancy occurs in aerated storage (such as cloth sacks) in an area where atmospheric humidity maintains a moisture content of 7 percent to 8 percent in the seed. Under these conditions almost none of the filled, threshed seed will need hypochlorite treatment after six months, and 50 percent to 75 percent of the filled, unthreshed seed will germinate without treatment after eight months. These conditions, however, are not conducive to longevity.

SEED TREATING

Purpose and History

If guayule seeds are sown directly after harvesting very few will germinate--usually 1 percent to 6 percent. On recently harvested seed the inner seedcoat--a thin, tough membrane enclosing the embryo--is nearly impermeable to oxygen and must be broken or made permeable. In addition some seeds have an embryo dormancy that generally lasts about two months after harvesting. Until this embryo dormancy disappears, the seeds will not germinate regardless of whether the seedcoat is physically punctured or otherwise made permeable. This embryo dormancy cannot be curtailed by any known chemical treatment.

Low temperatures, effective for relieving dormancy of some other species of seed, were ineffective and sometimes injurious to guayule. Benedict found that stratification of unthreshed seed with moist sand and peat, held at 5 C (41 F) for a short period, improved the germination of 2-year old seed but not that of freshly collected seed. Some improvement occurred in germination of threshed fresh seed held under these conditions for two weeks, but long stratification reduced germination.
and was detrimental to older threshed seed. Additionally storing the dry seed at freezing temperatures or below was not beneficial at any of the periods or temperatures tried, and it reduced germination in most cases (29).

The seedcoats of untreated seeds gradually lose their impermeability, at a rate varying with the conditions of storage and, somewhat, by seedlots. In some instances the majority have retained their impermeability for five years when held at 4 percent moisture in airtight storage. In other cases, when untreated seed was held in aerated storage at about 8 percent moisture content, the majority of the filled seeds became germinable in six months.

Washing and Soaking

Guayule seeds also become germinable after treatment with sodium or calcium hypochlorite which renders the seedcoat permeable to oxygen (presumably by oxidation of resins). The seed may, but does not necessarily, use the oxygen released by the breakdown of the hypochlorite.

The benefits of washing or soaking dormant seed for eight hours or longer prior to the hypochlorite treatment was reported by Benedict and Taylor (345). They found that the combination was more beneficial to germination than using either process singly or using the two in reverse order. The number of changes of water or quantity of water employed was immaterial. Apparently, soaking rendered the seed more responsive to the sodium hypochlorite.

The hypochlorite treatment also disinfects the seed, but this is a supplementary action unassociated with the purpose of relieving seedcoat impermeability.

Sodium hypochlorite (Clorox) is preferable to calcium hypochlorite. It is usually more easily available, mixes more readily with water, can be handled in large volumes of solution by pumps and is less injurious to workers, but it has the disadvantage of being less stable in storage. There is little, if any, difference in the effectiveness of the two hypochlorites. Other oxidants, such as hydrogen peroxide, perchloride and nitric acid have been used experimentally with success, but they lack the economic or other advantages of sodium hypochlorite. The following discussion is based on its use.

The standard procedure for treating unthreshed seed is to wash it in water for 12 hours to 20 hours, using 2-1/2 gallons of water per pound of seed. It should be stirred occasionally to assure uniform soaking of the seed, and the water should be changed two or three times. The water is then drained off and replaced with 2-1/2 gallons of sodium hypochlorite solution per pound of seed for two hours, during which the mixture is stirred briefly at 10-minute intervals. The solution is then drained off and the seed rinsed by flushing with a liberal quantity of water. Surplus water is removed by centrifuging or pressure and the seed is then dried.
The minimum period of washing for best results is eight hours. Periods as short as four hours are less effective, and longer periods up to 24 hours, respectively, causes progressive deterioration in the lots not also treated with hypochlorite; germination of the lot washed for 24 hours is significantly lower than the unwashed controls.

The magnitude of increase in germination brought about by washing and hypochlorite treatment varies inversely with the degree of dormancy present in the seed. In severely dormant seed, washing alone gives a slight increase in percentage of germination, but when washing is combined with hypochlorite treatment, a much higher percentage will germinate satisfactorily. In seed having only slight dormancy, particularly threshed seed, washing or soaking alone sometimes gives germination closely approaching that of the combined treatments.

Safety Measures

Persons working with and around the hypochlorite solution should wear rubber gloves, suits, and boots, as the solution is irritating to the skin and will eat holes in cloth or leather. The fumes are disagreeable and may be injurious in high concentrations. Good ventilation should be provided in the treating room, and the preparation of large amounts of solution should be done outdoors. Calcium hypochlorite is more dangerous than sodium hypochlorite because the fine dust drifts in the air and affects mucous membranes (346, 392).

The best strength of hypochlorite solution may vary with different seedlots and different periods of seed storage. Correct dosage is determined by trials of different strengths from 0.25 percent to 2 percent on small samples carried through germination tests. A solution containing 1.5 percent available chlorine is most frequently used for unthreshed seed less than a year old. Threshed seed requires a much weaker solution, usually 0.25 percent to 0.50 percent.

The quantity of hypochlorite solution also affects the treatment. The usual ratio is 1-to-20 by weight, or one pound of seed to 2.5 gallons of solution. With this ratio, 90 percent to 95 percent of the available chlorine is consumed within two hours. (This period has been adopted as standard.) Nearly all the chlorine in the solution is used during each treatment, so the solution cannot be reused.

Solutions of sodium hypochlorite deteriorate after use and sodium chloride and sodium chlorate are formed. The chloride is not particularly harmful to the seed. But some residue, possibly the chlorate, is so toxic that a minute quantity carried over in the seed after rinsing is sufficient to inhibit growth of the seedlings. Surprisingly, it does not hamper germination, but the seedlings become chlorotic a few days after emerging and soon die.

Metal parts of machinery in contact with sodium or calcium hypochlorite should be protected with asphalt. The chemicals are highly corrosive to iron or brass.
The duration of the treatment was found to be immaterial, providing changes in duration are compensated for by changes in the strength of the solution used. This compensation cannot be computed on a direct ratio because the strength of the solution changes throughout the period of treatment. The practical and economical course is to continue the treatment long enough for nearly all of the available chlorine to be consumed, and to start with the minimum concentration of solution adequate to relieve seed dormancy. A delay of up to 40 hours in drying the seed after treatment may be beneficial to seed germination (343. 392).

Treatment for Small Plantings

Seeds can be cleaned by gently rubbing between two sheets of sandpaper, and the seeds can be separated from the chaff by gravity. Dormancy can be reduced by treatment with sodium hypochlorite (Clorox) prior to planting. Best results will be obtained by soaking the seed for 12 hours in water with a weight ratio of 1-to-20, changing the water at least once. This should be followed by soaking, in a solution of one part Clorox to five parts water for two hours to four hours and planting in a loam soil with a covering of 1/8 inch to 1/4 inch of fine sand or soil. The seedbed should be kept moist until germination occurs, usually within two days to five days. The growing plants can tolerate some dryness but must be kept free of weed competition. Temperatures for germination and growth should be above 50 F and below 95 F (10 C and 35 C).

It is sometimes necessary to sow under conditions that require quick emergence. Quicker emergence and better stands result from soaking the seed before it is sown. This is accomplished by moistening at 70 F for 48 hours to 96 hours. The moist seed should be spread out to a depth of not more than 5 inches, preferably in trays, and aerated by stirring several times daily. Damp seed is somewhat harder for the seeders to manage, but this is not a serious consideration.

PRE-GERMINATION

When seed is kept moist and warm for a few days to get the germination process under way before sowing outdoors, emergence is as good or better than if actual sprouting has started; the seed can even be dried without losing the effects of pre-germination. Pre-germination gives an additional few days' margin to allow for unexpected delays in sowing schedules.

If the seed is saturated at the start of pre-germination, and then spread out to a depth of 3 inches to 4 inches and stirred twice daily, natural drying is sufficient to permit mechanical sowing. If total water used is less than 70 percent of the dry weight of the (unthreshed) seed, pre-germination is less effective. Stirring at least daily is necessary for proper aeration.
The disinfecting action of the hypochlorite treatment effectively controls molds so heating of pre-germinated or pre-sprouted seed does not occur, even when the seed is held for days in deep containers.

In greenhouse tests, a greater percentage of emergence was obtained from seed sown without pre-germination than from the pre-germinated lots. Outdoor sowings made at Salinas, however, showed markedly better germination and emergence from pre-germinated seed. In outdoor sowings made at other locations, some showed superiority of pre-germinated seed and others did not.

A comparison of other conditions showed that minimum daily temperature was the critical factor. Regardless of daytime temperatures, pre-germinated seed gave better stands of seedlings whenever minimum temperatures averaged below 60 F. (Reduced germination begins at about 68 F and becomes serious as night temperatures fall below 50 F regardless of warmer temperatures during the day.)

In the Indio sowings made in September, when the mean temperature was 80 F and the minimum 62 F, total emergence was higher from dry seed, though slightly slower. In early October, however, when the mean temperature was 76 F to 77 F and the minimum 60 F, the percent of emergence from pre-sprouted seed was greater and faster. In late October, when the mean was 70 F and the minimum 52 F, the difference in favor of pre-sprouted seed was still greater for both speed and total emergence. The ratio of survival to emergence was somewhat higher from dry sown seed than from pre-sprouted seed.

Various nursery sowings at Salinas showed that, when night temperatures fell below 50 F, germination of pre-sprouted seed was severely reduced. Threshed seed germinated more promptly after sowing than did unthreshed seed, and apparently was less influenced by unfavorably low temperatures. This difference was often sufficient to offset the effects of pre-germinating unthreshed seed (289, 343, 392).

FILLED PERCENTAGE DETERMINATIONS

Not knowing the filled percentage often results in poor estimates of the potential value of seed. The percentage of guayule seeds containing an embryo is quite variable and usually low compared to other kinds of seed. The filled percentage commonly ranges between 10 and 45, though instances as low as zero percent and as high as 70 percent have been noted (343, 392).

Cutting Method of Determining Filled Percentage

A strip of cellophane tape is mounted sticky side up, on a smooth, firm surface. The seeds are laid out on the tape and can be dissected with a scalpel and needle without the seed jumping when touched. Soaking the seeds makes them easier to dissect but more difficult to count. A magnifying eye loupe can be used for examination of the dissected seeds.
Ace tone Method for Determining Filled Percentage

A known number of clean, threshed seeds are put into a small beaker, and acetone is poured in. The specific gravity (.79 to .81) and very low surface tension of the acetone permit the filled seeds to sink and empty ones to float. The floating material is then skimmed off and discarded.

The "sinkers" are dumped onto a piece of 30-mesh screen. In about one minute the seeds are dry enough to count. The number of seeds so obtained are counted and divided by the original number of seeds in the sample for the filled percentage. It is good practice to inspect the seeds after counting with a magnifying glass, as it is sometimes difficult to distinguish foreign particles from seed with the unaided eye.

Acetone sinkers tend to be 100 percent plump filled seed and include practically all the filled seeds of most seedlots. Acetone floaters consist of empty seeds, a few that have rancid embryos, and some partly filled seeds of limited value for sowing. Acetone immersion is not detrimental to germination.

GERMINATION TESTS

In making germination tests of the seed, greenhouse sowings in flats are considered better than blotter germination. Sowings eliminate errors of interpretation involving seeds that had enough germinative energy to produce a root but not enough to emerge as a normal seedling.

STEM CUTTINGS

Vegetative reproduction by stem cuttings, though possible, is impractical because of cost and technical difficulties. Treatment with indole-butyric acid, a root-stimulating hormone, was found to be beneficial. The cuttings were started in water and then set out. They grew better than nursery transplants, and their establishment was more rapid.

The difficulties encountered in preparing and rooting cuttings result in costs many times higher for a planting unit, and the labor involved in hand planting is many times that of machine-planted seedlings. No exact data are available because no extensive field planting was ever attempted.
CHAPTER 3

NURSERIES

NURSERY OPERATIONS

Two methods of establishing field plantings were used by the ERP. The one most widely used involved transplanting shrubs from nurseries at an age of four months to 12 months or occasionally older. The other method, used only on an experimental scale, involved direct seeding in the fields. The direct seeding experiments showed that guayule could be grown successfully by this method. However, the amount of labor and cost to prepare a very level seedbed and the frequent irrigations necessary to establish seedlings appeared to make the nursery seedbed method more practical.

Growing the young shrub in nurseries presents many problems similar to those involved in field culture, although the nursery stands are more dense. The best nursery production is achieved on deep, well-drained, fine sandy loam soils.

Research and experience have contributed materially to the knowledge of growing guayule with overhead irrigation systems. Experiments indicate that it may also be feasible, under limited conditions, to produce seedlings using furrow irrigation methods. However, since this system has not been used for large-scale production, it is not discussed here.

Nursery methods used in the production of guayule seedlings are not greatly different from general nursery techniques employed in growing many species of forest tree seedlings. The seed is sown by mechanical drills in 4-foot beds that are irrigated by an overhead irrigation system. The plants are weeded, watered, cultivated and otherwise
cared for over a period of four months to eight months and then lifted, culled, packed and distributed for field planting. Under optimum conditions seedlings normally attained planting size at approximately four months of age.

While basic principles of plant propagation from seed apply to growing guayule, certain modifications of forest nursery practices are necessary because of the peculiarities of the plant and the requirements of the machines used for transplanting.

The general plan for producing guayule seedlings as developed by the Intercontinental Rubber Company was adopted by the ERP—though it was modified in details from time to time as local conditions or later experience dictated. It consisted of selecting land with good soil and a level or gently sloping terrain and installing underground water mains feeding overhead sprinkler pipes spaced at about 50-foot intervals. The posts supporting the sprinkler pipes also supported lath fencing, which served as windbreaks at 50-foot intervals.

The direct cost of production of seedlings in 1943 was about $2.50 per thousand plants. This included the cost of labor, nursery operations connected with the production and packing of seedlings. It also included the cost of seed and the cost of packing crates and materials. The cost of plants could undoubtedly have been reduced considerably in nurseries operated under a stabilized program and more normal conditions.

NURSERY SITE SELECTION

Economical production of planting stock of good quality depends a great deal on the selection of a nursery site.

Climate

Climates suitable to growing guayule in the field are also favorable for growing good nursery stock. Qualifying limitations are as follows: 1) A seasonal succession of temperatures must permit sowing at a time when minimum daily temperatures are high enough for good germination, and maximum daily temperatures are not high enough to severely injure newly emerged seedlings; 2) The sowing season must be followed by several months of prevailing temperatures favorable to growth and then by a season sufficiently low in precipitation to induce a state of relative dormancy; 3) The season when plants in the nursery can be held dormant should correspond to the season when transplanting to the field can be done with good prospects for success; 4) Nurseries should be located in areas that are not subject to severe storms, especially hail. An abundance of sunshine without excessive heat is desirable.

Topography and Location

Requirements of land best suited to growing guayule seedlings will
limit selection to the better farm lands. A reasonably level site should be selected for the nursery, as removal of soil from high spots during leveling operations exposes sterile subsoil that is usually unproductive for periods of two or three years. The gradient of the nursery site should be not less than 0.25 percent or more than 2 percent. If necessary, however, land with a slope from 4 percent to 6 percent can be used with proper leveling and contouring. Preferably, the site should slope in one direction.

A rough site is generally undesirable, because it contributes to the formation of water puddles and runoff and is otherwise difficult to handle. Slightly undulating land that can be leveled at reasonable expense without excessive removal of the surface soils is not objectionable. Surface irregularities in light soils with an infiltration rate sufficiently high to prevent runoff or ponding of water are not particularly objectionable. The area should have good, though not excessive, surface drainage. The nursery site should be above flood levels and, if possible, be protected from high winds.

The accessibility of highways and railroads for the transportation of equipment and supplies and the movement of planting stock is important.

Soil

Physical characteristics of the soil are more important than chemical ones, since fertility can be improved by the application of fertilizers.

Surface Soil. Guayule seedlings require a loose, friable soil that will permit tillage over a wide range of soil-moisture conditions without damage to the young plants and without producing undesirable physical conditions such as puddling or clods. These conditions are usually found in soils such as loamy sands, loamy fine sands, sandy loams, and very fine sandy loams. The ideal guayule nursery soil is a fine sandy loam. The loam and silt loam soil types may, in some cases, be satisfactory, but their workability range is narrower, and damage to seedling roots from weed pulling and tillage will be greater. The natural fertility of sandy soils is often less than that of heavier soils, but the intensive use to which a nursery is put makes the addition of commercial fertilizers a comparatively minor expense item. A good depth of soil is important: it should be 18 inches or more. This permits the preparation of a deep seedbed and usually indicates the absence of claypans and hardpans in the subsoils.

Areas with eroded surface soils should be avoided since, in such cases, the most fertile and workable portion of the soils has disappeared. The soil should be neutral or only slightly alkaline.

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Subsoil. A subsoil that is readily permeable is as desirable in a nursery as a sandy surface soil. Dense layers, such as claypans and hardpans, prevent downward percolation of water. Guayule seedlings require an abundance of moisture, but good soil aeration is necessary because they are easily drowned. Hence a loamy sand or a sandy loam subsoil is desirable.

Areas should be avoided where the water table is within 6 feet of the surface. The presence of alkali usually indicates poor or restricted drainage and, in many cases, a high water table. Such areas should be avoided. It is best to avoid or to examine carefully regions where hardpans or claypans are known to be present in some of the soils.

Water Supply

Quantity. Water requirements should be computed on a basis of 20 gallons per minute per net acre of nursery beds. Although a gravity water supply is generally the most satisfactory, water may be pumped into the lines by booster pumps from tanks that are supplied from wells. Settling tanks are necessary between the well and booster pump tank if the well contains sand or silt.

Quality. Water should be tested for harmful chemical or mineral elements. The tolerance of guayule seedlings to alkali has not been determined, but it is safe to assume that water considered satisfactory for irrigation of farm crops is safe for guayule. On this basis, water containing less than 700 parts per million of dissolved solids is quite satisfactory—provided the combined total of sulphates, chlorides and carbonates of potash and sodium do not constitute over one-third of the total. It should be neutral or only slightly alkaline in reaction (343, 392).

SEEDBEDS

Each 50-foot space between irrigation pipelines for the ERP operation was divided into either nine or 10 beds, 4 feet in width, separated by 10-inch or 12-inch paths traversing the length of the beds to provide space for the wheels of cultivating equipment. Crossroads at right angles to the pipelines were spaced to allow beds 400 feet in length. In many operations such as sowing and cultivating, however, the tractors were driven the length of two or more beds before turning on the crossroad.

Nurserymen have long argued the relative merits of broadcast vs. drill sowing, but experience in guayule nurseries proved the desirability of the band-sowing arrangement used by the Intercontinental Rubber Company. Within the 2-inch bands, guayule seedlings compete with each other and thus develop a compact form that is desirable for planting. The nursery bed cultivator developed by the ERP made it possible to cultivate the seedbeds economically during the early life of the seedlings, thus reducing considerably the tilth of the soil (343, 392).
SPRINKLING SYSTEM

The problem of leveling the overhead sprinkling lines was met by the use of 2-inch by 6-inch or 2-inch by 4-inch strips nailed to the 4-inch by 6-inch posts. This system saved considerable material and obviated the need of setting heavy posts to grade. The result was the speeding up of work and a considerable reduction in costs and labor requirements. (See Figure 7.)

Sprinkler lines were rotated in an arc so that spray continually moved and covered the entire space between lines. They were operated in unison by gang-type oscillators that operated connecting cables.

USE OF DUCKBOARDS

On heavy soils where trouble was anticipated from extended periods of wet soil, Intercontinental used duckboards. They were laid end-to-end between nursery beds to form a continuous ribbon of footing for machinery and men to prevent their sinking into the ground while seeding, weeding, cultivating, top pruning and fertilizing. Each duckboard was 1 inch by 8 inches wide and from 8 feet to 22 feet in length. Cleats on the ground side were spaced 2 feet to 4 feet apart and a spline on either end held it in line with other boards. Cleats are necessary to prevent the duckboards from slipping when machinery passes over them. The ERP did not use duckboards because they were unnecessary on the lighter textured soils selected for nursery purposes.

WINDBREAKS

Windbreaks help control wind erosion and wind damage to seedlings and facilitate a more even distribution of water from overhead irrigation. They may be of two types—snowfence or planted trees and shrubs. Greater height can be attained with planted windbreaks, but snowfence can be installed at once and, except for limited shading, does not compete with nursery seedlings. A combination of both types may be desirable on some sites.

The use of trees or shrubs is advocated in nurseries where snowfence windbreaks are likely to be inadequate. Height, density and fast growth are all important. Planted windbreaks should generally be limited to one row and be located so that sapping and shading of seed-bed areas is held to a minimum. Fast-growing species adapted to local conditions should be selected.

PROTECTION FROM WEEDS, PESTS AND DISEASE

Noxious Weeds

Pernicious perennial weeds are the most serious. Morning glory (field bindweed), Johnson grass and bermuda grass proved to be troublesome.
These usually require special control methods and systematic operations that are feasible only on small patches. Annual weeds are troublesome, but diligent weed control to prevent the development of seed will generally improve the situation within two or three years (344).

Pests

A number of pests may jeopardize nursery production of guayule seedlings. The most practical method of control depends on the degree of infestation and the extent of the area.

Pocket Gophers. Pocket gophers may do considerable damage in nursery beds by burrowing and disturbing the soil, thus killing seedlings.

Clean cultivation of nursery boundaries will keep pocket gophers back to the fence line or grassy areas, but those already present within the nursery must be removed. In small areas with normal infestation, trapping is recommended. Several makes of special traps commonly on the market are satisfactory.

Ground Squirrels. Ground squirrels can also be trapped, or strychnine-treated barley can be scattered around the burrows in tablespoon quantities to control them. If the grain is not being readily accepted and squirrels are still present, either carbon tetrachloride or methyl bromide can be placed in the burrows. The burrows should be covered with moist soil if treated with these gases. This method will not be particularly effective unless the soil is fairly moist.

Birds. Small birds may feed on the seed after sowing and until time of emergence. At Oceanside the small birds were identified as linnets, which are recognized as agricultural pests and are legally subject to control. In Indio two birds killed while feeding on nursery beds were found to have eaten 50 and 200 guayule seeds. Frightening the birds by shooting or other methods appears to be the most effective means of control.

Insects. The location of the nursery in areas known to be infested with harmful insects may mean extensive control operations or possibly the complete loss of a crop of seedlings. So far, only a few insects have been observed to be a serious threat (see Chapter 7). Where present, colonies of the harvester ant were found to carry away large quantities of seed from the seedbeds. These are easily controlled by insecticides.

Diseases. Diseases are of particular concern because in addition to the problem of local control, there is danger of spreading infection to other areas in shipments of planting stock. Exhaustive surveys should be made prior to selection of a site to determine the prevalence of diseases, and infested soils should be avoided.

Guayule nursery seedlings are not generally more susceptible to disease than seedlings of other species grown under similar conditions.
But some diseases widely prevalent in soils may cause locally severe losses where the rate of infection is high and cultural practices create soil conditions favorable to the rapid growth of the disease organisms.

The germination behavior of guayule seed, requiring moist surface soil for one to two weeks after sowing, imposes moisture requirements that are also favorable to the growth of disease. But if nurseries are located on soils having good drainage; if good tillage practices are used; and if, as soon as germination and emergence is well along, irrigation is reduced to that necessary for continued growth, disease should not be a serious menace.

Most of the common nursery diseases are caused by fungi that attack the plants either above or below ground. Wilting or an abnormal appearance, such as yellowing of the foliage, is usually the first symptom of disease. Examination of a wilted plant generally reveals rotted areas on the root or mold on the stem or leaves (53, see also Chapter 7).

SOWING

All sowing should be done with utmost care. Any saving made by speeding or by ill-advised streamlining on the job may be wiped out many times over if the resulting stands are patchy or poor. The objective is uniform stands of optimum density with no need to resow or thin.

Although a desert plant, guayule shows marked response to a plentiful moisture supply as long as good drainage and aeration of the soil are maintained. It also responds to warmth and is tolerant of high temperatures. It grows well at rather low levels of soil fertility, and its growth is influenced only slightly, if at all, by the relative length of night and day. These general growth characteristics are true of nursery seedlings as well as plants in field plantations. The principal difference in environment is the high density of stands in the nursery and the competition for light and moisture. Therefore, for practical purposes, stand density may be considered the main limiting factor in nursery production.

Season

The choice of season for sowing guayule in nurseries is governed by several factors—the most critical of which is temperature, particularly at night. Speed of germination and total emergence decline progressively when night air temperatures are lower than 60°F, regardless of higher temperatures prevailing throughout the day. Night temperatures lower than 50°F inhibit germination and cause very poor to totally failed stands. The inhibiting effects of low temperature can be offset to some degree by pre-germinating the seed at favorable temperatures prior to sowing. This method was used extensively by the ERP.

A guayule sowing season must be followed by a growing season of sufficient duration and proper temperature to permit growth of the
seedlings to usable size. The maximum daily temperature was considered to be about 95°F, though good stands were sometimes obtained when temperatures reached 100°F or higher for a limited period each day.

In places where guayule has been propagated on a large scale, the sowing seasons were found to be as follows:

Salinas, California  --May 1 to September 1; optimum May 15 to July 15

Carlsbad, California  --February to December

San Clemente, California  --March through October.

Time of sowing must be correlated with planting requirements, which in some nurseries will mean almost continuous sowing except during the winter months, when temperatures are not favorable for germination. It is desirable to schedule sowing over the longest feasible period so as to distribute the subsequent weeding job over a similarly long period, thus stabilizing the number of workers required for sowing and weeding.

Guayule seed requires a certain number of heat units for good germination. Germination is very prompt and the germination curves are nearly perfect when moisture and temperature conditions become optimum.

Exposure to temperatures of 10°F to 15°F is dangerous for guayule seedlings, and damage can be expected from prolonged temperatures of around 20°F. If the foliage is wet the damage will be greater; excessive moisture in the soil will also increase the damage, and a combination of the two is particularly harmful.

Sowing Density

Optimum sowing density may vary slightly between nurseries and localities due to soil and climatic differences. In general, enough seed should be sown per unit of area to produce 20 plants of usable size per square foot of seedbed, or an average of 32,000 usable seedlings per 400-foot by 4-foot bed. Allowing for culls, this will normally mean 25 to 30 seedlings per square foot of bed surface at the time of digging and lifting. Allowances should be made for losses during the growing season. The indicated density should be uniform throughout the seedbed. Before a sowing rate can be established, the number of seeds per pound of seed material and the utilization value must be known.

Seed Covering

Soil Type. The material used to cover the seed will vary with the type of soil in the nursery. Sand should be used in nurseries with heavier soils. In nurseries with light soils that do not crust or bake, a covering of native soil may be used. Material containing any amount of very coarse particles should be avoided; aside from the tendency to interfere with the spreading operation, it is likely to hinder emergence. Silt or clay in the covering material tends to form an undesirable crust. Sands containing salts also should be avoided.
Depth of Cover. The depth of seed covering differs with the coarseness of the material used, varying from 1/10 inch for fine sands, to 3/16 inch for coarser sand.

Guayule seed has so little emergence energy that it is very sensitive to depth of cover. Sleeth (321) found that, under greenhouse conditions where drying was not a limiting factor, reducing the depth of cover from 1/5 inch to 1/10 inch doubled the number of seedlings emerging, and that increasing the depth of cover up to 1/2 inch caused progressive reductions in stands.

Direct seeding trials in the field, involving depths of 1/4 inch to 3/4 inch, produced significantly better stands from the shallowest sowings (354). Under nursery conditions where overhead sprinkling permitted reasonable control of drying surface soil the sand cover, normally 1/8 inch to 1/10 inch, could be reduced to one-quarter or three-quarters of that amount without serious reduction of seedling stands. In both the greenhouse and nursery trials, the absence of any cover reduced germination.

The use of pure sand for covering the seed was found to give better emergence than when soil cover was used. At Indio, fine sandy soil in comparison with pure sand gave inconclusive results. At Salinas, stands where soil cover was used were only one-half to three-quarters as good as those with sand cover, and local creek sand containing some silt reduced seedling emergency by more than one-third.

Irrigation Prior to Sowing

Irrigating several days before sowing will germinate weed seeds. These will be destroyed during final ground preparation.

Machine Operations

After the ground was plowed and prepared for sowing, specially built mechanical seeders sowed the seed in seven narrow bands equally spaced and running lengthwise in the beds. The machines also covered the seed with a very thin layer of fine, clean sand. (See Figure 8.)

Belt-type seeding machines can be used for either moistened or dry seed (see Figure 9). A reasonably uniform distribution of seed in the rows will result when the belt operates at proper speed. With moistened seed, the belt must travel at a higher speed in order to prevent "chunking" of the seed as it falls over the end of the belt. This leads to alternate thick and thin spots in the seeding band.

The belt-type seeder should be adjusted to sow accurately the desired amount of seed per unit of area during the first few beds sown. The depth of sand cover may be adjusted at the same time. Minor adjustments should be made at the beginning of a bed and not while the machine is in motion.
FIGURE 8. GUAYULE SEEDS BEING SEEDED TO NURSERY BEDS (Fine sand was used to cover the rows of planted seeds to retain moisture and still curtail damping off)
FIGURE 9. SEEDER FOR GUAYULE NURSERY BEDS (The hopper in the background carries the sand to cover seeds)
Seed materials should be delivered to the sowing job in measured amounts to cover a predetermined area—such as two or four beds—so an accurate check can be maintained on the sowing rate. Dry seed for use without bulk material can be measured by weight; where bulk material is used, measurement will be by volume after a given weight of seed per unit of volume has been added to the material.

The shallow sand cover should be of uniform depth, completely covering the seed row. Depression furrows made by the seeder roller should be of uniform depth and width, and the seed should be well distributed and not scattered outside the row. The furrow made by the roller should be a distinct depression, at least 1/4 inch deep. If the seedbed is too firm or not adequately leveled, the depression made by the roller may be too shallow, and the seed, although covered by the sand, will be easily exposed to washing and uncovering by wind, rain or watering. Also, the surface on which the seed falls should be soft. A hard surface causes the seed to bounce and work out from under the sand cover.

**Irrigating Newly Sown Beds**

If dry seed is sown, irrigation can be delayed until a block or other convenient unit has been sown. Newly sown beds should not be left overnight or exposed to the danger of wind erosion—even moderate wind—without having been moistened.

When moistened seed is sown, beds should be watered as soon as possible. Irrigation through the germination period should be frequent, but only enough water is applied to moisten the beds. The frequency and amount of irrigation are influenced by the kind of soil and the type of sand cover (344).

**CARE DURING GERMINATION AND EMERGENCE**

**Irrigation**

During germination and emergency, guayule seed needs a liberal moisture supply. This is difficult to maintain at the shallow soil level where seed is sown without creating other difficulties—such as puddling and crusting of the soil, or providing conditions favorable to the growth of disease organisms. However, guayule is somewhat tolerant to drying after the processes of germination are well under way and before actual sprouting has occurred.

Nurserymen should strive to keep the surface of the sown beds continuously moist, but not waterlogged, during the germination period. (This means *moist*, and not *wet.*) Too much water will tend to lower soil temperatures, retard germination and encourage damping off. Unnecessary watering may wash away sand cover and expose the seed.
Frequency and Duration

Frequency and duration of watering are generally much more flexible on lighter soils. On clear days with moderate winds, four irrigations of five to 10 minutes' duration, depending on soil and seed cover, will suffice to keep the seed band in a moist condition. Toward the close of the emergence period, watering can be increased in duration and reduced in frequency.

During the fall, when the rate of evaporation is lower, early morning and late evening watering are most desirable so that full advantage can be taken of the daytime warmth. If watering occurs during the day, soil temperatures are lowered, causing slower germination. On windy days, however, more damage can result from wind erosion and baking than is offset by warming of the soil.

Gallons per minute delivered through one 400-foot overhead line depends on the spacing of the nozzles and the water pressure. The standard 3-foot spacing of nozzles delivers 30 gallons per minute at operating pressures of 25 pounds to 30 pounds. Two-foot spacing delivers 40 gallons per minute. With nozzles spaced 2 feet apart and with ordinary pressure, the average amount of water applied per hour is approximately 1/4 inch, but because of evaporation, only about 1/5 inch reaches the ground.

Irrigation methods also affect the health of the seedlings. Flooding led to serious seedling loss from disease. Overhead sprinkling with fine sprays was satisfactory.

Sand Splash Injury

Coarse spray overhead sprinkling caused losses from "sand splash." Injury occurred on a serious scale at a nursery near Bakersfield, California, in the spring of 1943, and it was observed also at the Deer Valley nursery near Phoenix, Arizona, and at Salinas, California. The seedlings were affected while in the cotyledon stage. External symptoms were principally a brown discoloration and withering at the tips and edges of the cotyledons. In several cases an entire cotyledon and the hypocotyl were affected (2).

At first disease was suspected, but no responsible pathogens could be found. Later, the injury was associated with the size of spray drops falling from the sprinkler nozzles. At locations where water pressure was high enough to break the stream into a fine spray, there was no injury; but, as pressure decreased throughout the length of the pipelines, injury appeared with increasing severity. The larger drops apparently splashed sandy soil onto the cotyledons, where it adhered and exercised injurious effect.

The most effective immediate remedy was to withhold further sprinkling until the plants put out permanent leaves, although this procedure sacrificed some newly emerged seedlings. The indicated
permanent remedy was to revise the irrigation system to provide higher water pressure and hence smaller drops.

**Cultivation**

During the germination period, cultivation of the soil is likely to increase losses from "soil splash", and will not aid germination. Cultivation should not be considered until germination is complete and the plants are well established. If abnormal weed conditions make cultivation necessary, the utmost care should be taken to avoid disturbing the seed bands (321, 322, 323, 343, 392).

**CULTURE DURING GROWING SEASON**

**Fertilizing**

Guayule is a low user of the major nutrients. Even at the high densities under which nursery seedlings are grown, the demand on the soil does not appear to be greater and may be even less than for field crops. In the Chualar loam of the Alisal nursery, additions of phosphorus and potash did not give significant increases in growth, and additions of nitrogen gave only nominal increases in height, growth and dry weights— with little increase in stem diameters.

In Hanford loamy coarse sand soil, only nitrogen, alone or in combination with potash or phosphorus, produced increases in plant size—with increases in stem diameter much less than for overall plant size. Kelley and Hunter (164) recommended the addition of 40 pounds to 50 pounds of nitrogen per acre per year for Chualar loam and 80 pounds to 100 pounds for Hanford loamy coarse sand.

On new nursery sites the need for fertilizer can be determined by noting the character of the existing vegetation or the previous year's crop, having the soil analyzed by a soil chemist or obtaining the past history of the land. In established nurseries, observation should determine whether or not the plants are healthy and well developed. In general, poor growth on cultivated land, where moisture and drainage is adequate, indicates the need for fertilizers.

Although there is some variation in soils, growth of seedlings should be stimulated by a moderate application of nitrogen combined with a much heavier proportion of phosphorus. There appears to be no need to add potash. The desired nitrogen-phosphorus combination might be obtained by combining either sulphate of ammonia or nitrate of soda with treble superphosphate.

An excess of nitrogen is considered undesirable, as it probably increases plant succulence, thus predisposing the plants to disease and retarding hardening off and induced dormancy.

**Time of Application.** In soils that are low in fertility it is best to apply fertilizer before sowing. This allows even distribution
and gives the plant a vigorous start. In other soils, particularly those with average fertility, it is better to delay application until plants are a few weeks or a month old.

Later applications should be made as soon as the need can be determined. If fertilizer is applied too late in the season, plants either may not be able to take full advantage of it, or a succulent condition may be induced at a time when the seedlings should be hardened off.

Cultivation

The major objects of cultivation are to remove competition from weed growth, maintain the soil in good tilth and provide better absorption of irrigation water, especially on heavier soils. (See Figure 10.) The first cultivation or two should be shallow, approximately 1/2 inch deep, to prevent injury to small seedlings. After seedlings have grown to a height of 1-1/2 inches, deeper cultivation of 2 inches to 3 inches is desirable. Still later in the season, chiseling to a depth of 4 inches to 6 inches may increase water absorption.

Top Pruning

The purpose of early pruning—which because of growth rate will probably be limited to spring and early summer sowings—is to open the canopy and permit the surface soil to dry, thus reducing the possibility of disease and stimulating growth in the diameter of the plant. When seedlings develop full tops there is little or no air circulation under the top canopy. A poorly ventilated bed surface encourages development of crown rot, Sclerotinia and other diseases. Topping allows the air and the sun to reach the soil. Seedlings will ordinarily have reached the proper size (closed canopy) for pruning 8 weeks to 10 weeks after sowing. The mower blade should be set to cut the plants about 6 inches above the ground.

Weed Control

Conservation of manpower, economy of operation and speed justify the use of a proven herbicide to eliminate weed competition. During the ERP modern herbicides were not available—experiments with these are now being conducted. In the meantime, the following information on oil sprays may be of some value.

Strength of Solution. Original results indicated that more concentrated solutions of oil produced greater weed control but also caused greater damage to guayule seedlings than the weaker solutions. It was assumed that the concentration of the solution was the determining factor. Experiments showed conclusively, however, that weed kill is not determined by the strength of the solution, but rather by the amount of oil applied per given area—other factors being equal. Straight oil, when applied at correct rates, gave results comparable to oil and water mixtures. The only reason for diluting the oil with water, therefore, is to control more accurately the amount of oil applied per bed.
Rate of Application. Spray should be applied at a constant pressure of 300 pounds. Pressure up to 400 pounds may be employed if the pump is capable, but 300 pounds is adequate. Pressure lower than 300 pounds should not be used, since it produces larger droplets and provides less effective cover.

At a ratio of three parts water to one part oil, approximately 7 gallons of solution was needed per bed. The spray was applied to three 400-foot beds over a period of about three minutes.

When to Spray. As in all operations aimed at weed control, the timeliness of application is important. Weeds are most vulnerable to oil spray while in the cotyledon stage. Although the same is true for guayule seedlings, they are more resistant to injury than the majority of weed species. Depending on conditions for germination, the first spraying should be applied while the weeds are still in the cotyledon stage.

There is a definite relationship between the action of oil spray and soil and atmospheric conditions. Guayule seedlings in wet soil are more susceptible to spray damage than those in dry soil. Greater damage results when water is applied too soon after spraying. During windy weather the spray drifts away and coverage is not adequate. As temperature rises the action of the oil increases. To compensate for these conditions, the following practices should be followed:

1) Avoid spraying when the ground surface is wet or when soil is saturated.
2) Delay irrigation until at least eight hours after spraying.
3) Do not spray when the wind is severe enough to interfere with coverage.
4) Decrease the application rate of oil to compensate for excessive temperature increases.

This last practice requires particular attention. During periods when temperature reaches 100°F and above, it is necessary to use 5-to-1 and even 6-to-1 solutions to avoid oil damage.

Successive applications of oil may be necessary. There is apparently no harmful cumulative effect from a moderate number of repeated sprayings on guayule, and seedlings past the cotyledon stage can be treated several times without permanent injury.

In experiments, seedbeds were prepared several weeks in advance of sowing and weed seeds allowed to germinate. Sowing then occurred without any further ground preparation or disturbance of the weeds that had germinated. The beds were then sprayed soon after sowing to destroy the weeds. This method allowed the guayule to germinate and reach a more resistant size before additional weed control was required.
Hand Weeding. Guayule seedlings are intolerant of shade, so it is particularly important to eliminate or reduce weed competition as soon as is practical during the first six weeks to eight weeks while the seedlings are becoming established. The growth of seedlings that have been suppressed by weeds for even a few days is seriously retarded (1, 21, 27, 292, 343, 392).

Irrigation

Frequency and Amount. After the plant has developed a substantial root system, frequency of irrigation can be decreased and the amount of water applied at each irrigation increased. Transpiration increases as the seedlings grow, and more water must then be applied to keep the seedlings vigorous.

Weather conditions must be considered; there is much more evaporation on warm, windy days and more in daytime than at night. When seedlings are small, however, daytime irrigation allows for easy checking of water distribution. When the seedlings grow larger, more water can be applied at one time, and night irrigation is preferable because of: 1) less evaporation; 2) less risk of sun scalding on hot days; and 3) lower wind velocities, so that water is applied more evenly to all beds and much watering with hoses is eliminated. (If water is applied while the wind is blowing, spotting or hose watering is necessary to completely cover the seedbeds.)

Sandy soils must be watered more frequently than the heavier soils, especially when seedlings are small.

Danger of Overwatering. Water applied must not remain on the surface of seedbeds. Percolation is slow on heavy soils, and the danger of overwatering is greater than on lighter or more porous soils. When puddling occurs, the danger of seedling diseases increases. Diseases are particularly likely to occur on areas underlain by hardpan or where subsoil drainage is poor. Irrigation on such areas must be carefully controlled. Spot watering may be a necessary supplement to the overhead system to reduce the danger of overwatering seedbeds that do not need irrigation at that time.

Overwatering will also cause seedlings to become succulent and top-heavy. After the seedlings are established, irrigation should be less frequent but with heavier applications.

Hardening Off

Hardening or conditioning nursery stock before transplanting is highly important. Slowly bringing the young plants into dormancy, by gradually decreasing the water supply, toughens them to withstand the shocks of topping, root pruning, lifting and transplanting. Stock that is severely stressed in hardening becomes susceptible to injury from Fusarium and similar fungi; but properly hardened stock begins new growth readily, establishes quickly, grows vigorously, and has a high survival rate. Unconditioned stock has a very poor survival rate when transplanted (345, 392).
Dormancy

In deciduous plants, dormancy is accompanied by defoliation limiting the losses of internal moisture until new roots and feeding are established. Dormancy is also accompanied by changes in the quantity and kind of food reserves stored in the plant and possibly by other less understood changes. In guayule plants, which are largely non-deciduous, these latter conditions principally govern transplantability. Since guayule growth is responsive to moisture and warmth, somewhat independently of other seasonal influences, dormancy may occur at any season of the year when moisture or heat is sufficiently limited.

Inducing Dormancy. In locations where irrigation is relied on to sustain growth during periods of favorable temperature, it is possible to put the plant under moisture stress by reducing or withholding irrigation, and (thereby) to induce a dormant condition or to cause hardening off.

Kelley (165) found guayule seedlings could be grown with such a limited moisture supply that they were continually in a "hardened" condition and could be transplanted successfully at any season of the year. But plants so grown are very small, and the larger plants apparently survive better than small ones when both classes are properly hardened off.

Kelley also found the percentage of plants that survived transplanting and the promptness with which they started new growth were directly related to the degree of dormancy or hardening off. These findings were confirmed by the work of other research workers.

Extended periods of high moisture stress or dormancy can reduce the number of leaves remaining on seedlings and can have a direct bearing on survival. Experimental studies indicate the remaining leaves actually form a toxic substance that impedes regrowth.

Erickson (100, 102) compared the transplanting of three classes of guayule plants: 1) normally grown lush stock "hardened" for two months by withholding water; 2) stock grown under moisture stress sufficient to cause the plants to be short, stocky and bluish; and 3) stock from the same bed but having had good growing moisture up to the time of transplanting. Survival of lot 2 was 77 percent, compared with 34 percent for lot 1 and 46 percent for lot 3. Erickson concluded that withholding irrigation from the plants in lot 1 for two months had not caused moisture stress in the soil long enough to produce the hardening off apparent in lot 2, and that lot 3 had no hardening off.

Low temperatures also limit growth of guayule and induce dormancy. When temperatures are sufficiently low over an extended period, the plants may reach a hardened off condition even in the presence of abundant moisture.

Artificial inducement of dormancy must be closely controlled when temperatures are high. Sudden and excessive reduction in the
moisture supply will cause plants to wilt instead of progress gradually into a true state of dormancy. When wilt occurs plants do not have a chance to store food and develop other desired characteristics needed for regrowth after transplanting.

When to Begin. Two factors determine the proper time to begin hardening off: the size of the plants and the approach of the lifting season.

The first criterion is reached when the plants are uniformly large enough for field planting. If additional growth is stimulated after the plants have reached the proper size, they become more succulent and susceptible to infection and the spread of disease. Therefore, if growth can be arrested as the plants approach the proper transplanting size, hardening off will serve a double purpose.

The other factor to be considered is the approach of the lifting date. For instance, if certain blocks of stock have not yet attained the optimum development, yet are large enough for field planting, then hardening off should begin at least 30 days before the date of lifting.

The ability of guayule to generate new growth upon transplanting does not seem to decline with age up to two years. Two-year old plants transplant as readily as half-year or year-old seedlings. Planting shrubs older than two years was not investigated, partly because of suspension of project operations, but also because most plants older than two years become too large to be handled satisfactorily in the planting machines.

Reduction in Irrigation. The period between waterings should be gradually lengthened to induce dormancy or hardening off. If all stock in a bed is of uniform size, plants could be allowed to reach a high moisture stress for at least two days before applying more water. But, when moisture stress is more severe and abrupt than the plants can manage by induction of dormancy, injury or death is likely to occur. The nature of the injury was reported by Addicott and Pankhurst (5) and further described by Campbell and Presley (50), who noted that drought injury also predisposed the plants to disease.

The amount of water applied during the growing season, the nature of the soil and the density of the stands all have a marked influence on the type of seedlings produced. Excessive watering of plants on sandy soils, particularly if the stands are dense and fertilizers are used, often results in plants with tall, succulent tops. Hardening such plants, even though water is generally reduced, usually results in severe drought symptoms, and only a few functional leaves survive.

Areas in a block that are under size or wilt sooner than the rest of the plants should be watered with a hose; otherwise, the larger plants will continue to grow and remain succulent and the condition of the smaller plants will not improve.
There is not as much need for cultivation during the hardening period as there is during the growing period; but the soil should not be permitted to become baked or crusted, and weeds must be controlled.

**Top Pruning Before Lifting.** Just prior to lifting, top pruning should occur with the topping machine set to cut the plants 1-1/2 inches above the ground—with a variation from 1 inch to 2 inches allowable. (See Figure 11.) This results in removing seven-eighths of the aboveground plant. Topping should occur the same day the plants are to be dug; however, it can precede digging by as much as four days if necessary for proper utilization of equipment and labor (326).

If watering is necessary to facilitate digging and pulling, it should precede topping, but should not precede pulling by more than two days.

**Digging, Pulling and Packing.** Preparation of nursery stock for distribution to the field involves two separate but dependent operations: 1) digging; and 2) pulling and packing. Lifting is a term frequently used with reference to digging or pulling, or it may be used to include both operations.

**Digging.** Digging operations are designed to undercut seedling beds at a specified depth to secure uniform root length and loosen the soil—thus reducing injury in pulling and facilitating hand pulling. Some variation in cutting depth from bed to bed is necessary because of lack of uniformity in ground conditions.

A sharp blade is essential for a clean cut, and minimizes clogging. In heavy soils, vertical knives may be attached to the digger to further loosen the soil. Lifting fingers are necessary under most conditions.

Erickson and Smith (102) conducted studies on handling and transplanting nursery stock with particular attention to hardening, topping, digging, storage and fast transplanting responses. They found there were only small changes in the carbohydrate content, except for levulins, during hardening. The levulin content seemed to depend on the length of time the plant was subjected to adverse conditions of temperature or water supply.

The experiments confirmed the findings of earlier workers—that topping at a height of 1 inch was essential and that best results were obtained when topping occurred within three days of digging. There was little danger of in-storage heating of hardened, relatively leafless plants, and such plants could recover from considerable dessication.

Erickson and Smith also concluded that guayule could be successfully transplanted, if under irrigation, in any month of the year at Salinas, and that nursery stock could be held in the beds for a year or more.

Relatively large plants were best suited for transplanting, with seven-eighths of the top removed and a root 7 inches long.
FIGURE 11. UNDERCUTTING GUAYULE NURSERY BEDS BEFORE LIFTING
Pulling. Normally a single crew unit consists of five persons lifting or pulling and one person packing the crates. A foreman can supervise the work of four single crew units working in two adjacent sections. Pullers remove plants from the ground, shaking dirt and leaves from them, and grade them according to established standards. Usable plants are then laid in small piles or bunches to be secured by the packer. Culls are left scattered over the ground.

All digging, pulling and packing operations are aimed at supplying the maximum number of seedlings at standard grade, and handled in such a manner as to assure minimum deterioration from exposure, excessive moisture, heating or other controllable factors (102, 343, 346, 392).

The following guides are aimed at obtaining a maximum number of plantable seedlings:

1) Stem diameter at root collar--6/32 inch minimum to 12/32 inch maximum, inclusive.

2) Tops--2-1/2 inches from root collar to tip, with an allowable variance from 2 inches to 3 inches, as devoid of leaves as possible.

3) Roots--set digger to cut at 6-inch depth; variation in root length from 5 inches to 7 inches is allowable.

4) Plants with coarse, spreading roots or branches that are too numerous or stiff to be handled by the planting machine should be discarded.

5) Plants injured by wireworms or other insects or by mechanical means should be discarded if the injured area exceeds more than half of the plant perimeter.

6) Plants showing indications of root or stem diseases or dead tissue which may have been caused by fungus should be culled.

7) Plants that have been subjected to excessive exposure should be discarded.

After digging, the plants are placed in crates. Crates should be firmly packed, with the last layer high enough to cause the lid to bulge about 2 inches when it is nailed in place. No pulling or packing should be done when there is free moisture on the plants--moisture increases the hazard of rots and molds in the crates.

Packing Materials and Methods. The ERP used shingletow as a packing material. The amount of moisture in the material and the amount of the material used varies with climatic conditions; length of time that will elapse between packing and resetting in the field and the planned method of storage.
A moisture content of 50 percent to 55 percent on a dry-weight basis is suggested. But some conditions warrant the use of more or less moisture in the packing material. Amount of packing material used will also vary with conditions. Generally, a thin layer should be placed on the bottom and top of the crate, and two layers within the crate, dividing the plants into three layers. Layers should be of about equal thickness, and dividers should be inserted between them. Under some conditions it may be desirable to divide the plants into as many as six layers separated with dry shingletow. (See Figure 12.)

COLD STORAGE

It is possible to hold properly packed seedlings in cold storage as long as 30 days without injury to them. A temperature range from 32 F to 38 F is satisfactory. Crates planned for cold storage should be packed with less than 50 percent moisture content in the packing material and should be lined on only four sides. Wax paper liners on all six sides of the crate will contribute to moisture condensation within the crates, resulting in molds and rots.

Refrigerated freight was used for long hauls and proved satisfactory. Fifty million seedlings were shipped from Indio, California to Torreón, Coahuila, Mexico, in refrigerated storage and all arrived in good condition, although some cars were en route for more than three weeks (343, 392; see also Chapter 7).

SUMMARY

Compared with a forest nursery, which may produce many species of conifers and hardwoods grown from one to three or four years in the nursery, a guayule nursery is not particularly complicated. The ERP experience in operating guayule nurseries extended over such a short period, however, that many problems remained to be solved (102, 343, 346, 392).
FIGURE 12. GUAYULE SEEDLINGS READY TO BE PLANTED IN THE FIELD
CHAPTER 4

DIRECT SEEDING

One of the major problems in growing guayule for rubber is the initial establishment of a stand of plants in the field. Common practice has been to sow seed in nurseries and transplant when the plants are four to 12 months old. Transplanting is a major item in the overall production cost of the crop and is often accompanied by plant losses. Since the entire plant is dug at harvest for rubber, the cost and labor in transplanting must be repeated for each crop (390).

FACTORS AFFECTING ESTABLISHMENT OF STANDS

The germination and emergence behavior of guayule seed determines the conditions under which successful direct seeding can be accomplished. These conditions are a minimum daily temperature no lower than 50 F (with possibly 5 degrees to 7 degrees leeway if pre-germinated seed is used); a maximum daily temperature not much above 90 F except for limited periods of the day; very shallow cover, not exceeding 1/8 inch for best results, and no crusting of soil to impede emergence; and abundant soil moisture at the sowing level during the germination and emergence period.

Control of weeds must closely follow emergence. The common weeds grow quickly and soon overtake guayule, which is intolerant of shade and competition.

Seedlings must be thinned to desired spacing. The proportion of sown seeds that will produce seedlings is so variable that sowing to produce uniform stands of predictable spacing is not possible (140,345).
DIRECT SEEDING TRIALS

Tingey conducted direct-seeding trials at Salinas, California during the summer, when temperature ranges were favorable. Experiments included the use of pre-germinated seed sown in hills as well as in drill rows along the edge of irrigation furrows. Later tests revealed that sowing depths of 1/8 inch to 1/4 inch, with no packing of the covering soil, gave much better stands than deeper sowing. They also indicated that thorough soaking of the soil immediately after sowing, followed by sufficiently frequent irrigations to maintain good soil moisture at the seed level during the germination period, was essential. Pre-germinated seed usually gave better emergence than dry sown seed at prevailing Salinas temperatures. Threshed seed was not as dependent upon pre-germination--the dry-sown threshed seed germinating nearly as well as the pre-germinated unthreshed seed.

The trials were made on small plots where precise leveling and control of irrigation, as well as excellent seedbed preparation, could be practiced (353, 354, 355).

Further direct seeding at Salinas by Davis evaluated the effects of soil temperature, type of land preparation, type of sowing bed, pre-sowing treatments of seed, dry-land sowings and production of stock in field sowings for transplanting. Partial or total failure of stand emergence occurred whenever any of the previously cited factors were unfavorable beyond the critical limits, but in the better combinations 10 percent or more of the viable seeds produced seedlings (83, 84).

Hilgeman gave the maximum-minimum temperature limits for direct seeding in the Salt River Valley of Arizona as 100 F and 40 F, and the feasible sowing season as late March to late May. He obtained the best stands by sowing at a depth of 1/8 inch to 3/16 inch with a loose soil cover. The drill row was on a shoulder of the seedbed and from 1 inch to 2 inches above the irrigation water level of the furrow. This required practically perfect "leveling" (147).

The best practice is to irrigate immediately after sowing, continuing the run of water until the beds are "blacked out", or saturated across from furrow to furrow. Thereafter, light irrigations can be made at sufficient intervals--to keep the soil moist until the stand is established--and then reduced in frequency.

When primary leaves appear on the seedlings, roots have penetrated to a depth of 8 inches to 10 inches. The surface soil can then be allowed to dry, thus reducing the risk from damping-off disease. This drying causes loss of some weaker seedlings, but the losses are less than those incurred from disease when higher moisture is maintained. Hilgeman concluded that post-emergence losses of weaker seedlings are common regardless of the moisture supply and may total 18 percent to 73 percent of initial stands. Recommended minimum sowing rate to allow for post-emergence losses is 50 viable seeds per lineal foot.

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Factors that do not appear to influence stands include planting in hills instead of drill rows, pre-germinating the seed prior to sowing, planting on the north or south sides of the bed and continuous, or daily irrigating.

Factors which proved unfavorable or highly variable are maximum temperatures above 95°F; deeper planting, or use of packer wheels; cover of sand, peat moss, manure, grass clippings or alfalfa meal; uneven bed preparation or seed placement more than 3 inches from the water line; and inadequate water supply, either in quantity or in regularity of applications.

Davis concluded that temperature limits for acceptable stands were a maximum of 95°F to 100°F and minimum of 45°F to 60°F, and that maximums of 80°F to 85°F and minimums of 50°F to 60°F were associated with best emergence. At Salinas, maximum temperatures are never a problem, and minimum temperatures are high enough for germination generally to prevail from May 15 through the summer. Sowings made after September 1 to September 15 are probably undesirable because of the subsequent short growing season (83, 84, 85).

In direct-seeding experiments in the Salt River Valley, temperatures too high in summer and too low in winter limited direct seeding to spring and fall. Fall seedings were found impractical because temperatures after November 1 were too low for growth and young seedlings were wiped out by disease, insects and unidentified "winter injury", which destroyed the tops. Problems of tilth in seedbed preparation and crusting during emergence could, no doubt, also be serious in such soil, but from recorded evidence they were not as serious as other factors.

Early reports of the infeasibility of direct seeding in southern Texas were confirmed by erratic results from direct-seeding trials on irrigated land and the failure of such tests on dryland areas. Cowley considered climatic conditions in southern Texas generally unfavorable for the establishment of guayule seedlings in the field, especially on land where irrigation is not possible.

In southern Texas, the rainy periods centering in May and September are characterized by high temperatures and high evaporation losses and are also normally the periods of heaviest weed infestation. Evaporation losses and temperatures are lower in winter, but rainfall is scanty and high winds tend to intensify the moisture deficiency.

Nevertheless, in small winter trials, some irregular stands were obtained without irrigation. Temperatures were favorable to germination, daily minimums being usually in the range of 50°F to 60°F, with only an occasional dip into the upper 40s. The irregularity of stands was associated with the difficulties of maintaining a uniformly shallow cover with an adequate moisture supply under the sowing techniques used. Blank or scant stands occurred where cover exceeded 1/2 inch.

Thinning directly-seeded stands by mechanical means was tried with little success. Tractor cultivators equipped with weeding sweeps were
driven crosswise to the planted rows. Theoretically, this should leave single plants spaced in checkrows for subsequent cross cultivation. Unless the sweeps were set far enough apart to leave considerable undis­turbed space at each "plant location," however, there were many final blanks where short blanks in the initial stand coincided with intended plant locations. In any event, further hand thinning was required. Also, the practice of seeding on the sides of raised beds with inter­vening irrigation furrows made cross cultivation somewhat difficult.

Vegetable growers in the area, who grew lettuce, celery, cauli­flower and other plants at spacings of 8 inches to 18 inches in the row, thinned with short-handled hoes incidental to the first weeding. The workers chopped out weeds and crop plants indiscriminately to achieve the appropriate spacing, and hand pulled remaining plants to leave one good specimen at approximately the desired spacing. At wartime labor rates, the combined operation cost was from $6 to $12 per acre, depending on density and size of weeds (71, 72, 73, 75).
CHAPTER 5

PLANTATION SITE SELECTION STANDARDS

CLIMATE

Temperatures below 5 F are considered unsuitable, those between 5 F and 10 F doubtful, and those above 15 F suitable. A mean annual rainfall between 15 inches and 25 inches is considered suitable, between 9 inches and 15 inches and between 25 inches and 35 inches doubtful, and below 9 inches or above 35 inches unsuitable.

PHYSIOGRAPHY

Mountains, hills, steeply undulating, eroded and gullied areas, swamps, lakes and salt flats should be eliminated as possible sites. No dry-farmed fields are acceptable where the slope exceeds 7 percent. Irrigated fields with slopes greater than 3 percent are not considered acceptable.

BIOLOGICAL FACTORS

Biological factors to consider are insects, diseases, weeds and natural vegetation. The accepted methods, standards, and remedial measures applied to all common farm crops when dealing with these factors should also be applied to guayule. (See Chapter 7.)

On certain soils and fields crown rot, root rot, and wilt are sometimes damaging to guayule, however, no special limits were set in
the early surveys to segregate areas subject to losses from these sources. Later Soil and Tract Reconnaissance Surveys made in Texas did designate fields infested with cotton root rot (389). Well-drained, light-textured soils and proper irrigation practices tend to minimize losses from this source. Past cropping history may be important, but such data are limited to observation. Nematode infestations were considered in the selection of nursery sites and later in the selection of experimental fields, but nematodes never caused serious losses.

WATER SUPPLY

The adequacy of irrigation water supply for guayule production can be classified on the basis of rate of flow and the seasonal amount of water available per acre. Amounts of irrigation water proposed initially by ERP are shown below in Table 4.

<table>
<thead>
<tr>
<th>TABLE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER REQUIREMENTS FOR GUAYULE PRODUCTION</td>
</tr>
<tr>
<td>Arid Areas:</td>
</tr>
<tr>
<td>Flow Rate: gpm</td>
</tr>
<tr>
<td>I Good (over) 6.0</td>
</tr>
<tr>
<td>II Permissible 4.0-6.0</td>
</tr>
<tr>
<td>III Doubtful 3.5-3.9</td>
</tr>
<tr>
<td>IV Unsuitable 0.0-3.4</td>
</tr>
</tbody>
</table>

| Intermediate Areas:                                  |
| Flow Rate: gpm | Total Amt: ac ft |
| I Good (over) 5.0 | 2.5            |
| II Permissible 3.5-5.0 | 2.0-2.5       |
| III Doubtful 3.0-3.4 | 1.5-1.9       |
| IV Unsuitable 0.0-2.9 | 0.1-1.4       |

| Coastal Areas:                                       |
| Flow Rate: gpm | Total Amt: ac ft |
| I Good (over) 4.0 | 1.7            |
| II Permissible 3.0-4.0 | 1.3-1.7     |
| III Doubtful 2.5-2.9 | 1.0-1.2       |
| IV Unsuitable 0.0-2.4 | 0.0-0.9      |

1 Intermediate areas have effective late spring rains and so require less irrigation than arid areas; coastal areas are favored by fogs and cool weather.
2 Gallons per minute.
3 Acre-feet.

On the basis of experience gained by two years of irrigating extensive acreages of guayule it appeared, however, that the original irrigation standards were too high and could be safely reduced by 1/3. Factors that should be included in evaluating the quality of irrigation water are the quantities of total dissolved solids--such as chloride, sulphate, carbonate, sodium, magnesium, calcium and boron--and the ratio of sodium to the sum of the alkaline bases.

General limits used in interpreting the quality of irrigation water are tabulated below. Later experience indicated that the original
standards for water quality were also a little too high, and that these standards can probably be adjusted downward to some extent, especially where these waters are to be used on deep, permeable soils.

TABLE 5
WATER DETERMINANTS QUALITY

<table>
<thead>
<tr>
<th>Quality of Water Class</th>
<th>Total Dissolved Solids</th>
<th>Sodium</th>
<th>Boron</th>
<th>Chlorides</th>
<th>Sulphates</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Good (less than)</td>
<td>525 ppm</td>
<td>40 percent</td>
<td>2.0 ppm</td>
<td>248 ppm</td>
<td>336 ppm</td>
</tr>
<tr>
<td>II Permissible</td>
<td>525-1400 ppm</td>
<td>40-60 percent</td>
<td>2.0-3.0 ppm</td>
<td>248-426 ppm</td>
<td>336-576 ppm</td>
</tr>
<tr>
<td>III Doubtful</td>
<td>1401-2100 ppm</td>
<td>60-80 percent</td>
<td>3.1-3.7 ppm</td>
<td>427-710 ppm</td>
<td>577-960 ppm</td>
</tr>
<tr>
<td>IV Unsuitable (over)</td>
<td>2100 ppm</td>
<td>80 percent</td>
<td>3.7 ppm</td>
<td>710 ppm</td>
<td>960 ppm</td>
</tr>
</tbody>
</table>

1 Ordinarily, the highest value in any one factor determined the rating, but adjustments were made to allow for special soil and climate conditions.
2 Parts per million.

In addition to the quantity and quality of the water supply, drainage conditions, groundwater recession and the cost of water should be considered. The standards established for the first two of these factors are given in the following tabulation.

TABLE 6
STANDARDS FOR DRAINAGE CONDITIONS AND GROUND WATER RECESSION

<table>
<thead>
<tr>
<th>Suitability Class</th>
<th>Sandy Soils (ft)</th>
<th>Heavy Soils (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Good</td>
<td>Over 7</td>
<td>Over 10</td>
</tr>
<tr>
<td>II Permissible</td>
<td>5-7</td>
<td>7-10</td>
</tr>
<tr>
<td>III Doubtful</td>
<td>4-5</td>
<td>5-7</td>
</tr>
<tr>
<td>IV Unsuitable</td>
<td>Under 4</td>
<td>Under 5</td>
</tr>
</tbody>
</table>
SOILS

Based on their profiles and closely related external characteristics, soils can be divided into five classes in relation to guayule: I, Excellent; II, Good; III, Doubtful; IV, Unsuitable; and V, Nonarable. In addition to soil profile characteristics, factors such as relief, erosion, external drainage, fertility, salt content and high water tables are considered in these classifications.

Class I

EXCELLENT LAND for the production of guayule; no apparent unfavorable conditions.

Soil Profile Characteristics:

1) Surface textures: Fine sandy loams, very fine sandy loams, loams and silt loams.

2) Profile: Friable. Textural variations throughout the 5-foot soil section should not change enough to retard or accelerate water penetration to a marked degree.

3) Internal drainage: Adequate.

Relief: Favorable for surface irrigation. No slope to exceed 3 percent in irrigated fields or 7 percent in unirrigated fields.

External drainage: Adequate. No flood hazards.

Fertility: Satisfactory.

Salts: Free, less than 0.1 percent salts.

Erosion: No material wind or water erosion under ordinary management.

Class II

GOOD LAND for the production of guayule; some unfavorable conditions.

Soil Profile Characteristics:

1) Surface textures: Loamy fine sands, loamy very fine sands, sandy loams, clay loams and silty clay loams.

2) Profile: Permeable soils with no iron, silica or caliche pans or clay pans above 48 inches. No soft caliche above 20 inches.
3) Internal drainage: Adequate to moderately adequate.

Relief: Favorable, or only slight corrective measures needed for surface irrigation. No slopes greater than 3 percent for irrigated fields or 7 percent for unirrigated fields. Minimum irrigation runs 300 feet.

External drainage: Adequate. No flood hazards.

Fertility: Satisfactory.

Salts: Free or slight (0.1 percent to 0.6 percent saline salts) content of salts on soils with permeable profiles.

Erosion: No significant accelerated water erosion. No more than slight wind erosion on light-textured soils.

Class III

DOUBTFUL LAND for the production of guayule; one or more moderately unfavorable conditions.

Soil Profile Characteristics:

1) Surface textures: Loamy sands, silty clays, a moderate amount of stones and gravel allowable.

2) Profile: Permeable soils with no iron, silica or caliche pans or claypans above 24 inches. No soft caliche above 15 inches and no pronounced gray or mottled layer due to poor drainage above the pan.

3) Internal drainage: Inadequate or restricted due to heavy-textured subsoil or heavy-textured lenses in recent alluvial soils. Excessive internal drainage; droughtiness due to excessively sandy and porous subsoils.

Relief: May be moderately unfavorable for management (compound slopes). No slopes greater than 3 percent on irrigated fields or 7 percent on unirrigated fields. Minimum irrigation runs 330 feet.

External drainage: Slow to poor surface drainage allowable. Flooding not more than once in 10 years.

Fertility: May be comparatively deficient in fertility.

Salts: May have slight (0.1 percent to 0.6 percent saline salts) content of salts on slowly permeable soils.

Erosion: May have accelerated moderate wind or water erosion.
Class IV

UNSUITABLE LAND, although arable for the production of guayule with present knowledge and methods; all arable land not in Classes I, II, or III.

Soil Profile Characteristics:

1) Surface textures: Sands, clays.

2) Profile: Caliche, iron and silica hardpans and claypans less than 15 inches deep.

3) Internal drainage: Poor or very slow due to claypans, hardpans, caliche or clay lenses. Water table within 5 feet of the surface. Extreme droughtiness due to sand and gravel subsoils.

Relief: Slopes greater than 3 percent for irrigated lands and 7 percent for unirrigated land.

External drainage: May have poor or ponded surface drainage. Overflows more than once in 10 years.

Fertility: Infertile.

Salts: Moderate (0.6 percent to 1 percent saline salts).

Erosion: Severely accelerated water or wind erosion.

Class V

NONARABLE LAND for the production of guayule. In this class are lands such as mountains, hills, strong salty lands, and annually or frequently flooded areas that are not ordinarily used for the production of cultivated drops (406, 407).

Table 7 shows the acreage in California, Arizona, New Mexico and Texas adaptable to guayule culture, according to surveys based on the above standard.
TABLE 7

ACREAGE ADAPTABLE TO GUAYULE CULTURE

<table>
<thead>
<tr>
<th>Region</th>
<th>Suitable Tracts</th>
<th>Doubtful Tracts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-irrigated</td>
<td>Irrigated</td>
</tr>
<tr>
<td>California</td>
<td>45,400</td>
<td>370,300</td>
</tr>
<tr>
<td>Arizona</td>
<td>-</td>
<td>309,200</td>
</tr>
<tr>
<td>New Mexico</td>
<td>-</td>
<td>39,000</td>
</tr>
<tr>
<td>Texas</td>
<td>471,700</td>
<td>55,900</td>
</tr>
<tr>
<td>TOTAL</td>
<td>517,100</td>
<td>774,400</td>
</tr>
</tbody>
</table>

1 The terms "suitable" and "doubtful" classify the degree of desirability of the land. Doubtful lands have inherent characteristics unfavorable to guayule production but are not wholly unsuitable. Factors considered are 1) climate, 2) water supply, 3) soils, 4) biological factors such as noxious weeds and the prevalence of diseases on certain types of soil and 5) economic considerations.

2 No fields smaller than 20 acres were considered in Texas and New Mexico and none smaller than 40 acres in California and Arizona.

3 These brushlands are used for grazing and have never been cleared for agriculture but would be suitable for guayule if cleared. They are in the unirrigated category (381, 382, 383, 390).
CHAPTER 6

FIELD OPERATIONS

PRE-PLANTING INSPECTIONS

Topographic mapping or other instrumental surveys are not necessary. Sufficient inspection is required to determine whether the land can be irrigated satisfactorily or can be put into condition for such irrigation at a reasonable cost. Except in very well drained soils the furrow method, with little or no ponding of water on the planted area, will be necessary. On the best drained soils a modified border method may be used.

The following points should be kept in mind while making subinspections:

1) Necessity of planting in reasonably long rows;
2) Erosion danger, both by irrigation and rainwater;
3) Cost of necessary leveling, if any;
4) Provision for disposing of wastewater;
5) Condition of present irrigation system;
6) Condition of pumping plant; and
7) Adequacy and condition of pipelines.
SEASON TO PLANT

On the basis of many ERP plantings, the best season appears to be the dormant or winter season. In most California valleys, the optimum planting season extends from about October 15 to March 15. Within these limits, deficient or excessive soil moisture may require modification of the planting schedule.

On irrigated lands the beginning of the planting season can be hastened by pre-irrigating the site. In the California valleys pre-irrigation should begin about September 1, so that soil moisture conditions will be favorable to good planting as soon as the planting stock is in a dormant condition—generally, this will be about October 1. Pre-irrigation should be timed far enough in advance of the natural rainfall season to preclude the possibility of planting delay—because wet planting sites will not become workable before heavy winter rains begin (359).

Planting operations in Texas, Arizona and New Mexico can be spread over a period extending from October 1 to April 1. More friable soils, and a rather even distribution of rainfall in the planting areas, provide generally favorable planting conditions during this extensive period. On unirrigated lands in Texas, this planting season may need to be modified because of drought periods.

PLANTING STANDARDS

Planting guayule is a technical operation requiring certain definite standards and techniques. The following standards are those used by the ERP.

**Soil Moisture in the Fall Season**

1) There should be enough moisture to work down clods;
2) There should be moisture in the upper 8 inches of seedbeds;
3) There should be enough moisture for satisfactory packing;
4) Final ground preparation unit must bring up some moisture; and
5) The soil should be dry enough that planting machines will operate properly.

**Soil Moisture in the Spring Season**

1) There should be enough moisture to work down clods;
2) There should be moisture to within 2 inches of the surface;
3) There should be enough for satisfactory packing;
4) The final ground preparation unit must bring up some moisture, but the soil should not be wet enough to form new clods.

5) The soil should be dry enough that the planting machine will operate successfully.

Roots

1) Root collars should be flush with the general ground surface to 1 inch below;

2) Plants should resist a reasonable pull test;

3) Severely bent roots should be avoided if possible; and

4) Entire root should be at an angle to ground surface, maximum of 40 degrees from vertical.

Defective Plants

1) Diseased plants usually discard (see Chapter 7);

2) Heated plants, plant if roots are healthy (see Chapter 3);

3) Mechanical damage, if root crown and 4 inches or more of root are present, they should be planted; and

4) Dry plants, if plants pass the "fingernail test," plant them.

Spacing

Under irrigated conditions, standard spacings of 28 inches by 20 inches and 28 inches by 16 inches were employed by the ERP. The first figure denotes spacing between the rows, and the second figures denote the spacings between plants within the individual row. For crop year 1944, 28-inch by 20-inch spacing was used on irrigated plantings in California, Arizona and New Mexico—but the closer 28-inch by 16-inch spacing was used in Texas.

The dry-land project in California and New Mexico, employed a standard spacing of 28 inches by 24 inches. Texas plantings were 28 inches by 20 inches—on the basis that soil and moisture conditions in those areas were suitable for supporting the closer spacing—while at the same time allowing a safety factor in the face of possible heavier losses through insects and disease.

Appendix B, Table 15 indicates the square inches of growing space afforded each seedling, and the number of seedlings per acre for various combinations of spacing. Somewhat wider spacings and longer rotations than those used by the project may be desirable. There is evidence that the 28-inch by 20-inch spacing with which most of the irrigated plantations were laid out is too close for a crop rotation of more than three years (393).
GROUND PREPARATION

Preliminary Preparation

The objective should be a tilled bed at least 8 inches deep, free of trash and clods.

Final Preparation

Almost without exception this operation consists of chiseling, packing and harrowing. A light chisel with coil or rigid shanks is used to bring moist soil to the surface. This permits a good job of planting and prevents dry surface soil from rolling into the planter shoes around the roots of the plants. Packing is by a cultipacker to firm the bed for the plants. A light steel harrow produces a mulch to check crusting and to smooth out irregularities. These three operations are done with the tools drawn behind each other: first the light chisel, then the cultipacker and finally the light steel harrow. The ground is left finely pulverized. It should be free of trash or weeds, loosened to sufficient depth, yet firm on the surface—and have moisture left at the surface immediately before planting (393).

LAND PREPARATION FOR IRRIGATION

Considerations

The special susceptibility of the shrub to injury from flooding and waterlogged soils indicates that all land used for irrigated guayule crops must be checked for proper preparation. Lands already used for other irrigated crops will ordinarily require little or no heavy leveling.

It is seldom possible to secure satisfactory penetration of water, in furrow irrigation, without ponding the water at the lower end of furrows or allowing some surface runoff. Wastewater must be disposed of at the lower end of each guayule field. Also, winter rain will, in some instances, be heavy enough to produce runoff from guayule fields. For these reasons, provision of surface drainage is one of the most important phases of land preparation.

Where no general drainage systems have been provided, each field becomes an individual problem. If it is possible to provide a waste ditch leading to a natural watercourse or other channel to carry off the excess water without damage to lower lands, a small area in the lowest portion of the field should be left unplanted. It will serve as a sump for disposal of wastewater through seepage and evaporation. To avoid waterlogging of the land, in and near the sump, surface waste must be at a minimum.

Good land preparation is the prime factor in reducing labor requirements during irrigation. The degree of surface finish is inversely proportional to the slope.
Irrigation Ditches. As part of land preparation, irrigation ditches should be planned, marked on the ground, and in some cases, constructed in advance of planting. The extent of this program will vary greatly, depending on the character of the present irrigation system.

A well-planned irrigation system, properly laid out, is essential. Whether furrows are supplied from surface gated pipe, underground pipelines with risers, or open ditches, the location and size of pipelines and ditches will have a direct bearing on water application and requirements for labor and irrigation equipment. Other considerations include available water supply, soil types, slope of the land and furrow direction (393).

PLANTING

The four-row standard machine was constructed from commercially manufactured transplanting units. Four units were placed 28 inches apart on a special chassis—a spacing not common to other crops. (See Figure 13.)

Under project operations, with the standard four-row machine run by an average crew, approximately 100,000 transplants were set out each nine-hour day—or about one acre per hour at 28-inch by 20-inch spacing. The average good planter could consistently feed about 55 to 60 plants per minute into the machine.

Crew employed consisted of the foreman, a tractor driver, two plant feeders, four planters and two follow-up crew members. Whenever possible the work was organized so that various positions were alternated. A greater output and a more satisfactory job were obtained.

WEED CONTROL: MACHINE CULTIVATION

The principal function of machine cultivation is to control weeds; other beneficial results are incidental. The objective should be a field of guayule relatively free of weed growth, with a minimum of damage to growing shrubs. From the standpoint of both cost and unnecessary loss of valuable soil moisture, this objective should be achieved with the fewest possible operations. If weeds are under control and the physical condition of the soil is satisfactory, there is nothing to be gained by continued cultivation.

Equipment

Standard models of integral and pull-type vegetable cultivators can be used. Cultivation of guayule presents few problems that are not found in the cultivation of other closely spaced row crops such as sugar beets and beans.
FIGURE 13 a and b. GUAYULE SEEDLINGS BEING TRANSPLANTED IN THE FIELD (two Views)
Procedure

Timing is an important factor in cultivation—the larger the weeds grow, the more difficult the operation becomes, and the more moisture and plant food are sapped from the ground. In general, cultivation should begin early in the spring when the ground can be worked and at the approximate peak of weed seed germination. By cultivating when weeds are small, many weeds not touched by the cultivating tools are choked out by loose soil covering them (393).

WEED CONTROL: HAND CULTIVATION

Hand hoeing is a necessary supplement to machine cultivation. The primary purpose is to conserve moisture by eliminating weed growth. Secondary purposes are to prevent the development and spread of weed seed and to simplify harvesting and guayule seed collection.

When to Hoe

Weed growth is largely regulated by sunlight, temperature, soil moisture, season, previous culture and other factors beyond control.

When or how often to hoe can be determined only by the weed growth. Under most conditions hoeing should be as follows:

1) During the winter and early spring on previous season plantings, when weeds appear, and soil conditions permit.

2) Immediately when general and continued rains end. This is almost sure to be the peak, when nearly all fields need work at the same time.

3) Twenty to 30 days after Number 2, on both irrigated and dry land.

4) Twenty to 30 days after Number 3 on irrigated fields; or after the first irrigation and generally after each succeeding irrigation. On non-irrigated fields no more may be required, at least until fall.

Correlation with Other Operations

Hand hoeing should tie in closely with machine cultivation, oil spraying and irrigation. In most cases it should occur only after machine cultivation. This gives the weeds that are cultivated out time to wilt, and reduces unnecessary hoeing. Usually three days to four days after cultivation is soon enough.

After oil spraying or other herbicide treatment, a period of a week to ten days should elapse before hoeing. This gives the larger weeds time to die, and reduces the amount of hoeing required. Enough time after each irrigation is needed for most weed seeds to germinate but not produce large weeds—usually a week.
In general, hand hoeing demands careful advance planning, crew training and timeliness correlative to other activities. Above all, hand hoeing should be thorough.

WEED CONTROL: OIL SPRAY

During World War II, oil spraying was the only effective weed control available. Although oil sprays have largely been replaced by other herbicides, this discussion is presented for any value it may still have.

The control of weeds through the use of selective oil sprays has been tested in California by the University of California College of Agriculture at Davis, and by many orchardists and vegetable growers. Although materials used are toxic to most weeds, they are not injurious to guayule. Selective oil sprays provide a means of controlling weeds within the planted rows and also during periods when continued rain and wet soil prevent the use of cultivators and hand hoeing. Thus, the winter weed crop—a real problem in California—can be attacked before it gets out of hand.

Spraying will not generally give 100 percent control, and some cleanup work with hand hoeing crews will be necessary. However, because spraying will kill a high percentage of weeds, and retard the remaining weed growth, cleanup can be accomplished with only a fraction of the work that would otherwise be required.

Materials

Through extensive field trials, several types and grades of petroleum products were found to effectively control weeds in guayule plantations. Commercial grade diesel oil was commonly used in spraying field plantations. It is an effective weed killer and can be obtained easily at a reasonable cost. But it is also likely to cause injury to guayule plants. Stove oil, sold for heating purposes, is a less effective weed killer but also is less likely to injure the plants. It can be sprayed on plants that are in vigorous growing condition or on young plants just putting out a first crop of leaves after transplanting. Both diesel oil and stove oil can be applied either straight or mixed with water. In testing on field plantations, the straight oil spray generally has given the best results. There is a better kill of weeds, with more uniform results. Straight oil spraying is a less expensive operation, and the output per machine and work day can be increased with less wear and strain on the equipment. Less equipment and fewer personnel are required, and no water supply is necessary. The principal disadvantages, however, are the greater danger of injuring the plants and increased fire and other hazards.

Amount of Oil to be Used

An 80 percent to 90 percent kill of weeds is considered acceptable. In late fall, winter, and early spring, 50 gallons per acre—when spraying
is confined to rows—of either diesel or fuel oil should be the maximum applied. During mid-summer months, 30 gallons to 50 gallons per acre will usually suffice—when spraying rows only. Covering the entire ground surface is unnecessary except under certain conditions during the winter rainy season. However, if it becomes necessary to spray the entire field, 80 gallons to 100 gallons per acre may be required. It is far better to remove the more resistant weeds by follow-up hand hoeing and cultivation than to attempt too high a percentage of weed kill at the expense of damaged guayule. Up to 15 percent of the guayule leaf surface darkened but not killed by the spray material is within acceptable limits of leaf damage (393).

SOIL-PLANT-WATER RELATIONSHIP

Because of the wide variety of conditions encountered in guayule-producing areas, no hard and fast rules exist regarding amounts of water to be applied and frequency of irrigation. The depth of soil available for root growth and its water-holding capacity are important soil factors governing the required frequency and quantity of irrigation.

As a general average, sandy soils, including loamy sands, will hold from 0.5 inch to 1 inch of available water per foot of depth; sandy loams, 1 inch to 1.5 inches; and silt and clay loams 1.5 inches to 2 inches. In heavier soils, however, part or most of the water becomes available so slowly that crops may suffer severely under extreme drying conditions even while the so-called available water is still present.

Characteristics Affecting Use of Water

Depth of Rooting. Irrigation frequency and quantity required by guayule is affected by the depth and character of root systems. During the first few months after guayule is transplanted into the fields, most of the roots will be in the upper 2 feet. In friable soils with satisfactory moisture the roots will be well distributed to a depth of 8 feet or more by the beginning of the second growing season in the field.

Weather. Weather conditions have a profound effect on the rate at which most crops, presumably including guayule, will use water, and also govern to some extent the lower limit to which the soil moisture may safely drop before irrigation water is applied. During cool, moist weather, transpiration rate is low. The slow movement of moisture, through the soil to the roots, that results from low moisture content may be sufficient to maintain proper growth. During hot, dry, windy weather, however, transpiration rate is very rapid and moisture must move through the soil to the roots fairly rapidly to prevent a shortage. The more rapid movement can be accomplished only when the soil moisture content is high. This latter condition is relatively more important in shallow, tight soils and may be hardly noticeable in deep sandy or loamy soils.
Quantity of Water at Each Application

Water quantity recommendations in the following table were obtained by combining the data on the water-holding capacity of soils and the depth of rooting of guayule, making allowance for the usual need to irrigate before soil moisture in the root zone has been depleted to the wilting point.

<table>
<thead>
<tr>
<th>Age of Guayule</th>
<th>Soil Class and Depth of Application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sandy</td>
</tr>
<tr>
<td>Less than one year</td>
<td>2-3 inches</td>
</tr>
<tr>
<td>One to two years</td>
<td>3-4 inches</td>
</tr>
<tr>
<td></td>
<td>Loamy</td>
</tr>
<tr>
<td></td>
<td>3-4 inches</td>
</tr>
<tr>
<td></td>
<td>5-7 inches</td>
</tr>
</tbody>
</table>

Frequency of Application

Little information is available on the rate at which guayule will transpire water. Moreover, experience with the crop under irrigation has been so limited that the degree to which plants may wilt or otherwise show need of water, in advance of serious slowing in growth, is unknown. However, it may be estimated that in loamy soils, young guayule fields will need to be irrigated at 18-day to 48-day intervals with applications heavy enough for 3 inches to 4 inches of water to be retained as soil moisture in the upper 2 feet or 3 feet of soil. For older plantings, more frequent applications may be necessary, depending on whether growth or stress is desired (44, 93, 393; see Chapter 8).

IRRIGATION PRACTICES

The ultimate aim of guayule irrigation is to supplement soil moisture derived from rainfall in amounts necessary to ensure early and rapid growth of the shrub. At the same time, irrigation water must be so applied as to present no hindrance to the maximum production of rubber by the plant. Disease losses resulting from improper irrigation must also be avoided.

Methods

Because guayule is much more sensitive to flooding than most cultivated crops, it is better to use the furrow method for all plantations except those on extremely well-drained soil. For the same reason, and also because of the ever present need for economy in the use of water, special care must be exercised in the distribution of water to the furrows.
Fixing Time and Quantity of Application

Moisture Distribution from Furrows. The rate of water movement throughout the root zone, in different directions from the irrigation furrow, will vary depending on the moisture content of the soil and the character of the soil and subsoil.

The fact that, in general, it is not possible to partially moisten soil to a considerable depth may be of great importance in guayule culture. Rubber formation seems to take place during periods of semidormancy produced either by low temperatures or limited soil moisture. In hot areas it may be necessary to induce or prolong this semidormant period by appropriate irrigation practices. Since it is impossible to bring the moisture content of the root zone to any given moisture content between the field capacity and wilting point, or maintain it there, it may be necessary to moisten fully only a part of the root zone. In appropriate cases this may be accomplished by allowing the water to penetrate to shallow depths or by irrigating in alternate furrows only.

Controlling Factors. Because of variations in soil types and crops of different ages, controlling factors in the application of irrigation water should be: 1) getting free water into the surface soil at the plant row to ensure moisture content and soil packing around the newly planted roots; 2) moistening the upper 1 foot or 2 feet of soil during the first season when the root zone is limited to that depth; 3) getting moisture 3 feet to 4 feet into the subsoil when the roots are working at those depths; or 4) moistening a limited part of the root zone to permit rubber formation without encouraging rapid growth.

Getting free water to newly planted roots without saturating the soil can present a serious problem. Irrigation of alternate furrows may be advisable to avoid saturation.

Stock, especially if succulent, planted in dry soil should be irrigated as soon as possible. In hot weather not more than a few days should elapse between such planting and irrigation.

During the first year's growth guayule roots are chiefly in the upper 1 foot or 2 feet. Plants cannot be expected to tolerate drying out of the soil more than a few inches below the surface without suffering a growth setback. At the same time the leaf area will be small and the rate of transpiration of water will therefore be slow. Irrigation can be delayed until there is evidence the moisture is being depleted in the soil—below the influence of direct evaporation from the surface.

During the second year's growth, roots will be found rather well-distributed at a depth of 3 feet or 4 feet, provided moisture has been available at these depths, and no impervious layer or stratum interferes with root growth. During this year, too, the leaf area will be much greater and use of water by the plant will be much more rapid. Irrigation can then be withheld until the soil becomes nearly dry in the lower portion of the upper foot.
Lack of moisture will not cause complete dormancy until the moisture content in the major portion of the root zone is reduced to the wilting point. This indicates that when semidormancy is to be induced, or continued to aid the production of rubber, irrigation should be withheld until the soil moisture in the major root zone—that is, at two feet and three feet—is reduced to about the wilting point.

The following approximate values for the available capacity of one foot of soil may be used:

<table>
<thead>
<tr>
<th>Soil Class</th>
<th>Loamy Sand</th>
<th>Sandy Loam</th>
<th>Loams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available capacity in acre-inches per foot of soil.</td>
<td>.75</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

On the basis of these values, uniform applications of 2 acre-inches to 4 acre-inches of water should be the aim with first year plants. Double those figures for second year plants during the growing season.

Time Required for Irrigation. To determine how much water is being applied to the land, compute from the rate of discharge and the area of the land being irrigated. A convenient fact to remember in this connection is that one cubic foot per second (450 gallons per minute) will cover an acre practically one inch deep in one hour (393).

SURVIVAL COUNTS

Survival counts serve: 1) to provide a record of the number of growing plants per acre on which to base an estimate of shrub yields and 2) to measure the effect that soil types, time of plantings, spacing, method of planting, strain of plants and other influential factors have had on survival.

Special counts or surveys to determine the survival and growth of guayule may become necessary to provide a basis for determining whether the field in question should be plowed up, replanted or retained as an acceptable stand of guayule.

Considering possible benefits to be gained from fill-in planting, two points may be noted. First, it probably is not necessary where first-year survival is 80 percent or greater. Second, where survival is low, fill-in planting, if successful, will tend to improve milling quality (that is, rubber content) in the final stand, even if it does not markedly increase total shrub yield. Such planting is expensive and should be used only where conditions are right for success.
When to Count

A general survival count of the current year's plantings should be conducted when the results of the count will provide an accurate picture of the number of live, growing plants finally established. Naturally, this should be near the end of the growing season when the main cultivation and irrigation operations have been completed, and when the possibility of loss from these operations and other causes—such as attacks by insects and disease—is at a minimum.
DISEASES AND INSECTS

DISEASES

Disease: Factors Affecting Development and Spread

Water. Free water around the roots for prolonged periods is detrimental to guayule. This condition may be produced by over watering or by the presence of an impervious layer in the soil. In nurseries, frequent use of the overhead irrigation system encourages the rapid spread of disease by keeping the tops of the plants and the soil surface continuously moist.

Temperature. Certain diseases that attack young seedlings develop at low temperatures. Whenever possible, seed should be sown only after soil temperatures are high enough for rapid germination and growth (50 F or above). Seeds sown at lower temperatures, because of their slower germination, are exposed for longer periods to soil fungi.

Density. Density in itself does not produce disease. But if a disease favored by high humidity and spread by contact is present, the greatest loss may be expected in beds with the highest density.

Storage Diseases

The development of diseases in planting stock depends on the season when plants are dug and packed, the moisture content of the plants and packing material, the length of time in storage and storage temperatures.
Poor survival of field-planted guayule may be caused by diseased stock. Everyone handling planting stock should be familiar with storage diseases to prevent the planting of seedlings having little or no chance of survival.

Storage diseases are caused for the most part by fungi, which are able to develop and spread through seedlings closely packed in a crate under conditions of moisture and temperature favorable to their growth. Not all fungi causes disease, however, and it is therefore necessary to distinguish between the superficial molds and those which cause disease such as Sclerotinia and Botrytis (102, 343, 346, 392).

Sclerotinia causes a watery soft rot of the top and roots, usually forming tufts of white cottony mycelium. It later forms hard, black, irregularly shaped bodies called sclerotia. The spread of Sclerotinia in crates is checked, but not stopped, at storage temperatures of 32 F to 34 F. It grows rapidly at 38 F or above (48).

Botrytis is usually referred to as "gray mold" because it forms patches of gray, fuzzy mycelium on diseased plants. It causes a soft rot of the top and roots and develops rapidly at 38 F or above, especially on plants held in storage over three weeks.

Superficial molds develop as gray or whitish, thin, appressed coatings on the leaves and stems. These molds do not damage the interior of the root or stem. Since they develop under the same conditions as Sclerotinia and Botrytis, their presence is evidence of undesirable storage conditions.

Season in Relation to Storage Diseases. The amount of storage disease to be expected in crated stock will depend on the number of diseased plants present in the nursery beds. During late fall and early winter, before the rainy period, these diseases are at a low ebb. After rainy periods, however, especially in the late winter or early spring, the number of diseased plants increases considerably.

Each crate may contain diseased plants, greatly increasing the danger of loss under storage conditions. Therefore, fall-dug stock can be held longer with less danger from disease than winter- or spring-dug seedlings.

Length of Time in Storage and Temperature in Relation to Disease. The "safe" storage period, from the standpoint of disease development, is intimately linked with storage temperature, humidity and moisture content of plants and packing material. The following list evaluates disease risk in stored stock for progressively longer periods of time in storage:

-- One week--little risk from disease if held at temperatures below 60 F;

-- Two weeks--some danger from disease if held at 40 F to 60 F.

No disease hazard if stored below 40 F;
-- Three weeks--should not be stored over 40 F. No danger if stored at 32 F to 40 F;

-- Four weeks--little hazard from disease if stored at 32 F to 34 F. Slight hazard if held at 34 F to 38 F. Considerable hazard if stored above 40 F; the danger of disease loss is proportionate to the temperature; and

-- More than four weeks in storage--considerable hazard if stored at 32 F to 34 F; may be badly diseased if stored at higher temperatures.

Heating of Stock in Storage and Transit

Under certain conditions the temperature inside a crate of seedlings may rise sufficiently to seriously injure or kill the plants. Tightly packed plants, especially those not completely hardened or those packed with excessive moisture in the packing material, are particularly liable to heating under storage or transit conditions of poor aeration and high temperatures.

The leaves, stems and roots of heat-injured plants become black and sodden. In extreme cases most of the seedlings in a crate may be affected. Heated plants, even if little injury is evident, should not be planted. Heating can be prevented by aerating seedlings in the crate, and stacking to leave airspaces between the crates; pre-cooling before shipping long distances by truck or rail; traveling at night to avoid midday heat; and allowing airspace under the canvas crate coverings.

Nursery and Plantation Diseases

Guayule has been grown as a cultivated crop for a comparatively short time, and its history under irrigated conditions is even shorter. Little was known about guayule diseases and their control when the federal government established the ERP. Disease problems were then exhaustively studied by the Bureau of Plant Industry, Soils and Agricultural Engineering. These studies provided much information and many guidelines for successfully preventing disease losses of economic importance. The control recommendations in the following discussion were prepared by the Bureau's Disease Control Division.

Pre-Emergence Damping Off. The excellent series of experiments by Sleeth revealed that some pre-emergence damping off usually occurs in guayule, and that at times it may reach disastrous proportions unless controlled. At Salinas during the period of May 5 to May 18, these losses ranged from 30 percent to 90 percent. Sp ergon, Thiosam, Arasam and Fermate were quite effective in controlling the disease and were nontoxic when applied as a dust to dry-sown guayule seed. When the dusted seed was pre-germinated some toxic injury appeared, but losses from this source were less than those from damping off of untreated seed under conditions favorable to the incidence of disease (321, 322, 323).
No feasible means of soil treatment for prevention of damping off has been found. Campbell tried Chloropicrin (tear gas) for disease and weed control and found that although it reduced both, the degree of control did not justify its high cost (53).

Chemical treatments of the soil included formaldehyde, aluminum sulphate, ferrous sulphate, zinc sulphate and sulphuric acid. Formaldehyde treatment resulted in somewhat better initial stands, but the acid treatments were obviously detrimental to germination.

Root Rot Caused by Fungi

Two types of root rot have been recognized on guayule— one caused by fungi and the other one caused by drowning. But either type of damage to root tissue has the same effect on the functioning of the roots: A sharp reduction of the intake and translocation of water. When the transpiration rate exceeds the rate at which water can be absorbed and conducted by the damaged root system, wilting occurs. Prolonged wilting eventually results in the death of the plant (51, 269).

*Phytophthora* root rot is characterized by black, sunken lesions. The aboveground portion of the infected plant suddenly wilts and the plant dies. In irrigated plantings the greatest loss occurs several days after irrigation, although plants may continue to die for a period of several weeks (42).

*Phytophthora* is probably present in most soils where guayule may be cultivated. Infection requires a high moisture content in the upper foot of soil, and soil temperatures sufficient to activate the fungus. Soil moisture in excess of field capacity for an extended period is particularly hazardous. Heavy, poorly drained soils are difficult to irrigate without waterlogging. Although root rot has been observed on dry-land plantings, it presents a problem only on heavy soils and those with poor drainage due to an impervious layer. Root rot does not develop until June or July in most areas, indicating that fungus activity is inhibited by low soil temperatures.

To prevent the development of *Phytophthora*:

1) Avoid irrigation practices that keep the upper foot of soil unduly wet for more than 12 hours to 18 hours;

2) minimize puddling at the head and tail ends of rows and at low spots in the field;

3) stop irrigation of heavy soil with poor internal drainage when the lower levels are saturated; and

4) in general, irrigate more frequently with shorter applications.

*Phymatotrichum* root rot, also called cotton root rot and Texas root rot, does not occur in California but is widespread in Texas and
Arizona. Infected plants have a decidedly unhealthy appearance. The roots when first attacked are covered with ochraceous-yellow mycelial strands. As the injury progresses, the infected portion of the root becomes shredded, brownish discoloration develops, the top wilts and eventually the plant dies (340).

In general, the conditions that favor its development are the same as those that favor other root-rotting fungi. Preventative measures outlined for *Phytophthora* root rot also apply to *Phymatomyctrichum*. In addition, as far as possible, discriminate against land badly infested with *Phymatomyctrichum*.

**Root Rot Caused by Drowning**

Standing water around the roots prevents the exchange of gases necessary to keep roots healthy. Waterlogging is common in shallow soils over claypans and hardpans. On poorly drained soils, drowning frequently occurs in depressions where runoff water accumulates. The rate of respiration is governed by temperature--at higher temperatures the oxygen requirement is greater and the production of carbon dioxide is more rapid. In dormant plants the respiration process is greatly retarded, and hence they are less subject to root rot by drowning than are vigorously growing plants. However, dormant plants can be killed by prolonged waterlogging. Therefore, areas in which waterlogging cannot be prevented guayule should not be planted (393).

**Crown Rot**

Crown rot frequently begins as a small lesion at the base of a branch that is covered with soil or is in contact with a clod. This lesion may increase in size until the plant is killed by girdling. The watermolds *Phytophthora* and *Pythium* are associated with this disease, and conditions that favor crown rot are essentially the same as those that induce root rot.

Preventive measures include:

1) Avoiding piling of soil around the bases of plants;

2) allowing no cultivator injury that could provide entrance points for fungi; and

3) keeping flooding or subbing water from around the crowns of the plants.

**Verticillium Wilt**

Plants affected by *Verticillium* wilt usually have a stunted, unhealthy appearance. The leaves are yellowish-green, and many of them dry and turn brown. However, some infected plants show no external symptoms. Positive determination of *Verticillium* wilt may be made by cutting into the plant. The presence of the wilt fungus is indicated by a dark brownish discoloration of the vascular tissue of the stem and root.
In fields repeatedly planted to cotton or other groups susceptible to Verticillium the soil is usually infested with the fungus. Green manure crops increase the amount of fungus in the soil by providing plant material on which it can grow saprophytically.

Verticillium wilt is favored by low temperatures, and little or no spread occurs during the summer when soil temperatures are above the maximum for the growth of the fungus.

To prevent the development of the disease:

1) Keep plants in a state of active growth by properly timed irrigations;

2) clean soil from farm machinery before moving from fields infested with Verticillium to fields not showing infection; and

3) avoid planting on land known to be badly infested with Verticillium (53, 311, 312, 313).

Dodder

Dodder is a parasitic, seed-bearing plant characterized by a yellowish or orange threadlike plant body. Dodder seeds germinate in the soil, developing into weak plants that soon die unless they make contact with guayule or other suitable hosts. Once in contact with the host plant, haustoria are developed. These drain nutrients from the host, the dodder roots shrivel and die, and the plant continues its existence at the expense of the host.

On guayule, dodder readily develops into an extensive twining plant that produces seeds resembling in color and in size those of guayule. These are not destroyed by the regular hypochlorite seed treatment. Since dodder can become a serious pest in guayule nurseries, every effort should be made to eradicate infested plants from field plantations where seed is collected. Control of the pest in plantations should include destruction of dodder-parasitized hosts around the edges of the fields to reduce the danger of infestation.

INSECTS

Extensive planting of guayule for rubber production brings with it insect problems. Large areas planted with a single species generally suffer more severely from insect damage than areas where plants are growing in their native environment. This is especially true when insects are introduced into isolated plantings where they may be relatively free from their natural enemies and other control factors. Special precautions should therefore be taken to avoid introduction of insects.
Although a limited amount of insect injury was experienced in California nurseries during the ERP, little is known about injury to expect in other localities. Wireworm damage, while not serious, did occur in the nurseries near Salinas. Lacebugs, termites and other insects caused serious damage in some research plantations in Texas, and grasshoppers and Lygus did limited damage to field plantations in a few localized areas in California.

Insects briefly discussed below are listed in the order of their probable importance to guayule production.

**Grasshoppers**

Grasshoppers breed in enormous numbers in range and pasture lands, alfalfa fields, ditch banks and roadways, and migrate to guayule and other crops. Larger populations of grasshoppers should be noted in these breeding grounds so they can be baited in their nymph stage before migration. Grasshoppers feeding on foliage, leaf petioles and even the bark of twigs and small branches can cause considerable injury.

**Lygus**

The Lygus, or tarnished plant bug, averages 6 millimeters in length, and varies in color from pale green to yellowish or dark brown, marked with yellow, black and sometimes red. The nymphs are pale yellow or green.

Several species of Lygus have been found breeding and feeding on guayule. Feeding, confined largely to the terminal buds, flower and immature seed, can retard growth and reduce seed yields, and may also reduce seed viability.

**Ants**

Three species of ants have caused injury to field-planted guayule: the California fire ant, harvester ant, and Texas leaf cutting ant. The California fire ant is small, with a red head and thorax and black abdomen. It barks the roots of guayule, causing the plants to die. While no serious losses have been experienced from this ant, it seems to be widely distributed in California. Plants killed by its attack have been noted in the Colusa, Bakersfield and southern California areas.

The harvester ant is a large reddish ant found generally distributed from California to Texas. It has been most destructive in nurseries, where it destroys seedling plants around the nests. The greatest damage experienced in plantation guayule has been from its seed-coll ecting habit. But if direct field-seeding becomes a practice, it will destroy stands where it occurs.

The Texas leaf cutting ant has been destructive to experimental guayule plantings in West Texas east of the Pecos River. It makes large nests, defoliating plants for long distances around the nests—and plants thus defoliated die.
Lacebugs

The lacebug is a small sucking insect--adult lacebugs are usually less than 8 millimeters long--with lacelike wings flat over its back. Lacebugs feed on lower leaf surfaces. This insect occurs from California to Texas, but greatest damage was experienced in the indicator plots and experimental plantings in Texas.

Termites

The tube-building desert termite caused injury to experimental guayule in Texas. Termites enclose dead portions of the plants in mud tubes and in some cases extend tubes up the sides of vigorously growing stems. They enclose and feed on leaves, thus killing or weakening the plants. Other species of termites have been found on guayule from California to Texas. The extent to which these other species may attach plantations is not yet known.

Diabrotica Beetles

Several species of Diabrotica occur in the Southwest. The 11-spotted Diabrotica, a small bright green beetle, 6 millimeters long--with 11 black spots on the elytra--has caused extensive damage to guayule. Beetles usually migrate into fields or nurseries suddenly, feed for several days, and then move out.

The most noticeable effect of the feeding is many holes in the leaves--apparently not injurious to plants more than 4 inches high. Damage experienced to date has been in the cotyledon stage in nurseries and field-seeded guayule. Beetles eat the cotyledon and terminal buds of small seedlings, often causing the plants to die. The beetle will not be injurious to transplanted field plantings, but if direct seeding becomes a general practice it will undoubtedly become a serious pest in many sections.

Darkling Ground Beetle

This is a black or dull brown beetle 7 millimeters to 9 millimeters long with the elytra finely striated and the body sparsely covered with short brown hairs.

Several species of darkling ground beetle occur in the Southwest. It is primarily a nursery pest but was found to cause serious injury to field-transplanted guayule in Arizona. If direct seeding in the fields becomes a common practice, this insect will undoubtedly be a major pest.

Woolly Bear Caterpillar

These very hairy caterpillars are gray in the immature stages and later black with yellow broken lines and cinnamon red hairs on the sides. They sometimes grow to 10 millimeters to 50 millimeters in length. They eat anything, but it is not believed that they will become
injurious to transplanted field guayule. They are primarily a nursery pest but would undoubtedly become a problem to directly field-seeded guayule.

**Aphids**

Several species of aphids occur on guayule, but serious injury to field-planted guayule has not been experienced. The greatest injury has been noted in the nurseries and greenhouses, and aphids would undoubtedly cause the same type of injury to field-seeded guayule.

**Thrips**

Thrips are small whitish and yellowish-dark brown insects about 1 millimeter in length that can hardly be seen with the eye. They are present on nearly all field-planted guayule, but the injury they cause is questionable. Most noticeably, they cause leaves to curl and growth to retard on seedling guayule in the nurseries and the direct field seedlings.

**Red Spiders**

These spiders are microscopic in size and their work is more readily detected than the spiders themselves. Several species occur in the Southwest. The species most often noted on guayule spins a fine webbing over the infested leaf surface, pierces the epidermis and extracts the juices. Mottled discoloration or a yellowing and dropping of the leaves results—depending on the severity of the infestation.

**False Chinch Bugs**

The false chinch bug is a small light or dark gray species, 3 millimeters to 4 millimeters long. Nymph false chinch bugs, pale gray with reddish brown abdomens, are sucking insects that cover leaf surfaces and terminals, extracting the juice in a manner similar to aphids. They breed in the late winter and spring on a number of host plants—their favorite being wild mustard. They reach the adult stage in late May and early June and do not cause further damage. Some damage has been experienced on limited acreage in fields that were allowed to become foul with wild mustard and other weeds. When the fields are cleaned in late May the nymphs may transfer to guayule. Effective cultivation to prevent development of the host plants will aid in preventing infestation of the planted shrub.

**Wireworms**

Wireworm attacks on field-transplanted guayule appear not to injure the plants. But serious damage may be experienced in the nurseries. The wireworms' habit of feeding on seedlings kills the plants or renders them unfit for field planting. Should direct seeding be adopted, wireworms will undoubtedly be a problem in some areas. Experiments in nurseries indicate that wireworm populations can be reduced by the use of soil fumigants—but these would be expensive for plantation use.
Whiteflies

Whiteflies seem to occur on field-planted guayule generally, but the heaviest infestation was in Arizona. As with most sucking insects, the greatest damage is done in the insects' immature stages. They are small, flattened and attached to the leaves. When numerous they cause discoloration and curling of the leaves, resulting in retarded growth.

White Grubs

Several species of white grubs and the grubs of related scarabid beetles occur in the Southwest and occasionally damage various plants by feeding on the roots. Although these insects have not been much of a problem on irrigated land, it is possible that certain species may inhabit the dryer areas in considerable abundance. These grubs, if numerous in the soil, could cause serious damage, especially in the nurseries.

Beetles

Certain leaf-feeding beetles, such as leaf beetles, blister beetles and flea beetles, may also find guayule foliage palatable. The banded flea beetle, *Systenia taeniata*, is a common garden pest in the West and has also been recorded feeding on such wild plants as cockle-burr, sunflower and wormwood. A small, active beetle has been observed feeding on the leaves of guayule. This was probably one of the flea beetles.

Bark Beetles

In Mexico a small bark beetle, *Pityophthorus nigricans*, was reported attacking the "stacked" guayule plants, causing rather serious damage. This beetle occurs in Mexico and Guatemala but is not known to be present in the United States. The bark beetle does not attack healthy plants.

Eriophyid Mites

These mites are microscopic. Their work is more readily detected than the mites themselves. Some species work on the surface of the foliage, causing a russetting and hardening of the epidermis or blister-like spots on the leaves. Others produce a fine hairy growth on the surface, its color varying with the host or mite. A number of species are gall makers, usually working inside the tissue and producing galls on buds, leaves or twigs.

Leaf Miners

Several leaf-mining insects infest composite plants. Leaf miners are ordinarily not important, but they occasionally become numerous enough to injure or destroy a large percentage of the foliage.
Leafhoppers

Some of the leafhoppers are general feeders, attacking a wide variety of plants. Both the grape leafhopper and the four-spotted leafhopper will feed on such plants as ragweed and sunflower.

Mealybugs

One species of mealybug occurs on white sage and occasionally on *Artemesia* in southern California. Another species infests both the roots and tops of buck brush, ragweed, and other plants. Mealybugs may occur on different parts of the plant, often in groups or masses. Heavy feeding weakens the host.

Scale Insects

Scale insects are usually found attached to the stems and branches, although some species also infest the leaves. They would be most serious on plants more than a year old, since some time would be required for the scales to multiply in large numbers after the plants become infested.

Lac Insects

Two or more species of lac insects, scale insects that produce shellac, occur in the Southwest. One or both of these could, no doubt, infest guayule.

Boring Insects

Different types of borers are found in various composite plants, tunneling in the stems or roots or both. A small bark beetle is known to attack the cut guayule stems in Mexico.

Certain borers might be capable of attacking healthy or fairly normal guayule shrubs. In addition, plants in a weakened or drying condition would, no doubt, be subject to attack by certain cerambycid and buprestid beetles that normally infest only decadent material (59, 181, 295, 392, 393).

Other Insects

There are several insects that might attack flower heads and thus interfere with normal seed production. For instance, the maggots of certain small fruit flies are sometimes found infesting the heads of composite flowers.

Various adult beetles and other insects frequently visit the flowers to obtain pollen or nectar, but these insects are not injurious. There are, however, some beetles that prefer to feed on petals and inner parts of flowers and may damage or destroy them before they are mature.
CHAPTER 8

HARVESTING AND MILLING

SHRUB GROWTH AND RUBBER DEPOSITION

During the ERP, it became obvious that increments of rubber in the shrub varied according to many factors, but those of greatest interest had to do with age and season. Cultural factors could be controlled, but the former could not. In spring, when vegetative growth was greatest, rubber deposition reached almost a standstill. Relative to shrub volume, there was often a drop in rubber content, though absolute rubber content remained at the same level or increased slightly. In summer and fall, there was an accelerated buildup of rubber, the rate depending on the moisture stresses to which the shrub was subjected. With irrigated shrubs the greatest rate of rubber formation came in late fall and early winter.

The greatest weight increment for shrubs, on irrigated tracts, in the hot interior climate was usually made in spring and early summer; while irrigated shrubs in the cooler coastal climate, and dry-farmed plants, made most rapid gains somewhat later in the season. During the winter season, shrub growth was negligible. With respect to age, the highest gains would probably have been made in the third and fourth growing seasons, with irrigated shrubs, and in the fifth and sixth seasons with dryland plants under normal climatic conditions. This would probably be more marked on spacings slightly wider than those used for the majority of the plantations. No adequate data were available to permit final conclusions about older plants. Close spacing did inhibit large gains even by the third year in some rapidly grown irrigated plantings.
Cultural methods affected the growth characteristics of guayule. Shrubs grown with plenty of water tended to have open crowns with coarse, heavy branches and no central stems. Dry-farmed guayule, especially as it increased in age, tended to take on an arborescent habit. Dry-farmed shrubs maintained a plant moisture content of about 44 percent, while irrigated shrub put under heavy stress dropped at times to about 34 percent. There was more shrub growth, and a greater efficiency in rubber production per unit of water available, with dry-farmed than with irrigated shrub.

Three phases of growth important to harvesting and milling operations were affected by the kind of culture. Dry-farmed plants had relatively higher leaf bulk per unit weight of entire dry shrub than did irrigated plants. This increased transportation and other handling job loads per unit of mill capacity, because the leaves were non-productive and the shrub was usually defoliated prior to milling. On the other side, however, dry-farmed shrubs had a higher rubber content and could be milled more efficiently. The dry-farmed shrubs also had the highest rubber-to-resin ratio and therefore tended to produce a better grade of crude rubber.

Greatest rubber content for a given age and weight of guayule shrub, regardless of culture or soil environment, has been found in plants which grew at moderate rates in which definite rest periods or dormant seasons occurred. The rate and amount of rubber increment was found to be correlated to stress induced by cold, drought, and possibly other factors. Slowly grown shrubs build relatively more of the phloem tissue in which most of the rubber is normally deposited. If the shrub is rapidly grown, the xylem is preponderant. Timing is important. Rubber deposition in the phloem is usually accelerated about 16 months after the tissues are differentiated in the spring, but not unless other vegetative processes have slowed down. If rapid growth continues through the season, schlerenchymatization of the phloem takes place before much rubber is accumulated. This tends to inhibit further rubber deposition (24, 34, 35, 39, 40, 44, 46, 80, 110, 232, 248).

PREPARATION FOR MILLING

Methods of harvesting and milling guayule may have an important effect on the quality and quantity of rubber obtained. A great deal remains to be learned about harvesting. One practice needing more study is that of milling the aboveground parts of the plant and leaving the roots for regrowth. This practice, called pollarding, would seem to offer opportunities to cut planting costs—as the shrubs might be mowed one to several times before the plant is dug to get the rubber out of the roots. The results of mowing have not been fully investigated, although it is known that the mowed branches are difficult to mill.

Transportation and storage are also important considerations. How the bulky shrub can be transported economically and how long it can be stored to extend the milling season are questions yet to be resolved.
The milling process itself needs more study, although existing methods are known to be capable of producing a rubber of high quality (110, 348).

**Shrub Conditioning**

It is desirable to condition the shrub before harvest for two reasons. One is to reduce the moisture content and leaf bulk to lighten the load on harvesting and transportation facilities. The other is to increase the rubber content of the shrub to improve per-acre yield and to make the most efficient use of available mill capacity.

Preparation should begin many months before milling to insure that the shrub is conditioned to produce the maximum amount of rubber. Lush shrubs may be easy to mill, but rubber returns will be low. On the other hand, if the shrub is too dry, there may be a loss of small branches that carry the greatest percent of rubber.

**Stress Theory**

The term "stress" has been used to designate a condition favorable for rubber development in the plant. The term may be too strong, as it means to some people a condition of "suffering" that might result in serious damage to the plant. A period when growth is retarded or stopped is needed, during which the plant will carry on active physiological processes, but remain in what might be considered a "resting" stage as far as growth is concerned.

Regardless of the term used it is known that cessation of growth is essential to the accumulation of rubber—and conditions such as cool temperatures or decreased water supplies are necessary. "Stress" is the term used to express the reaction of the plant to such conditions, and it should be interpreted to mean the conditions favorable for rubber production and unfavorable for growth.

Several methods for getting plants into suitable condition for harvesting have been tried. One is to prune lateral roots by running a blade along the sides of plant rows to deprive the plants of their water supply. This method, however, has been found unsatisfactory. A complete undercutting at various depths usually results in the death of the plant.

It was believed that defoliating living plants possibly would slow down growth and induce the kind of dormancy that would speed up rubber production. Preliminary attempts by the ERP to burn off leaves, set the guayule field on fire, and this method was abandoned.

A sand blast or some form of beater was also tried, but the mechanical means of removing the leaves from densely foliated plants were ineffective—particularly on the leaves in the interior branches. Chemical defoliation was not attempted by the project. Hormones were tried without success since guayule leaves have no abscission layer through which the hormones might work. Trimming back and discarding the tops was advocated as an aid to milling, but preliminary studies
indicated that the small branches contained the highest percentage of rubber and a greater total amount than any other part of the plant. Moreover, the quality of the rubber in the small branches was superior, so the idea of trimming and discarding the trimmings was abandoned.

It was also suggested that interplanting with a quick growing annual to deplete the soil moisture would bring about a stress condition which, in turn, would increase the rate of rubber formation. This method held promise in the dryland areas in Texas, but in actual practice did not prove feasible.

One factor causing stress is the alkali content of the soil. But very high salt concentrations in the soil resulted in a low rubber content, even though the shrub made only limited growth. Genetic differences and soil fertility also affected rubber yield, but still largely according to the stresses imposed.

Soil-moisture stresses operated any season of the year. Plants with limited water supply--on dry-farmed tracts or on salty soils under irrigation--consistently showed a higher rubber content than plants where a plentiful supply of moisture was readily available. While low winter temperatures caused cessation of vegetative growth and provided a slowing-down period in which rubber was formed, the effective rubber-instigating temperatures were never definitely determined, and the relative weight of this factor is known only in a most general way.

The most effective treatment found for irrigated land was to withhold irrigation for a period prior to harvest. Best results were obtained when water was being withheld at periodic intervals to get the best balance between extractable rubber and shrub growth.

Stress was occasionally too heavy. In soils of low moisture-holding capacity, removal of the water supply resulted in sudden shock rather than slowly developed stress and dormancy. Wilting was prolonged under heavy stress, and many of the leaves and small twigs died back. Where growth stopped so abruptly and absolutely, there was little or no opportunity for rubber formation, nor was there much storage space made available in that season's growth. Heavily stressed shrubs nearly always showed a poor rubber content, and total shrub yields were cut back.

Cold, insects and disease also retarded growth, but apparently acted differently from moisture stress because no evidence was obtained that they resulted in an increase in rubber deposition.

Under California climate, the conditioning of dry-farmed tracts was more or less automatic. The season of greatest rubber deposition came in fall and winter; the fall was too dry and the winter too cool for continued growth. Moisture in the soil was used up by midsummer and the shrub soon became dormant and dry. The highest rate of rubber increment usually took place before November, and harvest could then be started. Winter harvest was found to be the best, according to both Intercontinental Rubber Company and ERP experience.
Conditioning irrigated shrubs presented several problems. Main sources of difficulty were light sandy soils in areas of high temperature. Moisture in such soils was rapidly depleted, and shrubs, instead of moving gradually into stress conditions, were forced to change suddenly from a state of vigorous growth to one of acute stress when the water supply was shut off. Very heavy stress adversely affected rubber development. Moderate stress provided for the greatest rubber buildup and left the shrub healthy.

While the rubber content in guayule (as a percentage of the weight of the shrub) rose through fall and winter, it dropped back when growth began in the spring. The lowest percentage content usually occurred in May. This seemed the rule for all ages and strains. Low temperatures restrict vegetative growth, stimulating rubber development. During the period of greatest rubber formation, however, the shrub needs a crop of healthy leaves to carry on photosynthesis. Loss of leaves from heavy stress in the growing season may have led to poor rubber content because of a reduction in photosynthesis. Moderate stress to promote dormancy in late summer and fall appeared essential to the best rubber yields.

As indicated, moisture control afforded the only artificial means of pre-harvest conditioning, and it was sometimes upset by soil or climatic conditions. On soils where moisture could not be withdrawn slowly, it was necessary to wait for cool temperatures to bring on dormancy in the shrub. In such cases the highest rubber content was not reached until late winter, and harvest had to be delayed. Again, early fall rains while the weather was still warm induced renewed shrub growth and delayed rubber deposition.

Such conditions were not necessarily undesirable, because they permitted extending the harvest over a longer season of optimum rubber content. Staging the harvest on the richest dryland shrubs in October, it could be continued through to the irrigated shrubs in late December—finally ending in March on the plantations that developed most slowly. Except under the pressure of the war emergency, it did not appear feasible from the standpoint of maximum rubber yield, to harvest in the spring and summer months when vegetative growth was most vigorous (28, 44, 110, 232, 390, 393).

DIGGING

The Intercontinental Rubber Company developed a system for harvesting guayule utilizing an undercutting device to sever the plant roots at depths of about 10 inches; a side delivery rake to gather the undercut plants into windrows; and a large ensilage cutter, mounted on a tractor-drawn running gear, to cut the shrubs into fairly small pieces for loading into trucks headed into the mill (see Figure 14).

The ERP used the same general system of undercutting, but a lighter, more readily portable shrub digger was developed (see Figure 15). This
FIGURE 14. WINDROWED GUAYULE SHRUBS AND PICKUP BALER
FIGURE 15. GUAYULE PLANTS BEING DUG PRIOR TO PROCESSING
served not only as an undercutter but also lifted the plants clear from the earth and dropped them onto a smooth-packed soil surface, facilitating raking and pickup. The shrubs were too heavy to be loaded by hand, a bale-loading device was perfected so that trucks moving down the field picked up the bales without stopping (348, 390).

CONDITIONING THE HARVESTED SHRUB

Conventional extraction of rubber from guayule shrubs presents certain difficulties not encountered in extraction from most other rubber-bearing plants, because of the anatomical structure of guayule and the manner in which the rubber is distributed through the plant system. Latex is not borne in long tubes or ducts but makes up the content of single cells. Because the cells are not interconnected, latex cannot flow from one cell to the next, precluding removal of the rubber from guayule by tapping—as is done with hevea.

Since the rubber hydrocarbon is distributed through the root, stem and branches of the shrub, some means must be found for disintegrating plant tissues, releasing rubber from the individual cells and then recovering it. It is necessary for rubber in the plant tissues to be in such a form and condition that subsequent separation and recovery can be accomplished. The possible "cure" or "conditioning" during which latex in the cell coagulates to a flocculated mass was the subject of much research and many empirical studies. Methods tried include sunning, parboiling, defoliating prior to storage and retting—in which the plants were exposed to bacterial action. During the wartime emergency it was first thought that sunning should occur prior to milling. Therefore plants were sunned for four days to seven days after digging, then baled in the field and hauled to the mill. There they were placed in storage and not milled until the moisture content dropped to about 18 percent to 20 percent. This procedure was later found unnecessary—the best results were obtained by milling freshly harvested shrub.

It should be pointed out that conditioning involves not only the amount and quality of rubber within the shrub but also the chemical character of the shrub itself. For instance, the shrub can be dried down very rapidly to a low moisture content (1 percent to 2 percent) without a loss of rubber, as shown by chemical analysis. Milling this type of shrub will give rubber of acceptable quality, but yields will be low. Low yields were also due to entrapment of the rubber by other plant materials resulting in loss as "sinks".

An ERP postwar recommendation for additional research pointed out that virtually no basic work has been done on harvesting guayule (110). It has been demonstrated that guayule must be processed as soon as possible after the plants are harvested. The first problem to be solved, however, is the manner in which to harvest. There are two approaches to the problem: in one, the plants that have reached a suitable age may be undercut and completely removed from the field; in the other; plants may be pollarded, leaving the root systems in the ground for re-establishment of the stand by regrowth and ultimate reharvest (81). It is
essential to determine how many times a plant can be pollarded before renewal of the planting stock becomes necessary. In addition more must be learned about the milling of "tops". In limited studies so far removal of leaves has been a problem. Finally, an economic study of pollarding as compared with undercutting will have to be made. Decisions regarding the manner in which the shrub is harvested will be in part dependent on the processing techniques to be used.

Usual harvesting operations in the field took all the aboveground portion of plants and 6 inches to 8 inches of root system. Although the roots contained fair amounts of recoverable rubber, they did not contain as much as the stems and branches. It was not worth the effort involved to get out more of the roots when the plants were lifted.

Handling the shrub after it is harvested poses problems. It has been advocated that shrubs, after harvest, be cut into short lengths, by some device such as an ensilage cutter, and then elevated into a conveyance to be taken to the factory for processing. This method of handling presents two drawbacks: first, it is difficult to remove the foliage by parboiling; and second, baling either whole or pollarded shrubs is easier than handling cut shrub. Regardless of the method, suitable machinery would have to be developed.

Parboiling followed by defoliation has been an accepted practice for demonstrable reasons. There are several additional reasons supported by logic but for which tangible evidence is lacking. Leaf materials constitute approximately 25 percent of the dry weight of the plant and obviously constitute an unproductive load on the milling system, since the leaves contain no recoverable rubber. There is some evidence that milling the shrub without leaf removal increases the amount of metals, especially copper, iron and manganese in the raw rubber. These materials in particular are deleterious to the keeping quality of the rubber. Parboiling induces coagulation of latex within the cells. However, more research is needed into the time required and the effect of parboiling on variations in the character of the rubber as reflected by its molecular weight and cleanliness.

The leaves have some possibilities as agriculture fertilizers, and are also sources of resinous material that may prove to be of value. They may also be compressed into satisfactory structural material (110, 348, 351).

STORAGE

One of the major problems in handling guayule for milling is maintaining a constant supply of shrub. This usually involves storage for some period of time, and postwar studies were made on the effect of various storage conditions. The results of these studies were compared with results obtained by milling shrub fresh from the field.

Two methods of storage were: 1) shrubs were dug and field-cured for seven days, baled with leaves on and stored up to six weeks, then parboiled
and defoliated, stored up to six weeks, then milled. The control consisted of shrubs harvested and processed with a minimum delay (110). The results are described below.

**Baled with Leaves On**

Under the conditions of this experiment, increased periods of storage with leaves caused a decreased yield of rubber hydrocarbon in the crude. There was an apparent decrease of rubber in the shrub and a slight decrease in the resin in the crude rubber, but not enough to make any appreciable difference in rubber quality. The total amount of crude recovered per ton of shrub harvested decreased as the length of storage increased.

**Baled without Leaves**

In storage, defoliated shrubs showed an increase in percentage of rubber hydrocarbon accompanied by a decrease in percentage of resin.

**NO STORAGE**

The rubber recovered from milling freshly harvested shrubs had mooney (viscosity) values and molecular weight markedly higher than any rubber produced from stored shrubs. Lowered mooney values and molecular weights after storage are strongly indicative of rubber deterioration through oxidative process. The amount of insolubles in rubber from freshly harvested shrub was markedly lower than rubber obtained through other methods.

The physical properties of crude rubber progressively deteriorated under storage because of continued degradation of the rubber hydrocarbon in the shrubs. On the other hand, the physical properties of the crude are improved by a depletion of resins during the storage period. Optimum improvement occurs at about five weeks of storage. Deterioration results thereafter.

**RELATION OF YIELDS TO MILLING OPERATIONS**

From the milling standpoint, the best shrub was not necessarily that which gave the most shrub tonnage per acre or the most pounds of rubber per acre. Rather it was the shrub with the highest rubber content, harvested in late fall or winter when the moisture content and leaf bulk were lowest and the maximum gains in rubber had been made. Generally, dry-farmed shrubs were preferable to irrigated ones and old plants preferable to young ones.

Mill capacity was more or less constant, with some variations in milling time according to the condition of the shrub milled. For the same capacity, under fairly uniform conditioning treatments, greatest crude rubber output was obtained from the richest shrubs. More efficient milling and a higher recovery of available rubber were also
possible with the richer shrubs. Factors that affected rubber content, therefore, affected milling.

The age of the shrubs and the time of harvest appeared to be the most important. Young shrubs were poorer in rubber than mature shrubs and because of their relatively high resin content tended to yield a poorer quality crude. Winter harvest and milling were best for obtaining shrubs at the peak of their rubber buildup and at the lowest moisture content. Less drying was needed prior to milling, and deterioration between harvest and milling presented less of a problem than when storage was necessary.

Leaf bulk lowered the productive milling capacity. Leaf bulk varied with age of the shrub, type of culture and season of harvest. In the first year, leaf weight was about 30 percent of shrub weight for both dry-farmed and irrigated plants. In the second year it was 20 percent for irrigated and 25 percent for dry-farmed. Data were not available for older age-classes, though on one dry-farmed tract with 10-year old shrubs sampled in midwinter, leaf bulk was less than 5 percent of shrub weight. (Shrub in the winter season generally had fewer and smaller leaves than when it was growing vigorously in spring and summer.)

When guayule is dormant, it tends to be very brittle, and branches are easily broken off. Digging, raking, windrowing and drying before baling caused much breakage and loss of the smaller branches and twigs rich in rubber. Some tracts were gone over twice with rakes to recover such material. When the conditioning operations were changed to baling immediately after digging, losses were reduced because there was less mechanical handling.

Shrub type affected harvest losses noticeably. Dry-farmed shrubs, or the more slowly grown irrigated shrubs, were dug easily and the fields left clean. The large, rapidly grown, irrigated shrubs, in contrast, left more fractions in the ground due to heavy roots and to light soils that did not permit as clean a cutting as the heavier texture (110, 348).

CLEANING AND DEFOILIATION

A rotary trommel has been developed for successful defoliation of plants after parboiling except in the case of pollarded shrub. During the ERP one field was harvested by pollarding. In this case the loss of twigs and branches through the screened section of the trommel approximated 30 percent of the original dry weight. A different defoliator would have to be developed if pollarding became the standard harvest practice. Other developments would be necessary to keep abreast of advances in plant breeding. Some of the guayule stramonium hybrids have very large leaves. The trommel equipped with screens large enough to pass these leaves would probably result in excessively high losses of branches and twigs.
Storage of the shrub after defoliation, termed "retting", involves a microbiological process that has several shortcomings. The actual "ret", induced by mixed microfloral population present in the atmosphere varies greatly from season to season and from location to location. A pure cultural ret would necessitate costly installation to provide sterilization of the material, maintenance of a pure culture inoculum and apparatus for maintaining proper environmental conditions throughout the period of ret. It is doubtful that this process would be economically feasible as a method of removing resin, as retting does not result in rubber with physical properties that approximate rubber obtainable by solvent extraction.

During the ERP some investigation was done on the storage of shrubs as ensilage under essentially anaerobic conditions. This work gave indications that the shrub could be stored as ensilage but further study is needed (110).

ERP PROCESSING PROGRAM

Because of the wartime urgency of the work, the program might be defined as an attempt to secure the maximum amount of rubber of acceptable quality in the minimum amount of time. There evolved a process outlined below.

1) Shrubs were undercut in the field to a depth of about 10 inches.
2) Dug shrubs were windrowed in units of 4 rows each.
3) Shrubs were field-cured for an indefinite period, based on the end moisture content.
4) Foliate shrubs were baled in the field and transported to the mill.
5) Baled shrubs were stored in covered or open storage 30 days to 60 days, presumably depending on the degree of latex coagulation.
6) Whole bales were parboiled in a continuous parboiler. The wires were removed and the bales broken open.
7) Shrubs were defoliated in a screened rotary trommel.
8) Defoliate shrubs were comminuted in a hammermill and pneumatically conveyed to a surge storage bin.
9) Shrubs were automatically discharged from the surge bin and weighed*. A weightometer automatically controlled the rate of discharge from the surge bin.

10) Weighed shrubs were dried in a rotary drier to the accepted optimum moisture of 13 percent to 15 percent.

11) Cut and dried shrubs were passed through two sets of grooved crushing rolls of consecutively decreased clearance.

12) Crushed shrubs were mixed with water at an approximate water-to-solids ratio of 5.5-to-1 and charged to the first of four tube pebble mills (five at Bakersfield). The dry weight of shrubs fed and water-to-solids ratios were not accurately controlled but were an improvement over private operations.

13) Slurry from the fourth mill was diluted to a water-to-solids ratio of approximately 40-to-1 and discharged into a modified Dorr thickener. (At Bakersfield a rectangular tank was used.)

14) Bagasse was removed from the bottom of the thickener (or tank) by an air lift and sent to a continuous centrifugal filter. (A vacuum filter was used at Bakersfield.) The filter cake was further dried and charged to Dutch ovens as boiler fuel.

15) Rubber and cork were skimmed from the top of the thickener and charged batchwise alternately to two pailas and held for 1-1/2 hours to 2 hours at 250 psig.

16) Rubber and cork were discharged pneumatically to a second thickener.

17) Cork was removed from the thickener by air lift and added to the bagasse.

18) Rubber was skimmed from the top of the thickener and, together with a small amount of soap, was charged to a scrub mill.

19) Rubber with clean hot water was charged to a second small tube pebble mill, the rinse mill.

20) Rinsed rubber was discharged from the rinse mill into a high-temperature (around 150 F) retention tank, from which it was discharged and dewatered over a vibrating screen to the drier.

*Actually, automatically controlled rate discharge from the bin was never very successful. For the most part feeding the raw material to the process line was accomplished manually. Continued use of the weightometer, to record amounts of shrub fed, permitted, to some degree, a controlled feed rate even though it was not automatic.
21) Rubber was treated with antioxidant and dried at atmospheric pressure in a 5-zone single- or two-belt drier at increasingly higher temperatures. (The single-belt drier was the more successful.)

22) Dried rubber was blocked into 100-pound bales and boxed for shipment.

The process used by the ERP had certain distinct advantages over the one used by private industry. Variables in the process line were more closely controlled than had been the case previously. An antioxidant of one kind or another was used consistently, and a rubber of better keeping quality resulted. Because of the increased use of hot water, and innovations such as the rinse mill, the end product was cleaner and more uniform. Drying was a continuously controlled process, and dried rubber was superior in uniformity and quality. Of particular importance during wartime was the fact that personnel requirements were materially lowered. This was especially true in the rubber drying and packaging department.

During the postwar research period some modifications were made in the milling process. A flow chart of the improved milling process is shown in Figure 16.

In these studies the raw material entering the milling process had widely differing characteristics. Such differences were due primarily to variations in field cure and fluctuations in climate. Irregularities in the type and duration of shrub storage also played a role. Of minor importance were variations in the location of the fields and in the strains and age of the plants.

Parboiling and defoliation were generally used in all the tests. A number of changes in the general processing were tried with varying results. The first was experimentation with cutters. Crushers and hammermills that use any sharp-edged cutting device were not efficient in processing guayule. A conventional 4-speed hammermill was installed in the mills near Salinas, towards the close of the ERP, and this functioned with only minor maintenance until the close of the project. A similar machine would be recommended for future operations. The use of crushing rolls was also found desirable. Turning of the front and rear rolls at differential speeds imparted a "smearing" action to the rubber-bearing cells that was highly advantageous in securing rubber release.

Storage studies demonstrated that coagulation of the latex in freshly harvested shrubs could be easily completed by parboiling and subsequent mechanical treatment without the addition of coagulent chemicals. It was also found that the hydrocarbon recovery could be increased from 90 percent to 99.5 percent by increased crushing.

As part of this study, investigations were made to determine whether the rubber hydrocarbon was being degraded by the various processing steps. Degradation was judged by the molecular weight of the rubber hydrocarbon. A drop in molecular weight would probably indicate degradation by oxidation and chain cission. None of the separation or
FIGURE 16. FLOW CHART FOR PROCESSING RUBBER FROM GUAYULE
FIGURE 17. SPENCE MILL IN WHICH MOST ERP RUBBER WAS MILLED
FIGURE 18. PEBBLE MILL FOR SEPARATING RUBBER FROM PLANT TISSUE, SALINAS, CALIFORNIA
recovery of water-solvent materials and the recovery of more resin that might contain fractions not found in the resin from worm deresination (20, 62, 63, 110).

**LATEX PRODUCTION**

Several attempts were made to remove rubber from the young plants as latex. The shrub had to be in very fresh condition or no latex could be recovered. Environmental work revealed that physiological fluctuation of the plant from season to season has a profound bearing on the stability of the latex. When shrubs were brought in from the field, kept fresh with the addition of fresh water while cutting, pressed and then milled again using fresh water with dispersing agents, the resultant slurry consisted of dispersed latex, water and a fairly high proportion of finely divided plant solids. Solids were removed by clarifying the liquor in a modified cream separator. After removal of the plant solids the liquor was again run through the separator, resulting in 2 dispersion fractions; one of these contained a major portion of the dispersed latex and the other was principally water. The fraction containing the latex, termed "flush-cream", contained about 7.5 percent rubber. Before it could be used practically, the flushcream was concentrated to a rubber content of 35 percent to 50 percent by adding a chemical creaming agent.

Rubber produced by this method was of high quality with a very low insoluble content and less resin, but it was difficult to produce (110, 162).
APPENDIX A

EXPERIMENTAL PLANTINGS AND ERP INDICATOR PLOTS
APPENDIX A

EXPERIMENTAL PLANTING AND ERP INDICATOR PLOTS

PLANTINGS

West and Southwest

In a 30-year period prior to 1942 the Intercontinental Rubber Company made more than 50 experimental plantings of guayule, scattered over California, Arizona and Texas, and a few additional small plantings in the southern and southeastern states. Commercial guayule was grown near Santa Ana and in the Santa Maria and Salinas valleys of California and also at Continental, Arizona.

Commercial plantings were primarily in the coastal valleys of California, where the annual rainfall is from 12 inches to 20 inches. Rubber hydrocarbon yields for a harvest after four years' growth varied from 400 pounds to 1,600 pounds per acre, with an average rubber content of 11.5 percent. The higher yields were obtained on better lands that now are largely devoted to the production of high-priced crops.

From the interior valleys of California to central Texas, the rainfall is generally not sufficient to grow guayule satisfactorily without irrigation--except in the Sacramento Valley. Here the company obtained yields of 400 pounds to 800 pounds of rubber hydrocarbon per acre, and a rubber content of 8 percent to 11 percent from 4-year old shrubs. These higher yields were obtained only on the better soils of the Sacramento Valley. Another area that offered promise without irrigation was in the Rio Grande Valley of Texas, where plantings at Dilley and Hebbronville yielded 600 pounds of rubber hydrocarbon per acre with a rubber content of 7 percent to 9 percent from 3-year old shrubs. One test, however, with a spacing of 12 inches, gave a yield of 900 pounds of rubber hydrocarbon per acre from 3-year old shrubs.
Intercontinental grew guayule under irrigation in the Salinas and San Joaquin valleys of California and also in the Salt River Valley of Arizona. Better rubber yields were secured with irrigation in the Salinas Valley, but these increases were slight and probably did not justify the added cost. At Shafter, California, 500 pounds of rubber hydrocarbon per acre and a rubber content of only 4 percent were secured by the end of the third year under irrigation. At Litchfield, Arizona, 1,110 pounds of rubber hydrocarbon per acre and a content of 5 percent were obtained at the end of the fourth year. Under irrigation at Avondale, Arizona, a rubber yield of 500 pounds per acre and a rubber content of 8.8 percent were secured after only two years.

Southeast

The company's few experimental plantings in the South and Southeast were made in an effort to determine the response of the shrub to soils and climatic influences there. A small planting was made in 1927 at the Coastal Plain Experimental Station in Tipton, Georgia. All plants were dead by January 1928. This loss was attributed to root rot fungi. Temperatures were recorded as low as 14 F, which caused only shedding of the leaves. A second planting was made at this station in 1928, but most of the plants were dead by 1929. The cause of this loss also was root rot.

In March 1927 a planting was made at Windsor, South Carolina. During January 1928 a temperature as low as 8 F killed the shrub to within 8 inches of the ground. This plot was discontinued in February 1928.

A planting was also made at Picayune, Mississippi, in March 1927. Seedlings used in this planting had already started to grow when they arrived from California, and many died soon after planting and during the summer. By February 1928 only the largest, most vigorous seedlings were alive, and these were very few.

Considering all factors, the company's information on guayule response to the soils and climate of the southern and southeastern states is not sufficient to conclude whether guayule will grow there. Almost all of the plots were planted in the spring of 1927, admittedly from a very poor grade of stock. Also, the winter of 1927-28 was one of the coldest. There are no analyses on record from any of these plots. It might be reasoned from later studies at other locations in eastern and southeastern Texas that guayule would not do well under conditions of high rainfall that prevail in the South and Southeast. The shrub would probably remain in an active state of growth because of high rainfall during fall and early winter and would be less resistant to cold weather in these regions. Furthermore high soil moisture conditions during the spring, summer and early fall would encourage the growth of root rot, which has been listed previously as a major cause of losses in these regions.
ADDITIONAL GUAYULE PLANTING

The government purchased the Salinas properties from Intercontinental in February 1942 to begin an emergency program for the production of rubber from guayule. One of the most pressing problems was to determine what other areas in the southwestern states were suitable for the crop. If guayule were to be grown on a large scale, it would obviously be necessary to grow it in areas other than along the Pacific Coast and a few other small areas from which the company had secured promising results.

During World War II, 135 indicator plots were established in California, Arizona, New Mexico and Texas under the supervision of the Bureau of Plant Industry, Soils and Agricultural Engineering. The results obtained from these plots were summarized by H. W. Reynolds and R. L. Holmes in 1945 (278). The following information is from their report.

These test plots, established from 1942 to 1944, were planted to provide information on climate and soil conditions suitable to guayule production. While results from these plots were essentially the same as those obtained on larger plantations, some minor differences were noted. Test plots also include a much larger range of conditions than the production plantings.

A few of the eight 1-acre plantations established in 1942 were laid out on the Latin Square design, providing replications for different spacings, varieties and treatments (irrigated or dry). Some of the other plots were half irrigated and half dry.

With the exception of subplots laid out for spacing tests, practically all the California plots were laid out with a 28-inch spacing between rows. Most of the plots in Arizona, New Mexico and Texas were established with wider row spacing but exact spacing was not recorded. Spacing within rows was 30 inches, 24 inches or 12 inches.

During the spring of 1943, 47 additional plots were planted in the same general area but under different soils and climatic conditions. They included only variety 593 and a standard between-row spacing of 28 inches. Spacing between rows was 24 inches for plots under rainfall only, and 20 inches for those under irrigation. Several of these plots were 1/2-acre, and in most Texas plots only half was planted in the spring of 1943, with the balance reserved for planting in the fall.

Very few new plots were established during the spring of 1944, but most portions of Texas plots planted in the fall of 1943 were replanted because cold had killed the young seedlings.

Rubber analyses for plots established in 1942 were made in November 1942; February, July and November 1943; February 1944; and February 1945. Analyses for 1943 plots were made in November 1943; February 1944; and February 1945. The first two samplings included leaves in dry weight and the percentage of rubber is based on plants including leaves.
Beginning with July 1943, all samples had leaves removed before analysis, and the percentage of rubber is based on the defoliated shrub. As the spacing of plants in Arizona, New Mexico and Texas was wider than in California, it was concluded that the yields would have been greater on the closer spacing.

Shrub weight increased faster between 1944 and 1945 on irrigated Arizona plots than in the other locations. Increase was nearly twice that of New Mexico and Texas shrubs and about three times that of California plots.

Percentage of rubber was the highest in Arizona plots at the end of the first season but the lowest after about three years. No increase resulted in percentage of rubber between the 1944 and 1945 samplings in Arizona, but slight increases resulted during the same period in both the California and New Mexico-Texas areas. At the end of the third season of growth, the highest yield resulted in Arizona even though the percentage of rubber was lowest. This was because the Arizona shrub weights were high.

**Soils**

Results from the indicator plots verified those from plantations in that plants survived best on medium-textured soils, such as sandy and silty loams, which do not contain underlying layers of heavier textured materials. The heavy textured materials interfered with the normal movement of soil moisture after irrigation or rainfall and caused excessive moisture to accumulate in the upper soil horizons, a condition favorable to the growth of root-rotting organisms and improper soil aeration. Good survivals accrued on several plots that contained rather heavy-textured soils, but only when they had good structure and uniform texture in the root zone.

**Salt Tolerance**

Guayule did not grow where the first 12 inches of topsoil contained concentrations of sulphates and chlorides greater than 0.2 percent or where the 12-inch to 24-inch soil layer had concentrations above 0.6. Additionally, no growth resulted when the average salt concentration per foot of the 12-inch to 60-inch zone was 0.6 or over. Growth was impaired where there was as little as 0.2 in the first 12 inches and where the 12-inch to 24-inch layer contained 0.2 to 0.6 salt, or where the average concentration per foot of soil below the surface 12 inches was 0.2 to 1.0 salt. The shrubs were more tolerant of sulphates and chlorides in their second year of growth than during the first year. After one season of growth, shrubs growing in areas known to contain concentrations of sodium salts (black alkali) were less than half the size of those in parts of the same plot that were free of salt. The shrubs growing in salt areas also displayed extremely heavy stress as compared with shrubs in salt-free areas.

Guayule made little growth on soils that were practically sterile—such as the Superstition sands—in the East Mesa and Yuma Mesa areas of
extreme southeastern California and southwestern Arizona. But shrubs on a Yuma plot, located on a Superstition loamy fine sand, responded to fertilizer treatment in an area where alfalfa had been plowed under before the establishment of guayule.

Guayule withstood a winter flooding on a well-drained silt loam soil in the Upper Sacramento Valley of California, but was killed on two plots in the Rio Grande Valley after a summer flooding when the shrub was actively growing.

Differences in soils are great and readily overshadow the differences in climate if the shrub is irrigated, except in the comparison of soil extremes between the immediate coastal and the interior valleys. In general, areas of high temperature and long hours of sunshine with a controlled water supply favored the growth of guayule. In many cases, rapid growth was offset to some extent by a decrease in the percentage of rubber; nevertheless, the highest yields of rubber were obtained in such instances under irrigation. Plants grown without irrigation, under climatic influences that subject the shrub to extreme stress of long duration, produced a lower rubber content and yield than those that received less severe treatment. This indicates that, although a certain degree of stress favors rubber formation, extreme stress of long duration with a loss of all or part of the leaves is not conducive to the formation of rubber.

Cold Tolerance

Damage to shrubs from freezing temperatures was recorded on plots at Roswell and Artesia, New Mexico and Lubbock, Texas, after the winter of 1942-43. Minor cold injury was recorded near San Angelo, Texas. Minimum temperatures of 7 F and 10 F recorded at Roswell on January 18, 19, and 20, destroyed practically an entire plot which was not well hardened at the onset of winter. A minimum temperature of 6 F on January 18 caused a mortality of 3.4 percent on a plot at Artesia, with considerable injury to the aboveground parts of the surviving shrub. At Lubbock a temperature of zero F was recorded on January 19, and 7 F was recorded during early March. Greatest injury appeared to result from the March freeze, because the shrub was not as dormant as it had been in January. A survey made during May revealed a mortality of 33.4 percent with varying degrees of injury to the aboveground parts of most of the surviving shrubs.

During the 1943-44 winter, additional plots sustained moderate to severe cold injury. The greatest damage resulted in the upper Rio Grande and Pecos valleys on plots at Canutillo, Texas and Las Cruces, Roswell, and Artesia, New Mexico. Moderate injury was recorded on plots south and east of these stations.

Temperatures of 11 F and 9 F caused considerable damage at Las Cruces, especially on subplots in which the shrub was not well hardened as a result of late-summer irrigations. A survey at this plot indicated a correlation between cold injury and shrubs that were not well hardened—because they had been irrigated in the late summer. This same correlation existed in practically all the plots.
All shrubs that had been placed in the colder areas in the fall of 1943 were killed by cold. These plants were young and tender and had barely become established at the onset of freezing temperatures.

An unusually mild 1944-45 winter prevailed at nearly all places where indicator plots were located. Temperatures around 26°F, as late as April, caused slight terminal injury to shrubs that had started spring growth at plots near Ballinger, Wall and Tankersley, Texas. At Lubbock, the shrub sustained only slight injury from temperatures of 19°F and 22°F, recorded on April 4 and 5. But very little if any new spring growth had started at this time.

Weed Competition

During the spring of 1942, considerable damage resulted to Sacramento Valley plots from such common winter annuals as black mustard and wild oats. Perennials such as Johnson grass, wild morning glory and Bermuda grass were troublesome in the Sacramento San Joaquin and Imperial valleys. Summer annuals such as puncture vine and careless weed caused some trouble in both the San Joaquin and Imperial valleys but were readily controlled by regular cultivation.

In Arizona the most difficult weeds to control were Bermuda and Johnson grass. Mallow was troublesome in a few plots, particularly during the fall months. Puncture vine occurred in most of the plots but was readily controlled by regular cultivation. Wild morning glory was also troublesome in many of the Arizona plots, and as in California, constant cultivation was necessary to keep this pest under control.

Some damage resulted from weeds in Texas and New Mexico indicator plots, especially during the spring, summer, and fall of 1942. Heavy late summer and fall rains, which usually prevail throughout the Lower Rio Grande Valley and Plains area, and mild fall and winter temperatures caused rank weed growth and necessitated cultivation during the fall and throughout the winter season. Less damage resulted from weeds in western, northwestern, and central Texas and in New Mexico, because rainfall is less plentiful and the growing season is shorter here than in the Rio Grande Valley and Plains region. Perennials such as blueweed, wild morning glory, Johnson grass and Bermuda grass have been the most troublesome. Annual or biennial weeds such as crabgrass, puncture vine, horse nettle, sandburs, stink grass, plains bristle grass and Texas needle grass were also troublesome and required regular cultivation to keep them under control (213, 278, 390).

Rubber Accumulation

There was a rapid accumulation of rubber during the latter part of the second year. From July 1943 to February 1944 the yield of rubber per acre nearly tripled. This indicates the desirability of delaying harvest until the post-growing season rubber accumulation period is over—approximately the beginning of the third growing season. Percentage of rubber by weight increased very little between the second and
third years, but with a great increase in tonnage of shrub, the yield of rubber per acre practically doubled. A study of seven irrigated plots that contained randomized subplots with three different spacings showed the closest-spaced shrub added more dry weight than wide-spaced shrub between the first and second years. Between the second and third years there was little difference in amount of dry weight added between close and wide spacings, but close spacing produced approximately 3,200 pounds more shrub per acre.

TABLE 9
POUNDS OF SHRUBS ON SEVEN IRRIGATED PLOTS PLANTED IN 1942*

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>Spacing 28&quot; x 30&quot;</th>
<th>Spacing 28&quot; x 24&quot;</th>
<th>Spacing 28&quot; x 12&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 1943</td>
<td>2,716 lbs</td>
<td>3,231 lbs</td>
<td>3,540 lbs</td>
</tr>
<tr>
<td>February 1944</td>
<td>6,568</td>
<td>7,244</td>
<td>9,343</td>
</tr>
<tr>
<td>February 1945</td>
<td>11,408</td>
<td>11,688</td>
<td>14,652</td>
</tr>
</tbody>
</table>

*Based on 100 percent stand of shrub.

For some individual plots the percentage of rubber was significantly higher in the close spacing, but when all seven plots were considered, the general statement that rubber percentage is higher in closely spaced shrub could not be proved. There was a great increase in percentage of rubber between 1943 and 1944, but no increase between 1944 and 1945.

TABLE 10
RUBBER PERCENTAGE FOR SEVEN IRRIGATED PLOTS PLANTED IN 1942

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>Spacing 28&quot; x 30&quot;</th>
<th>Spacing 28&quot; x 24&quot;</th>
<th>Spacing 28&quot; x 12&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 1943</td>
<td>4.00</td>
<td>3.82</td>
<td>4.16</td>
</tr>
<tr>
<td>February 1944</td>
<td>6.60</td>
<td>7.19</td>
<td>6.85</td>
</tr>
<tr>
<td>February 1945</td>
<td>6.32</td>
<td>6.43</td>
<td>6.69</td>
</tr>
</tbody>
</table>

Closely spaced shrubs added more rubber per weight than the wider spacings during both the second and third years. The highest rubber yield was also produced on the close spacing in February 1943, 1944 and 1945.
TABLE 11

POUNDS OF RUBBER PRODUCED ON SEVEN IRRIGATED PLOTS
PLANTED IN 1942*

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>28&quot; x 30&quot;</th>
<th>28&quot; x 24&quot;</th>
<th>28&quot; x 12&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 1943</td>
<td>109 lbs</td>
<td>128 lbs</td>
<td>137 lbs</td>
</tr>
<tr>
<td>February 1944</td>
<td>433</td>
<td>489</td>
<td>546</td>
</tr>
<tr>
<td>February 1945</td>
<td>716</td>
<td>751</td>
<td>944</td>
</tr>
</tbody>
</table>

*Yields based on 100 percent stand of shrub.

The greatest tonnage of shrub in dry-farmed plots was produced on the closest spacing at the time of each sampling—as was the case for irrigated plots.

TABLE 12

POUNDS OF SHRUB PER ACRE ON FOUR DRY-FARMED PLOTS
PLANTED IN 1942*

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>28&quot; x 30&quot;</th>
<th>28&quot; x 24&quot;</th>
<th>28&quot; x 12&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 1943</td>
<td>1,366 lbs</td>
<td>1,564 lbs</td>
<td>2,140 lbs</td>
</tr>
<tr>
<td>February 1944</td>
<td>3,161</td>
<td>3,275</td>
<td>4,527</td>
</tr>
<tr>
<td>February 1945</td>
<td>5,153</td>
<td>5,289</td>
<td>7,038</td>
</tr>
</tbody>
</table>

*Based on 100 percent stand of shrub.

Percentage of rubber was lower in dry-farmed plots than in irrigated plots at the time of the first sampling, but was higher in all spacings in later samplings.

The closest spacing in dry-farmed plots produced the highest yield of rubber at the time of each sampling. The yield of rubber practically doubled in each spacing between the February 1944 and 1945 samplings.

In comparing irrigated and dry-farmed plots after about three years of growth, tonnage of shrub on irrigated plots was twice that of dry-farmed, and the yield of rubber was over 50 percent more.
TABLE 13
POUNDS OF RUBBER PRODUCED ON FOUR DRY-FARMED PLOTS PLANTED IN 1942*

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>28&quot; x 30&quot;</th>
<th>28&quot; x 24&quot;</th>
<th>28&quot; x 12&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 1943</td>
<td>38 lbs</td>
<td>44 lbs</td>
<td>61 lbs</td>
</tr>
<tr>
<td>February 1944</td>
<td>227</td>
<td>251</td>
<td>329</td>
</tr>
<tr>
<td>February 1945</td>
<td>431</td>
<td>421</td>
<td>601</td>
</tr>
</tbody>
</table>

*Yields based on 100 percent stand of shrub.

TABLE 14
YIELD COMPARISON OF IRRIGATED AND DRY-FARMED PLOTS PLANTED IN 1942

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>Average of 39 Irrigated Plots</th>
<th>Average of 11 Dry Plots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry wt (grams)</td>
<td>Percent Rubber</td>
</tr>
<tr>
<td>November 1942¹</td>
<td>136</td>
<td>1.46</td>
</tr>
<tr>
<td>February 1943²</td>
<td>164</td>
<td>3.86</td>
</tr>
<tr>
<td>July 1943²</td>
<td>212</td>
<td>3.29</td>
</tr>
<tr>
<td>November 1943²</td>
<td>390</td>
<td>4.89</td>
</tr>
<tr>
<td>February 1944²</td>
<td>386</td>
<td>6.17</td>
</tr>
<tr>
<td>February 1945²,³</td>
<td>647</td>
<td>6.38</td>
</tr>
</tbody>
</table>

¹ All determinations made on the basis of sample including leaves.
² All determinations made on the basis of defoliated plants.
³ Based on averages of 33 irrigated and nine dry-farmed plots.
⁴ Based on 100 percent stand of shrub.
APPENDIX B

TABULATION SHOWING NUMBER OF PLANTS PER ACRE FOR DIFFERENT SPACINGS
APPENDIX B

TABULATION SHOWING NUMBER OF PLANTS PER ACRE FOR DIFFERENT SPACINGS

The tabulation below shows the computed square inches per plant and number of plants per acre for various spacings, ranging from 36 inches by 36 inches down to 24 inches by 6 inches. Theoretically, best results should be obtained by square spacing. For example, if about 11,000 plants per acre were planted, 24 inches by 24 inches would seem best. But if a machine planting 28 between rows were available, this tabulation shows that a spacing of 28 inches by 20 inches results in planting approximately the same number of plants per acre as 24 inches by 24 inches—with only 16 square inches less growing space available per seedling (393).

TABLE 15

PLANTS PER ACRE AT DIFFERENT SPACINGS

<table>
<thead>
<tr>
<th>Spacing</th>
<th>Square Inches per Plant</th>
<th>Number of Plants per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>30&quot; x 18&quot;</td>
<td>1,926</td>
<td>11,610</td>
</tr>
<tr>
<td>36&quot; x 36&quot;</td>
<td>1,080</td>
<td>5,808</td>
</tr>
<tr>
<td>36&quot; x 30&quot;</td>
<td>900</td>
<td>6,969</td>
</tr>
<tr>
<td>36&quot; x 24&quot;</td>
<td>864</td>
<td>7,260</td>
</tr>
<tr>
<td>28&quot; x 28&quot;</td>
<td>784</td>
<td>8,007</td>
</tr>
<tr>
<td>30&quot; x 24&quot;</td>
<td>720</td>
<td>8,712</td>
</tr>
<tr>
<td>36&quot; x 20&quot;</td>
<td>720</td>
<td>8,712</td>
</tr>
<tr>
<td>28&quot; x 24&quot;</td>
<td>672</td>
<td>9,347 dry</td>
</tr>
<tr>
<td>36&quot; x 18&quot;</td>
<td>648</td>
<td>9,680</td>
</tr>
<tr>
<td>30&quot; x 20&quot;</td>
<td>600</td>
<td>10,471</td>
</tr>
<tr>
<td>24&quot; x 24&quot;</td>
<td>576</td>
<td>10,890</td>
</tr>
<tr>
<td>28&quot; x 20&quot;</td>
<td>560</td>
<td>11,226 irrigated</td>
</tr>
<tr>
<td>30&quot; x 12&quot;</td>
<td>540</td>
<td>11,616</td>
</tr>
<tr>
<td>28&quot; x 16&quot;</td>
<td>448</td>
<td>14,000</td>
</tr>
<tr>
<td>28&quot; x 18&quot;</td>
<td>504</td>
<td>12,445</td>
</tr>
<tr>
<td>24&quot; x 18&quot;</td>
<td>432</td>
<td>14,520</td>
</tr>
<tr>
<td>36&quot; x 12&quot;</td>
<td>432</td>
<td>14,520</td>
</tr>
<tr>
<td>28&quot; x 14&quot;</td>
<td>392</td>
<td>16,014</td>
</tr>
<tr>
<td>30&quot; x 6&quot;</td>
<td>360</td>
<td>17,424</td>
</tr>
<tr>
<td>28&quot; x 12&quot;</td>
<td>336</td>
<td>18,695</td>
</tr>
<tr>
<td>24&quot; x 12&quot;</td>
<td>288</td>
<td>21,780</td>
</tr>
<tr>
<td>36&quot; x 6&quot;</td>
<td>216</td>
<td>29,040</td>
</tr>
<tr>
<td>28&quot; x 7&quot;</td>
<td>196</td>
<td>32,029</td>
</tr>
<tr>
<td>28&quot; x 6&quot;</td>
<td>168</td>
<td>37,551</td>
</tr>
<tr>
<td>24&quot; x 6&quot;</td>
<td>144</td>
<td>43,560</td>
</tr>
</tbody>
</table>
APPENDIX C

PLANTATION EQUIPMENT REQUIRED
APPENDIX C

PLANTATION EQUIPMENT REQUIRED

Production of guayule as a cultivated crop, especially on irrigated land, was found to be a rather intensive type of row-crop farming. This required large amounts of farming equipment, especially for ground preparation and cultivation (393). Listed below are the equipment needs as determined by the ERP.

TABLE 16

EQUIPMENT REQUIREMENTS

<table>
<thead>
<tr>
<th>Item of Equipment</th>
<th>Number of Units Required per 1,000 Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Planting, Summer Fallow &amp; Ground Preparation</td>
</tr>
<tr>
<td>Tractor, crawler--over 30 hp</td>
<td>5</td>
</tr>
<tr>
<td>Tractor, crawler--20 to 30 hp</td>
<td>3</td>
</tr>
<tr>
<td>Tractor, crawler--under 20 hp</td>
<td>3</td>
</tr>
<tr>
<td>Tractor, wheel type w/cultivator</td>
<td></td>
</tr>
<tr>
<td>Machine, planting</td>
<td>3</td>
</tr>
<tr>
<td>Plow, 4-bottom</td>
<td>2</td>
</tr>
<tr>
<td>Plow, ditching</td>
<td></td>
</tr>
<tr>
<td>Harrow, Portuguese</td>
<td>1</td>
</tr>
<tr>
<td>Harrow, 2-section, steel</td>
<td>4</td>
</tr>
<tr>
<td>Chisel, heavy duty</td>
<td>1-1/2</td>
</tr>
<tr>
<td>Chisel, light duty</td>
<td>3</td>
</tr>
<tr>
<td>Cultipacker</td>
<td>3</td>
</tr>
<tr>
<td>Disc--offset</td>
<td>3</td>
</tr>
<tr>
<td>Harrow, 5-section, wood</td>
<td>1</td>
</tr>
<tr>
<td>Float or Eversman leveler</td>
<td>1</td>
</tr>
<tr>
<td>Truck, stake, 1-1/2 ton</td>
<td>4</td>
</tr>
<tr>
<td>Truck, pickup, 1/2 ton</td>
<td>2</td>
</tr>
<tr>
<td>Grader</td>
<td>1/2</td>
</tr>
<tr>
<td>Ditcher, Martin</td>
<td>1/2*</td>
</tr>
<tr>
<td>Oil sprayer (integral attachment for</td>
<td></td>
</tr>
<tr>
<td>crawler tractor under 20 hp)</td>
<td>3/4</td>
</tr>
<tr>
<td>Oil storage units</td>
<td>1/2</td>
</tr>
</tbody>
</table>

*For irrigated land only.
<table>
<thead>
<tr>
<th>Operation</th>
<th>Acres per Unit Hour</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discing</td>
<td>2.00</td>
<td>9-foot disc</td>
</tr>
<tr>
<td>Plowing</td>
<td>1.50</td>
<td>4-bottom plow</td>
</tr>
<tr>
<td>Harrowing</td>
<td>4.50</td>
<td>5-section heavy wood harrow</td>
</tr>
<tr>
<td>Chiseling</td>
<td>1.50</td>
<td>9-foot chisel--deep chiseling</td>
</tr>
<tr>
<td>Cultivating</td>
<td>2.00</td>
<td>4-row cultivator</td>
</tr>
<tr>
<td>Planting</td>
<td>.90</td>
<td>Holland 4-row</td>
</tr>
<tr>
<td></td>
<td>.75</td>
<td>Kind of 4-row</td>
</tr>
<tr>
<td>Floating</td>
<td>2.00</td>
<td>10-foot float</td>
</tr>
</tbody>
</table>
### TABLE 18

**EQUIPMENT NEEDS FOR HARVESTING 1,000 ACRES OF GUAYULE SHRUB**

Basis: 6-Month Period of 100 Working Days

<table>
<thead>
<tr>
<th>Item of Equipment</th>
<th>2-year Irrigation</th>
<th>3-year Irrigation</th>
<th>3-year Dry</th>
<th>4-year Dry</th>
<th>5-year Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor, crawler, under 20 hp</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tractor, crawler, 20 to 30 hp</td>
<td>2</td>
<td>2.75</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Digger--2-row</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Baler, portable, motor driven</td>
<td>2</td>
<td>2.75</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Trailer, 2-wheel, flat rack</td>
<td>2</td>
<td>2.75</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Trucks, 5-ton, flat rack</td>
<td>1.75</td>
<td>2.50</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
APPENDIX D

RUBBER EXTRACTION METHODS DEVELOPED IN MEXICO

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APPENDIX D

RUBBER EXTRACTION METHODS DEVELOPED IN MEXICO

An improved method of rubber extraction was developed by the Centro de Investigaciones Química Aplicada in Saltillo, Coahuila, Mexico. The center was in full operation during 1977 and produced rubber for experimental purposes.

Shrubs are first dipped in hot water for 10 minutes at 75 C (167 F). This coagulates the rubber and removes foreign material and leaves. The plants are then passed through a hammermill and a Bauer mill (a device used in paper making) which break open the rubber-filled cells. Caustic soda is added during the pulping process to help break open the rubber-filled cells for separation of the rubber from the vegetable matter. The pulping is done in water and the rubber and brown, pungent resins conglomerate into the spongy form known as "worms." The material is then transferred to a slurry tank, where the waterlogged bagasse sinks and the rubber worms float and are skimmed from the surface. The resinous worms are then rinsed to remove the caustic soda with detergent added to the water. The guayule worms containing 17 percent to 25 percent resins, are extracted with warm acetone, which carries away about 95 percent of the resins. The acetone is then distilled from the resin-water mixture and recycled. After steam treatment to remove the residual acetone, the gray-white guayule rubber contains about two percent resin, as well as cork and debris that failed to sink in the slurry tank. The deresinated rubber can be dissolved in a solvent and filtered to remove the residual insolubles (cork, fiber, dirt). This filtered solution is homogeneous and the rubber can be bleached, protected with antioxidants or treated with reagents to give a high-quality, uniform product. While in solution, the rubber can be altered by polymerization chlorination, copolymerization with methacrylates and other chemical reactions that produce rubbers with different properties. The end product is a rubber of high quality with very low amounts of ash, copper and iron (54).
APPENDIX E

SUMMARY OF GUAYULE SEED INFORMATION

Findings of the Emergency Rubber Project
APPENDIX E

SUMMARY OF GUAYULE SEED INFORMATION

Based on Findings of the Emergency Rubber Project*

1. **Approximate Collection Dates** (California and Arizona)

   First Year Plantations—Non-irrigated plantations, crop ripens about September 1.
   - Irrigated plantations, July to December, depending on climate and frequency of water application.

   Second Year and Older Plantations—On both irrigated and unirrigated land the first crop ripens in late June. On irrigated land, collections may continue to December, depending on climate and number of irrigations.

2. **Number of Probable Collections** (California)

   Unirrigated (Dry) Plantations—Plan on two collections, one when 40 percent to 60 percent of the seed is ripe, and the second when the remainder ripens.

   Irrigated Plantations—Three to seven collections are possible, depending on the climate and frequency of water application.

*(392)
3. **Formula for Estimating Yields**

\[
\text{Actual Number of Plants per Acre} \times \frac{\text{Average Number of Flower Stalks per Plant}}{7,500} = \text{Pounds of Clean Seed Available per Acre}^1
\]

4. **Approximate Range of Seed Collections per Acre per Season**
   (California)

<table>
<thead>
<tr>
<th>Age of Plants</th>
<th>Rough Weight</th>
<th>Cleaned Weight</th>
<th>Treated Weight</th>
<th>Threshed Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Year</td>
<td>10 to 100</td>
<td>5 to 50</td>
<td>3 to 30</td>
<td>0.6 to 6</td>
</tr>
<tr>
<td>Second Year &amp; Older</td>
<td>100 to 20,000</td>
<td>50 to 1,000</td>
<td>30 to 600</td>
<td>6 to 120</td>
</tr>
</tbody>
</table>

5. **Average Reductions by Cleaning and Treating or Threshing**

Cleaning reduces the rough machine-collection weight by approximately 50 percent.

Cleaning reduces the weight of hand-collected seed by approximately 33 percent.

Gravity separation reduces the clean seed weight by approximately 20 percent to 50 percent.

Treating of clean seed reduces the weight by 40 percent, and treating of threshed seed reduces the weight by approximately 17 percent.

Threshing reduces the clean seed weight by approximately 80 percent.

Threshing reduces the clean seed volume by approximately 90 percent.

---

1. Amount actually secured with machine picker will be about one-fifth to one-half of this amount; by hand-collection about 50 percent to 90 percent of this amount.

2. The seed crop varies so widely from the plant's response to environmental factors that a cited average would be nearly meaningless and misleading to anyone undertaking the growth of guayule for the first time. For discussion of yield influences and the proportions of the crop recovered by hand and machine collection, respectively, consult the text under "Seed Collection."
6. **Usual Strength of Sodium Hypochlorite Solution Used for Treating Seed**

Clean, Unthreshed Seed--1.5 percent solution

Threshed Seed--0.25 percent to 0.50 percent solution.

7. **Usual Quantity Ratio of Sodium or Calcium Hypochlorite Solution Used for Treating Seed**

Clean, Unthreshed Seed--ratio: 1:20 by weight or one pound of seed to 2.5 gallons of solution

Threshed Seed--ratio: same as for unthreshed seed.

8. **Variations in Filled Percent by Types of Seed**

<table>
<thead>
<tr>
<th>Type of Seed</th>
<th>Percentage of Filled Seeds Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncleaned</td>
<td>0 to 70, generally 10 to 45</td>
</tr>
<tr>
<td>Threshed and Gravity Separated</td>
<td>85 to 99.</td>
</tr>
</tbody>
</table>

9. **Typical Numbers of Seeds per Pound**

<table>
<thead>
<tr>
<th>Type of Seed</th>
<th>Seeds per Pound Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Untreated Unthreshed</td>
<td>200,000 to 275,000</td>
</tr>
<tr>
<td>Clean Treated Unthreshed</td>
<td>300,000 to 412,000</td>
</tr>
<tr>
<td>Clean Untreated Threshed</td>
<td>500,000 to 600,000</td>
</tr>
<tr>
<td>Clean Treated Threshed</td>
<td>600,000 to 700,000.</td>
</tr>
</tbody>
</table>

10. **Normally Desirable Moisture Content of Seed in Storage**

<table>
<thead>
<tr>
<th>Storage Type</th>
<th>Moisture Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary Aerated Storage</td>
<td>7 percent moisture content</td>
</tr>
<tr>
<td>Temporary Sealed Storage</td>
<td>7 percent moisture content</td>
</tr>
<tr>
<td>Long-term Sealed Storage</td>
<td>dry to 4 percent moisture content promptly after cleaning and place immediately in sealed containers.</td>
</tr>
</tbody>
</table>
11. **Storage and Safe Temperatures for Seed**

Moist Seed—Do not exceed 120°F even for limited periods when drying the seed after treating it.

Dry Seed in Open Storage—Extended periods of temperatures over 120°F in arid areas have not seriously affected viability.

Dry Seed in Sealed Storage—Extended periods of alternating high and low temperatures have not been detrimental.

Seed with 7 percent moisture withstood minus 112°F for 72 hours and plus 195°F for 24 hours without loss of viability.

Seed at 4 percent moisture content placed in sealed storage promptly after cleaning can be kept satisfactorily for more than 10 years.

Seed in open storage in high areas of high humidity is likely to lose viability rapidly after 1-1/2 to 2 years.

12. **Sowing Rate Frequently Used**

<table>
<thead>
<tr>
<th>Clean Treated Seed*</th>
</tr>
</thead>
<tbody>
<tr>
<td>To sow 1,000 nursery beds (4 feet by 400 feet)</td>
</tr>
<tr>
<td>1.25 pounds per bed</td>
</tr>
</tbody>
</table>

To provide enough seedlings to plant 1,000 acres of plantations at 28 inches by 20 inches spacing (assuming one bed will provide seedlings for two acres of plantations).

| 625 pounds. |
|  |

*Using seed 40 percent filled and 35 percent viable.

13. **Optimum Temperatures for Germination of Seed in Nursery Beds**

Minimum night temperature should be 65°F to 70°F.

Daytime temperatures should be approximately 86°F to 100°F, with 110°F for several hours daily not seriously detrimental.

14. **Definitions of Terms**

Achene—A fruit consisting of an embryo and its seedcoat enclosed by a dry pericarp. It does not include floral parts that may grow attached to the pericarp.
Aerated Storate--Storage permitting exchange of atmospheric gases with those created by seed respiration, as in cloth sacks.

Available Chlorine--The oxidizing power of compounds containing chlorine. (The available chlorine rating of a solution of sodium hypochlorite is not grossly different from the percentage of sodium hypochlorite.)

Clean Seed--Seed that has been separated, to the extent of practical working limits, from other materials, such as leaves, sticks, dirt and seeds of other species.

Clipper Cleaner--Seed-cleaning machine manufactured by the A.T. Ferrell Company of Saginaw, Michigan, consisting of two or more perforated screens in a reciprocally moving riddle that may be supplemented by provision for passing the seed through an air blast for further cleaning. Various models are made.

Embryo Dormancy--Any condition of the seed embryo in which the absorption of moisture, air and warmth does not initiate normal germination. (Distinguishable from seedcoat dormancy in which impermeability of the seedcoat prevents water or air from reaching the embryo.)

Filled Percentage--Ratio of the number of seeds that contain embryos to the total number of seeds.

Gravity Separation--Segregation of particles of unlike density, density being considered as relation of weight to space occupied.

Gravity Separator--A machine for accomplishing gravity separation on a continuous flow basis. More completely described in the accompanying text.

Long-term Storage--Storage longer than two or three years.

Sealed Storage--The opposite of aerated storage. Storage in full containers impervious to the exchange of atmospheric gases with the contents.

Seed--The grains or ovules of plants used for sowing. The term as used without a qualifying adjective refers to the guayule achene with its attached florets and subtended bract.

Short-term Storage--Storage for less than two or three years.

Treated Seed--Seed that has been treated with sodium hypochlorite or calcium hypochlorite.

Threshed Seed--Synonymous with achene from which the florets and bract had been removed by threshing.
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BIBLIOGRAPHY

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