WILD LETTUCE AS A SOURCE OF NATURAL RUBBER

by

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CURVES

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1. INTRODUCTION

The world's peace-time requirements of rubber were met by rubber-tree plantations. It was generally assumed that a sufficient supply would be available from these rubber plantations at all times. The Far East became the rubber-tree growing center of the world since suitable climate and abundant, cheap labor favored its development in these regions. Approximately 98 per cent of American crude rubber stocks were imported from Malaya and the East Indies.

There are two possible sources which can alleviate the rubber shortage. First, the production of synthetic rubber. Second, rubber from rubber-bearing plants grown in the United States.

The idea of obtaining rubber from domestic plants is not a new one. In the past, whenever the price of plantation rubber went skyward, or in times of national emergency, enthusiastic crusades were started to make the United States self-sufficient in rubber. There are a large number of plants, either native or introduced, growing in the United States which contain rubber — at least several hundred, and probably close to a thousand. A relatively few of these have been investigated thoroughly, and a much larger number to a small extent. The information or results of these investigations is available, but is scattered throughout many publications, and not collected to allow comparison and evaluation of the different possibilities.

The first part of this investigation is to consist of the collection of the information and a presentation of the essentials of description, distribution, ecology and rubber content, in condensed form. One of the plants known to contain rubber, and on which very little work has been done is wild lettuce. The second part of the problem is to obtain information necessary to establish the place of wild lettuce, as a source of natural rubber, among the other rubber-bearing plants.

II. LITERATURE REVIEW

DANDELION

Botanical name: Taraxacum kok-sagyz

Description: Low, leafy perennial plant; leaves elliptical, smooth, about one inch wide and four to five inches long, 30 to 40 springing from crown near the ground; characteristic flower stems, 10 to 30 per plant; seeds minute, wind distributed; root robust, two to five main branches, sometimes 14 inches long.

Rubber-bearing parts: Rubber occurs in the laticiferous tubes of the roots, leaves, and stems, the greater portion being present in the roots.

Distribution: The natural habitat of the kok-sagyz is the Tian Shan mountain area of the Republic of Kazakstan in Central Asia. (11) The plant has been distributed throughout various parts of Russia. Dandelions of different species, but essentially the same appearance, are found around the world in the middle latitudes. The dandelion "belt" of the north temperate zone cuts across North America in the north and few of the plants are found in the extreme southern part of the United States except at high altitudes.

Ecology: In general the plant demands humid conditions and soil of high fertility. The environmental complex of its native habitat can be matched in the northern United States and Canada. (11) Suitable areas in the United States coincide with the sugar beet areas.

Rubber: Although all species of the dandelion probably contain some rubber, the emphasis on this plant as a rubber producer is placed on a few species developed by Russian scientists and botanists by breeding and selection. The specie kok-sagyz is regarded as the most important possibility among the dandelions.

In 1931, the dandelion first became known as a potential economic plant in the Soviet Union. In 1932 the United States Department of Agriculture made some efforts to obtain seed, but was unsuccessful. (11)

Individual analyses reports range from a rubber content of a few tenths of one per cent up to 27 per cent of the dry weight of the root. In 1935, A. Prokof'ev (55) gave the rubber content of one year old roots as from five to ten per cent, and indicated a higher percentage for older roots. Latex obtained from the roots contains 30 to 40 per cent of the total rubber present, and has a concentration of from 30 to 59 per cent rubber. (55) The United States Department of Agriculture reported in January 1942, that the favorable reports on performance in Russia did not appear to be verified by actual field performance in that country. In contrast to the reported rubber content in the roots of 10 to 27 per cent, recent information indicates that when grown on a large scale by Collective Farms the maximum per cent rubber is three to five, and the average one to 1.5. (70) The same source reports that the average yield of the kok-sagyz root per acre is about 1/2 ton; on the basis of maximum rubber content this would be only 50 pounds of rubber per acre. In large scale production in the European parts of the Soviet Union, yields up to 3,000 pounds of raw roots have been obtained on an acre of fertile land. This amounts to about 30 to 60 pounds of rubber per acre. (11)

The first shipment of seed from the Soviet Union was received by the United States Department of Agriculture in May, 1942. Experimental plantings were made in various parts of the United States to determine the suitable localities, as well as soil, climate, and other conditions. Results of those first experiments are reported in an Associated Press report by R. E. Geiger (AP Features Writer, Roanoke Times, Nov. 23, 1942):

1) The first United States Forest Service experimental plantings in Montana were harvested.

2) The yield was estimated by R. A. Coster, in charge of Montana plantations, at from 4,500 to 5,000 pounds of roots per acre, capable of producing from 150 to 200 pounds of rubber per acre. This yield was greater than the yield in Russia, but the land was irrigated, whereas in Russia dry land is utilized.

3) The plants matured in about half the time it takes in Russia.

4) The possibility of synchronizing the production of sugar beets and dandelion were not promising. The successive root crops would impoverish the soil. Other food crops raised now would be eliminated. High labor requirements and scarcity of machinery would limit production.

Cultivation and Harvesting: (11) The seed requires extensive preconditioning treatments before planting. The soil also requires exacting preparation, and planting must be done with care in order to obtain good, uniform stands. The plants require weeding and selective thinning for good yields. If spring-planted, kok-sagyz is harvested as an annual in the late fall. Two-year plantations are harvested at the end of the peak of seed bearing, or about the first week in July. Seed gathering takes place in June, and extends over a period of two weeks. The roots are dug with a modified beet lifter, cleaned, and dried to 20 to 30 per cent moisture either in ventilated barns or through application of artificial heat. Both seed gathering and harvesting make heavy demands on labor.

Processing: Processing consists of slicing and steaming the raw material, with lye or some other anticoagulant added, and separating the crude rubber by decanting or centrifuging, after which the rubber is coagulated, washed, and sheeted.

GOLDENROD

Botanical name: Solidago (Over 100 species)

General Description: Erect perennials, leaves linear to elliptical; stems up to ten feet high.

Development by Thomas A. Edison (10) In 1926 the late Thomas A. Edison together with Henry Ford and Harvey Firestone organized the Edison Botanic Research Corporation whose purpose was to investigate the possibilities of obtaining a domestic source of rubber. The headquarters for this investigation was at Edison's laboratories at Fort Meyers, Florida. The reason for this selection of location was that most of the known rubber-bearing plants were tropical or semi-tropical in nature and therefore would probably lend themselves to this climate where the plants could be cultivated and studied at the gardens of the corporation. Edison hoped that such a study of plants would reveal one which could be grown like a farm crop and planted and harvested by machinery. He wanted one adapted to the soil and weather conditions of a large portion of this country, and, if possible, a perennial so that it would not be necessary to replant each year. It would of course have to contain rubber of good quality and in sufficient quantity to be practical. After a short trial with such known rubber-bearing plants as guayule, castilla, Euphorbias, and milkweed. Edison decided that for one reason or another these would be unsuitable.

A survey of the Southern States was then started and crews sent out with instructions to collect any plants that would meet some of the requirements. The men in these crews were selected for their lack of botanical knowlege because Edison thought that thereby he would be better able to obtain all the rubber-bearing plants, the men not being affected by prejudices which would act to emphasize one species at the expense of another. The plants collected by the crews were sent to his laboratory at Fort Meyers where they were identified by skilled botanists and then analyzed for rubber content. Seed, if available, and roots were also sent in and, if the plant proved to have any promise, it was planted in the gardens for further study. As the news of this project reached the public, interested people all over the country began sending in samples. After testing in the neighborhood of 25,000 plants Edison decided that goldenrod (Solidago) was by far the most promising.

At this time Edison concentrated all his efforts to increasing the rubber yield of goldenrod. Through testing in the gardens, Solidago leavenworthii was found to have the highest rubber content, and therefore the field of Edison's work was narrowed down to this plant. It was during this state of the research that Edison died (1931). After his death the work was continued by the Edison Botanic Research Corporation until 1936 when the entire project, including the results of the past ten years work and the best strains of Solidago on hand, was turned over to the United States Department of Agriculture.

Development by the United States Department of Agriculture: This research was carried on by two divisions of the Department of Agriculture. The botanic research by the Bureau of Plant Industry was under the direction of Dr. Loren G. Polhamus, and the engineering aspects of the problem were undertaken by the Bureau of Chemistry and Engineering.

The cultivation of the selected strains was continued at the Department's experiment station near Savannah, Georgia, and the extraction features continued at the Department's Regional Laboratories in New Orleans, Louisiana, Washington, D. C., and Philadelphia, Pennsylvania.

The Department of Agriculture reports (70) (Jan. 5, 1942) that only a small amount of propagated material of improved strains of goldenrod was available in 1941. A maximum planting of 60 acres was deemed possible in 1942. A twenty-fold increase was expected in 1943. The use of unselected goldenrod is quite out of the question because of low percentage of rubber and small leaf yield. During a Senate hearing (Jan. 6, 1942) on a bill to provide for the planting of guayule, Paul H. Appleby, Under Secretary of Agriculture, requested the inclusion of a provision for planting 15,000 acres of goldenrod (76). If the preceding report of the Department of Agriculture is true, this implies the intended planting of strains not considered "improved". The expected yields from the plantings was between 50 and 100 pounds of rubber per acre the first year, with a gradual increase to 500 pounds per acre in the fifth year (10).

By 1933, nearly 100 species of Solidago had been recognized by botanists in the United States (50). The work on goldenrod was continued under the direction of Dr. Polhamus as before mentioned. Several publications have been issued at intervals describing the investigations.

In 1933 a report on goldenrod was issued by the Department of Agriculture (50). Some of the 100 species were found to be confined to local areas, others were widely distributed and showed many variations in different parts of their range. Just as there was a great difference among species in flower, leaf, and growth characteristics, there was also a great difference in rubber content. A summary of the work follows:

The plants used for analysis were collected in 1931 at several localities near Washington, D. C., in the vicinity of Charleston, South Carolina, and in the northern part of Florida. Whenever sufficient material was available, separate analyses were made of leaves, stems and roots. In order to obtain information as to the value of the entire plant as it might be harvested with a mowing machine, several plants of each lot with all leaves and stems were made into a composite sample. In general, the analytical method described by Hall and Goodspeed (29) was followed. (See also "Analysis" section page 74.)

While it was impossible to have separate stem and root samples of every lot, in no case was a significant percentage of rubber found in the stems or roots of any plant, and results indicate that *Solidago* can be considered important only for rubber in the leaves. Since in goldenrod, the leaves represent a very small proportion of the plant, only species having a high rubber content in the leaves, together with a large leaf production, would be considered important. Species such as *S. minor*, and *S. tenuifolia*, which have minute, slender leaves, and a comparatively large amount of stem, are unimportant though they rank high on the basis of rubber content of the leaves. *S. rugosa*, which produces a comparatively large amount of leaves, ran consistently high on the basis of rubber content of entire plants, although the highest rubber content found was only 1.55 per cent.

Leaf specimens from 24 species of goldenrod were tested. While a great variation in rubber content was found in the species of which several samples were collected; in general, it was possible to grade them on the basis of rubber in the leaves into species with high and species with low rubber content. Of the 24 species, a sample of S. altissima had the highest rubber content, 6.34 per cent. Samples of 10 other species had a rubber content of more than three per cent. The lowest percentage was found in S. squarrosa with a content of 0.86 per cent, but in both S. erecta and S. racemosa, the rubber content was less than one per cent.

A high variation in the rubber content of the leaves was found in some high-yielding species, due either to individual plant variation or to habitat or seasonal effect. This variation is sufficient to indicate a real possibility of plant selection on the basis of rubber content and the development of cultural practices based on optimum conditions of rubber production. That some of the species were found to be more variable than others may be due to the fact that some species, being more common than others, were collected under a greater variety of conditions; or it may be that some species were less well established or have been crossed with other species.

The variation is particularly striking in the case of S. altissima, a very common species collected from 14 localities. Leaves of 12 of 14 samples collected were analyzed, the lowest percentage of rubber being 1.28, the highest 6.34, and the mean of 12, 3.45. S. serotina, of which five samples were analyzed, also showed considerable variation in rubber content, the range being from 2.40 to 5.64 per cent. Of the species having leaves with a relatively high rubber content, *S. minor* and *S. rugosa* showed the least variation. In general, the species grouped together by taxonomists were found to be grouped on the basis of comparative rubber content. A conspicuous deviation from this rule however, was found in 3 species, *S. graminifolia*, *S. minor*, and *S. tenuifolia*, which usually are classified under the subgenus *euthamia*. *S. graminifolia*, with percentages of 1.03 and 1.09, had a low rubber content, while *S. minor* with a high content of 3.53 per cent and *S. tenuifolia* with a 2.9 per cent were relatively high in rubber. Analyses of the other species appear in the tabulation on page 69 .

Non-rubber Constituents of Goldenrod: (50) In goldenrod there is, in addition to the rubber, an appreciable quantity of non-rubber substance which can be extracted with acetone. This material consists primarily of resins, although there are also small amounts of fats, oils, and sugars. Little is known of the chemical identity of the resins or of the possible use to which they might be put, although it has been suggested in the case of similar resins from other rubber-bearing plants that they might be used in paint and varnish or in the manufacture of soap. Since significant amounts have been found in several species of goldenrod, the by-product value of the resins is worthy of consideration. The highest acetone extract found was 26.45 per cent in one leaf sample of *S. minor*. The mean of five samples of this species was 21.03, lowest 16.24 per cent. Acetone extracts greater than 15 per cent were obtained from samples of four other species. These include 3 of 4 samples of *S. fistulosa*, 2 out of 4 of *S. puberula*, one out of 5 of *S. serotina*, and one of *S. neglecta*.

A positive but very small correlation of 0.397 ± 0.070 was found between rubber content and the resin content of the 68 leaf samples of goldenrod. It would appear probable therefore, that in <u>Solidago</u> there is a relation between the rubber content and the acetone extract. (50)

Latest reports up to 1942 state that selected strains of <u>S. leavenworthii</u> have been developed, averaging between six and seven per cent rubber (of the dry leaves). Individual plants have tested as high as 12 per cent, but when these plants are propogated the progeny do not show this high rubber content. (10)

<u>Factors in Variation</u>: It has been confirmed that there are many environmental factors which influence the rubber content of goldenrod. Good growing conditions reduce the percentage of rubber in the plants. However the yield of leaves is higher, and thereby the acreage yield is usually higher. Shade reduces the rubber content; in fact, goldenrod grown in heavy shade contains almost no rubber. Heavy rains during the latter part of the growing season reduce the rubber content; dry weather produces the opposite effect. The percentage of rubber increases with the age of the leaves up to the time the seeds mature on the plant. However, as the plants mature, some of the leaves drop off and are lost, so that it is necessary to harvest the plants before the leaves have reached their peak in rubber content in order to obtain the highest yield of rubber per plant.

<u>Advantages of Goldenrod Rubber</u>: The advantages of goldenrod rubber are as follows:

1) Quick, annual crop.
2) Not necessary to replant each year.
3) Seeds are sown just as in many common agricultural plantings.

4) Very little care in cultivation required.
5) Lends itself readily to conventional harvesting methods.
6) Does not require fertile ground.

Disadvantages of Goldenrod Rubber: The disadvantages of goldenrod rubber are as follows:

1) Inferior quality—tensile strength of goldenrod rubber is only about 1,500 pounds per square inch as compared to hevea's 3,200. It is also lower in abrasion resistance (35 per cent of hevea). (70) It seems possible that when goldenrod rubber is freed of impurities its properties will more nearly approach those of hevea. As yet no means has been found to do this without a very elaborate procedure. For certain uses, rubber from goldenrod is acceptable despite the impurities but it does not lend itself to large-scale substitution for hevea rubber. (70)

2) Extraction difficulties. Solvent extraction seems to produce a rubber which is inferior to rubber removed by mechanical means. This is presumably due to the fact that the plant contains other substances which have the same solvent properties as rubber. (The Bureau of Chemistry and Engineering is at present trying to devise a modification of the guayule rubber extraction process to use on goldenrod. As yet no information as to the success of their work has been released.)

3) Flowering goldenrod yields a pollen causing "hay fever". Widespread planting of goldenrod would certainly multiply the agonies of persons susceptible to this pollen.

Solidago has been tried by the U.S.S.R., and N. B. Koyalovich (37) reports that under Russian climatic conditions the best plants for the accumulation of rubber in leaves are, Solidago sempervirens, S. serotina, and S. leavenworthii.

GUAYULE

__Botanical name:__ __*Parthenium argentatum*__

__Description:__ An erect woody shrub, usually not over two feet high, with a native dry weight of rarely more than 2-3 pounds. It is a hardy perennial and under undisturbed, natural conditions, lives probably 40-50 years (45). It has small composite flowers which usually produce little seed, but are capable of producing abundant seed under suitable conditions. Powers of vegetative reproduction are very weak. In nature, growth is very slow. Natural reproduction is almost entirely by seed. The seeds are very minute, 1,000 weighing less than one gram. Seed is very fertile and retains its vitality for many years. It is incapable of germination at once, and can do so only after a considerable lapse of time. During the dry season the shrub is dormant, but after a week or so of rains it flowers vigorously and each plant produces a hundred or more minute seeds, few of which survive the critical infancy.

__Distribution and Ecology:__ Guayule occurs as a natural growth on the high, arid plateau of central Mexico, with a small projection into Texas. World-wide search has failed to find it anywhere outside of this area of approximately 130,000 square miles (13). It is also probable that not a single plant grows in 115,000 of these square miles (14). In the main it confines itself to altitudes between 4,000 and 7,000 feet and limits itself almost exclusively to the limestone hills and slopes.

Rainfall in guayule's natural habitat ranges from 7 to 14 inches annually.

A. N. Lebedev performed some more recent work in the U.S.S.R. on the effect of different fertilizers and soils on guayule (38). It was found from tests on guayule raised in hot-houses, that an increase in P_2O_5 content of soils brought an increase in rubber yield.

<u>Development</u>: As early as 1852, it was known that the bark of this shrub carried a resilient substance which on analysis proved to contain 80 per cent of a distinctive resin. This gum, guayule rubber, could be recovered from the bark by chewing, and this possibly led to its discovery. In 1876 the first samples of guayule rubber appeared at the Centennial Exposition in New York, shipped from Durango, Mexico. Beginning in 1888 a series of unsuccessful attempts were made to extract in marketable form the rubber known to be in guayule.

In 1900, a solvent process was patented by an Italian chemist, W. Prampolini. (13) In 1902 he succeeded in interesting T. F. Ryan and Senator N. W. Aldrich in his proposal, and means were provided for a thorough test, with unsuccessful commercial results (13). However, the potentialities of guayule were impressed upon Ryan and Aldrich, and through their efforts, laboratories were established. An exhaustive series of experiments was begun under William A. Lawrence, assisted by his daughter. Their work finally resulted in a purely mechanical extraction process, patented by Lawrence in October, 1903.

In 1904 the Continental-Mexican Rubber Company (a subsidiary of the Intercontinental Rubber Company) was incorporated, and a small commercial unit erected at Torreon, Coahuila, Mexico. The product from this unit was sold successfully, and during 1905 and 1906 a factory was erected at the same location having a monthly capacity of 1,000,000 pounds of wet rubber as then marketed (800,000 pounds dry). D. Spence (61) reports the first shipment of guayule rubber to the Manhattan Rubber Company in 1904.

In 1910 guayule rubber made up 19 per cent of America's total rubber supply (13). In 1912 the Mexican revolution drove the Continental-Mexican Rubber Company out of Mexico. Before leaving, the company's botanists picked seeds from hundreds of varieties of the shrub and took them to the United States to continue experiments (5). In 1913-14, over 1,000,000 shrubs were set out in southern California. From this mixed Mexican seed thousands of selections and analyses were made in succeeding years (43).

When guayule became of public interest in 1917, Mr. F. Ephriam, in a letter to the editor of "Chemical and Metallurgical Engineering" (20) makes certain claims which are not quite consistent with the information given by Carnahan (13). Quoting Ephriam: "In 1904, I operated at Torreon, Mexico the first plant extracting rubber from guayule by mechanical means as per my U. S. Patent No. 779,696, Jan. 10, 1905. (Mexican Patent No. 4079, Oct. 22, 1904). Several smaller concerns, established later, paid royalties, but the more important ones infringed upon my patent rights".

In 1925, 8,500,000 pounds of dry rubber were shipped to the market. Up to 1931, the mentioned Continental-Mexican Rubber Company had produced about 60 per cent of the 160,000,000 pounds of dry commercial guayule rubber marketed to that time (13). The exploitation of guayule continued at a fluctuating rate. Thirty years of practically constant experiments have been conducted mainly to isolate the most responsive varieties, and to develop cultural methods suitable to complete mechanization of the entire cycle from picking the seed to milling of the rubber.

Rubber: Many conflicting and ambiguous statements appear in the literature concerning the percentage of rubber in guayule. As is usual for most plants, rubber contents vary greatly depending on the many possible variables such as specie, strain, habitat, time of year, age, etc.

The first extensive account of guayule was prepared by F. E. Lloyd in 1911 (39). Lloyd describes field conditions and factory methods in addition to the results of his histological investigations on the formation and distribution of rubber in the plant. It was well established at that time that the wild plants belonged to a series of innumerable races, that these varied to a considerable extent in characteristics, and that reproduction was parthenogenetic, at least in part. The method of improvement selected therefore, was to select the best strains as determined by analysis and cultural characteristics and to propogate from these plants without the introduction of cross-breeding. At first difficulties were encountered in germination of seed. With the solution of this difficulty, and through segregation and selection of superior strains, the rubber content of field-grown plants was gradually increased.

Climatic conditions have also been studied. To summarize: guayule demands a winter rainfall of 12 to 15 inches, or comparable irrigation. It cannot stand winter temperatures below 15°F, and most of all, demands a long dry spell in the summer months for good rubber production (5). Although the shrub flourishes in Georgia and Florida, it contains practically no rubber when grown there. The summer rains give new life to the foliage, and the shrubs make very good growth, but rubber is in all cases negligible in the leaves, occuring mainly in the stems and roots.

Lloyd gave the dry weight percentages for wild plants as follows:

whole plant	9.5 per cent rubber
trunk	9.9 per cent rubber
root	7.8 per cent rubber
branches and leaves	9.7 per cent rubber

The figure for leaves does not agree with subsequent tests which show very little rubber in these parts. It became known that the trunk wood contained very little or no rubber, the concentration being in the bark. The proportions of bark and wood are therefore of some importance. T. J. Whittlesey reported in 1909 (76): For average plants of 12 to 36 inches high, weighing 6 to 32 ounces dry, with 9 per cent pure rubber in the whole plant,

trunk;	46.4 per cent bark
trunk bark:	25.7 per cent rubber
root bark:	8.5 per cent rubber
root wood:	1.7 per cent rubber
branches and leaves:	64 per cent of the total weight of the plant

A report by A. H. King, quotes De Kalb (35): "California guayule grown under irrigation has been known to produce as much as 28 per cent of its net dry weight in rubber. Also, by a four-year intensive irrigation method 25 tons of the dry plant may be grown per acre." Hall and Long (30) in 1921, in summarizing state: "---whereas the native shrub yielded an average of 10 per cent rubber, the content of the cultivated plants fell in some cases to less than 2 per cent". (Hall and Long did not work with guayule; the report refers to other investigations).

D. Spence (63), Vice President of the Intercontinental Rubber Company, in a general description of guayule at Salinas, California (operative center for the company), reports in April 1930: "Recent investigations have shown that the young guayule plants grown from seed sown in our nursery at Salinas less than a year ago now contain 6.3 per cent of pure rubber on a bone-dry, deleafed basis. On the basis of the number of these seedlings (by count) per acre actually growing in the nursery, the above represents a yield of 1,164 pounds of pure rubber per acre per year. We have prepared and are going ahead to set out an additional 2,500 acres of guayule this spring and annually thereafter."

Physiology: Rubber will not flow from the guayule on injury in the form of a latex, but is enclosed in special cells or the cortex. The possible function of the rubber in guayule has been a matter of interest. Lloyd (39) concluded from his studies that there appeared to be no direct physiological relation between the rubber and resins in the plant, and that the rubber appeared to have no physiological function in the guayule plant. Various other attempts at correlating rubber and resin content were unsuccessful. D. Spence (62) in reporting advances (1928) in connection with guayule states that rubber does not exist in the cells in the form in which it is recovered, but is present chiefly as a colloidal suspension in the plant juices. Lloyd, in a later article (4 D) also confirmed that the rubber occurred as a colloidal suspension in the parenchyma cells.

W. B. McCallum (43) reports that resin is formed in a definite system of resin-secreting glands, and that the amount is relatively constant and has no connection with the rubber-forming cells. Natural protection against drought, and action as a reserve food supply are the theories advanced for existence of the rubber.

Cultivation and Harvesting: Two major plans for guayule production have developed: McCallum five-year cycle Plan: (5) (13)

1) Presprouted seeds are planted thickly in nursery beds and covered with a thin layer of sand.

2) After 8 to 12 months a machine collects the seedlings, shearing the roots eight inches below the surface.

3) The seedlings are transplanted by machine, 8,000 plants per acre, in a manner to permit cross cultivation.

4) Cultivated three times per year, after heavy rains.

5) Harvested after four years; plants are plowed up in windrows, and dried from 35 to 20 per cent moisture in the field. Harvester picks up dried plants, chops them into 1/2 inch sections and blows them to trucks, which transport the material to the extraction plant.

At the end of five years, as much as 2,500 pounds of rubber per acre has been obtained. (400 pounds per acre per year average)

Spence Plan for Broadcast Sowing: (5) (13)
(Dr. D. H. Spence -- Stanford University)

1) Seed sown broadcast in open field

2) Allowed to grow for one year

3) Seeds taken from plants

4) Harvested as in the McCallum Plan

The shrub thus grown contains about 6 per cent rubber. A yield of more than 1,000 pounds of rubber per acre per year is stated.

The latter plan obviously requires the handling of much larger quantities of material. It has the advantage of quick return.

Processing: The present continuous method as patented in 1928 by G. H. Carnahan is used by the Intercontinental Rubber Company. Investigators, in pointing out the rubber possibilities of various other plants, often state that extraction methods similar to the guayule method could be used. An outline follows:

1) The chopped shrub is fed by screw conveyors and belts through cleaning devices to an attrition mill.

2) Passed through macerating rolls.

3) Passed through a series of four tube mills, charged with flint pebbles. Six parts of water are added here to one of guayule.

4) Slurry is washed with fresh water.

5) Passed into a modified Dorr thickner. Here rubber "worms" and lighter fibers float to the top and are automatically skimmed off. Waterlogged cellulose material is removed from the bottom.

6) Skimmings passed into a pressure tank where 300 to 350 psi is maintained for two hours, forcing water into the non-rubber material.

7) In a second modified thickner, almost pure rubber floats to the top, and is skimmed off.

8) "Worms" are scrubbed in a ball mill, and discharged to a settling tank.

9) Rubber agglomerating on top is separated by passing on a screen.

10) Wringer rolls, and vacuum drying reduce moisture content to one per cent.

The plant of the Intercontinental Rubber Company was placed in operation in 1930. It has a capacity of 15,000 pounds of dry rubber per day of three 8-hour shifts; ten men per shift operate the plant.

Studies in the preliminary separation of wood from bark, and subsequent processing of the latter only, have been made. A patent for such a process was granted in 1929 to Thomas A. Edison (to Edison Botanic Research Corp.); U. S. Patent 1,740,079 (18). "---bark and pithy materials of plants such as guayule are separated from woody material without disintergrating the latter. Bark and pith only are treated for rubber."

<u>Economics</u>: In the early days of guayule production, the wild shrub was collected and pressed into bales of 80 to 120 Kilograms to be sold to processing plants. These bales sold for: (76)

1904	$ 3.50 per ton
1905	$ 15 to $20 per ton
1909	$ 50.00 per ton

Imports at New York in three months of 1908: (76)

October	850,000 pounds
November	925,500 pounds
December	1,444,000 pounds

A. H. King in 1918, urged the expansion of the guayule industry (35). "---such an industry would be a financial success, paying, it is conservatively estimated, 6 per cent without irrigation or $180.00 per acre per year on irrigated land."

In 1926, G. H. Carnahan, President of the Intercontinental Rubber Company (14) made some calculations on the basis of past experience with cultivated guayule: To maintain a cultivated output of 250,000 pounds per year (1/4 of the crude requirements of the United States in 1926), would require a cultivated area of 640,000 acres; 1/4 maturing annually. The entire area would be 1,000 square miles. Considering the labor requirements, this would represent an annual return of 25,000 pounds of rubber per man employed.

Guayule rubber has never been able to give serious competition to Hevea, or plantation rubber. In spite of improved methods, it has cost more in the past to produce guayule rubber than to produce plantation rubber. Under existing methods, guayule cannot be produced for less than 15 cents per pound. (5).

In the past, the volume of guayule marketed has varied almost directly with the price of plantation rubber. Living guayule shrubs represent a warehouse of rubber. It is obviously better to keep the rubber in "storage" when prices are low, and extract maximum amounts when prices are advantageous.

It is natural that plans for the expansion of guayule production should come under consideration during the present emergency (1941 __). During 1941, a bill was brought before the Senate (73) to provide for planting of 45,000 acres of guayule. The possibilities of guayule were thoroughly discussed at the hearings on this bill. A report by the United States Tariff Commission was presented: "---information available indicates that the capital investment for agricultural equipment, nurseries, buildings, maintenance shops, rubber extraction mills, and deresinating factories probably would amount to about $20,000,000 for every 100,000 long tons of yearly productive capacity. If substantial quantities of guayule rubber were deresinated, the cost of deresinating would not exceed one or two cents per pound." In an extension of the hearing, Paul H. Appleby, Under Secretary of Agriculture, requested the extension of the proposed acreage to 75,000 (Jan. 6, 1942). The bill was passed with the higher figure as a limit.

In 1942, a bill was introduced to amend the above bill, striking out the statement "not to exceed 75,000 acres of" (74). During the proceedings, information was supplied by C. M. Granger, Assistant Chief, Forest Service, Department of Agriculture. It was stated that harvesting from the proposed expanded program would begin at the end of 1944. With the expected yield of 33,000 tons of guayule rubber in 1944 and 1945.

This production would require about 88,000 acres, and to produce an annual crop of 80,000 tons of rubber, about 500,000 acres would have to be in use. Mr. Granger also stated that the best rotation economically would be seven years. An annual rental of $30 to $35 an acre would be paid for irrigated land. To handle the proposed expanded program, 56 extraction plants would be required, each requiring about 420 tons of steel in construction and equipment.

The early 1943 harvest was from 580 acres of 13-year old shrubs acquired by the Government last year (1942)*. The 550 acres of guayule at Salinas, California, will yield about 600 tons of milled rubber. Guayule plantations being established now are expected to yield about 20,000 tons from the harvest starting late in 1944, and thereafter the planting and harvesting schedule should produce about 80,000 tons annually.

A late report was given in the "Roanoke Times" to the effect that the proposed expansion described above would not be carried out. New plantings and construction would be limited.

Physical Properties: On account of the resinous character of the early guayule rubber it was often doubted whether this was the same compound as obtained from Hevea. The presence of large amounts of impurities undoubtedly led to these conclusions. Chemical tests have proved it to be the same hydrocarbon.

In 1927, Spence and Boone (65) published the results of some

* "Witcombings" published by Wishnick-Tumpeer, Inc., Vol. 9, April 1943, No. 3.

physical tests of guayule rubber grown in Mexico and California. Their samples were obtained from the Continental-Mexican Rubber Company. A comparison of California guayule with plantation crepe, using a pure gum compounding formula:

cure (min.)	crepe tensile psi	crepe elongation per cent	resin extracted and processed psi.	resin extracted and processed elong.	processed only psi	processed only elong.
5	4,270	730	3,800	685	2,655	830
10	4,280	670	4,105	650	2,640	800
15	3,860	655	3,755	630	2,110	770
20	3,350	625	3,450	615	1,845	745

The results with this and other compounding mixes, seem to indicate that guayule which has been extracted (derisinified) compares favorable with Hevea.

J. H. Doering (18) in 1934 reports on tests made in which the rubber used in tires and tubes was exclusively guayule. The tires were of the 4.50 x 21 size and were tested in Florida over a period of two years. These tires failed at mileages between 8,500 and 10,500 because of tread wear. The inner tubes gave satisfactory service throughout the duration of the test.

In the past, the resin content of guayule made it very desirable for certain purposes, such as friction cords in tires, inner tubes, and for plasticizing tire tread stocks. However, the tensile properties and abrasion resistance are lower in the plain guayule. D. Spence (61) states that acetone solubles (resins) can be reduced to less than 1/2 by simple digestion of the rubber "worms" in a boiling 2 per cent solution of caustic. However, because of the very desirable properties for many manufacturing purposes of the acetone soluble constituents, it is doubtful whether complete elimination should even be considered.

It has long been known that the guayule shrub, and particularly the rubber it contains, deteriorate rapidly after the shrub is pulled from the ground. The shrub is usually in prime condition for milling about 30 days after uprooting and partial drying. Thereafter, deterioration, more or less, depending on subsequent conditions of storage, takes place. Rubber is lost, and worst of all, resulting in a product of inferior physical quality (61). Oxidation into resinous products had been assumed as the cause. However, Spence found that the acetone extract in the deteriorated, soft and sticky rubber, is invariably lower than in the fresh shrub rubber. Evidently, depolymerization is one of the effects encountered.

Spence (62) found in 1928 that by fermenting the carbonhydrates into sugars, organic acids and CO_2 and by putrefactional decomposition of protein, the acetone extract could be cut by 60 to 70 per cent, the final rubber having a resin content of 9 to 10 per cent instead of 25 to 30, with consequent improvements in properties when vulcanized. A patent based on these findings, in which a large part of the organic matter was converted to water solubles under controlled conditions, was issued to Spence in 1933 (64). Practical application has not appeared to the present.

INDIAN HEMP

Botanical name: (Two species)

1) *Apocynum cannabinum*
2) *Apocynum androsoemifolium*

Distribution and Ecology: A common plant throughout the United States and southern Canada. Extends from the warm plains of Florida and the valleys of southern California to at least 6,000 feet altitude in the western mountains. Grows best in gravelly or sandy soil, and requires a fair amount of soil moisture. Propogates abundantly, both by seeds and by creeping rootstocks.

Rubber: The Indian Hemp was considered by Hall and Long (30) as one of the most promising plants for further investigations as a rubber producer. The first studies of the latex of *Apocynum* were made by Fox in 1912 (25). Though Fox worked only with *A. androsoemifolium*, the two species are very much alike in all respects. Fox found that plants grown on dry, sandy soil west of Akron, Ohio, gave a latex containing 2.27 per cent rubber and 20.7 per cent resin; plants grown in the swamps of South Akron gave a latex of 1.12 per cent rubber and 15 per cent resin. These two isolated samples cannot be taken as representative. The quality of the rubber was stated to be much superior to milkweed rubber.

Leaf samples of *A. cannabinum* collected by Hall and Long near Lincoln, Nebraska, gave a high of 5.1 per cent rubber and a low of 4.5 per cent. Other plants from more westerly locations gave percentages in the vicinity of 1.5 per cent. Samples of *A. androsoemifolium* gave below one per cent rubber and were not considered promising.

MADAGASCAR RUBBER VINES

(Mexican morning glory)

Botanical name: *Cryptostegia:* 1) *grandiflora*
2) *madagascariensis*
3) a hybrid of the two

Description: All are perennial plants. The two parent species, *C. grandiflora* and *C. madagascariensis*, have been mistaken for each other and the names often misapplied. The most striking differences are the type of growth and leaf characters, *grandiflora* having a stronger tendency to grow as a trailing vine with long whip-like shoots and broadly elliptical leaves with reddish midribs, while *madagascariensis* has narrower, firmer, and smoother leaves with white midribs. When grown on lawns or in borders, the plants of the latter are usually trimmed to a rounded form. (77-'32) The hybrid grows similar to *C. grandiflora*, but the leaves bear a closer resemblance to those of *C. madagascariensis*, and their floral characters are intermediate between those of the parent species. Both parent species and the hybrid produce abundant crops of viable seed. However, the hybrid does not come true to type from seed.

Distribution and Ecology: The plants were introduced first into Mexico and then into Florida. *C. madagascariensis* was introduced into Florida about 1900, and has been planted extensively as an ornamental. C. grandiflora has largely escaped cultivation and become established in the West Indies and many portions of Mexico. Plantings of both species have been made at several points in southern California and Arizona, and the plants seem to grow well (77-'32). Cryptostegia has proved well adapted to a variety of soils in southern Florida, although its younger growth is sometimes injured by low temperatures and strong winds during the winter months. Moisture requirements are not excessive though growth is checked by a deficiency. Notable resistance to drought has been recognized in C. grandiflora in northwestern Mexico.

To determine the cultural requirements of the two species and the hybrid which was subsequently developed at the United States Plant Introduction Garden at Coconut Grove, Florida, various methods of cultivation and exposure have been tried (52). Methods of propogation, both sexual and vegetative have been tested and compared. Morphological variations within the two species have been studied, and also differences between the two species and the hybrid.

Rubber: Commercial rubber has been produced from Cryptostegia plants in Madagascar and India and marketed as "palay" or "pulay". Some samples were on display at the Exposition of Madras in 1856.

Hall and Long (30) in 1919 tested one sample of C. grandiflora from lower California and found 5.1 per cent rubber in the leaves and one per cent in the stems.

The hybrid was discovered in the spring of 1927 by Alfred Keys. Much of the subsequent work on these plants as rubber producers has been concentrated on the hybrid. Investigation of the rubber-producing capacity of Cryptostegia has included comparison of the rubber content of all three, determination of seasonal variation in content, and determination of individual plant yields (52). In May 1931 a series of analyses was undertaken by the Department of Agriculture under the direction of Messrs. Polhamus, Hill, and Elder, to obtain comparable data on rubber content. Samples consisting of approximately 500 leaves each were picked at random from several plants of each species and the hybrid at about the same date each month for 10 months. All precautions were taken to put the comparison on an equal basis. The results showed that the rubber content of the leaves of the hybrid was higher than that of either species in every month. In some months it was more than double that of the other two. The following percentages are on the dry weight basis:

	Average analysis at peak of rubber content	Highest individual analysis
C. grandiflora	3.13	3.34
C. madagascariensis	2.94	3.14
hybrid	5.97	8.60

There was found to be a consistent increase in the rubber content of the leaves of the hybrid between the ages of one and 3-1/2 months. Leaves between 3-1/2 to 5 months showed no significant increase. Leaf size data showed no relationship to rubber content, as leaves had attained full size at the end of one month. (52)

Experiments conducted on the hybrid showed only small intermonthly correlation of rubber content. The differences in individual content were attributed largely to effects of soil and exposure conditions rather than to differences in rubber-producing capacities. Records of seasonal variations in resin, or acetone solubles, and variation among individual plants were also made. C. grandiflora and C. madagascariensis indicated a strong tendency for high rubber content to be associated with high resins, and low with low. The hybrid lacked all correlation.

In contrast with desert plants, which usually secrete less rubber under conditions of vigorous growth, the species of Cryptostegia yield a greater percentage of rubber under those conditions, and it appears probable that the higher rubber content of the hybrid may be connected with their increased growth vigor. (77-'32)

Rubber in Cryptostegia is in every part of the plant except the woody portion of the stem and root. Rubber occurs in the latex form.

The Department of Agriculture in 1942 (70) did not consider Cryptostegia as a practicable source of emergency rubber. The reasons given were: slow propogation, costly extraction, and low yield of rubber as compared with other sources.

A newspaper article appeared in the November 15, 1942, issue of the Roanoke Times in which H. Coles, executive vice-president of the Florida State Chamber of Commerce, makes some very optimistic statements as to the future of Cryptostegia. A large new industry for the South, together with a complete solution of the rubber problem is envisioned. The Baruch Report is quoted as placing Cryptostegia as second in importance to guayule. We have also the following statement: "Where labor is low in cost, the tip of each plant could be cut with a sharp instrument and the drops of rubber latex allowed to fall into a small cup. It is estimated that one man can make from 3,000 to 4,000 cuts in a day, and produce about one pound of rubber per day". Sixty to one hundred pounds of rubber per acre per year is given as the yield.

MILKWEED

Botanical Name: Asclepias (over 100 species)

General Description: (30) The genus comprises somewhat more than 100 species, and is best represented in tropical and southern Africa. About 46 species are native to the United States and Canada, and a number of these are represented by additional varieties and forms of more or less importance. All of the North American species are perennials with deep roots. These roots spread, in most cases, by horizontal branches which give rise at intervals to vertical roots, these in turn dividing when they reach the surface to form the crown from which new stems arise. In some species this creeping of the roots is so extensive that a single plant comes to occupy areas of large extent, covering them with dense stands of stems. Vegetative propogation by portions of the horizontal roots is entirely feasible. In one species (A. subulata) there seems to be only a single taproot.

A few of the milkweeds have woody stems, but these die down to near the base each winter, new shoots appearing from the same root or stump at the beginning of the following growing season. Injured or severed stems are usually replaced by new ones. The stems are erect in some species, spreading in others, and a few inches to eight feet or more long, but they are always straight with few or no branches. The bast fibers are long and stronger than in most native plants, for which reason they have been considered in the manufacture of cordage and cloth.

The leaves are nearly always opposite or whorled and occur at regular intervals to the top, the upper leaves being nearly as large as the lower ones. It is not unusual, however, for the lowest and the topmost leaves to be alternate on the stem, and in a few cases all of the leaves are greatly reduced in size. Many of the species are clothed with a woolly tomentum of plant-hairs, while others are quite smooth and naked.

The flowers appear in clusters in the axils of the upper leaves and often at the apex of the stem. The flowers are followed by pods filled with numerous seeds. Natural propogation is chiefly by seeding. The seeds are slow to germinate, and some difficulty has been experienced in getting fieldsown seeds to grow at all. Alternating temperatures seem to be necessary for successful germination in some cases.

Several of the species, especially those of the narrow-leaved group, are poisonous to stock. The genus is characterized by the presence of a milky sap or latex, which is carried in special vessels of the laticiferous tissue.

Earlier Investigations: The first recorded attempt to prepare rubber from any of the plants which grow north of the Mexican border was that of William Saunders in 1875 (59). Saunders experimented with the common milkweed (*A. syriaca*). The investigations were carried on about 1871 at London, Ontario. Saunders reported the preparation of an elastic, vulcanizable gum which he thought could be manufactured at a profit. By a fermentation and solvent extraction method, he obtained a five per cent yield of this gummy substance. No serious attempts were made to commercialize this discovery. A. T. Saunders (58) reported in 1910 the results of examinations made in 1900 of a milkweed, the specie of which is not given. About two grams of rubber was prepared.

An extensive examination of common milkweed was made by Fox in 1911. (24, 25) Fox carried on his experiments at Akron, Ohio. He obtained two to three per cent of rubber from A. syriaca "on the basis of the latex". His conclusions were that "while rubber is a product of the plant, the amount is so small, its quality so inferior, and its cost of production so high, that a profitable industry is out of the question". Fox deserves much credit for carrying his experiments on milkweed and other plants so far, even though working with plants having discouragingly low yields. Weish (40) in 1913, aware of Fox's discouraging conclusions, made a study of the common milkweed, but concentrated on other products to be obtained from milkweed such as fiber, resins, etc.

Hall and Long (30) did extensive work on milkweed, among other plants. Of course they did not repeat Fox's work, but concentrated on other species, especially the desert milkweeds.

Asclepias subulata

Description: (30) A rounded perennial herb, woody at the base in some types, three to eight feet high, two to six or even ten feet broad when growing in low places where water accumulates after rains, narrow and few-stemmed when on dry upland slopes; roots deep, ending in a much branched crown; 12 to 30 stems in poor plants, 500 or more in robust forms, straight, either simple or with a few straight branches; leaves reduced to linear.

Distribution and Ecology: This species ranges from southeastern California, western Arizona, and western Sonora across Lower California to the islands off the west coast. (30) The northernmost location is Searchlight, Nevada. To the east it extends slightly beyond Florence, Arizona. The plant nowhere occurs in great abundance. Usually it grows as scattered clumps on the foothill slopes and in dry, stony streamways, which are flooded with storm water for a short period after infrequent rains. Occasionally the plants are found growing in better soil depressions where water remains for some time. Here they form large, bushy plants. At Sentinel, Arizona, such plants were found to weigh from 12 to 16 pounds. (30) The normal rainfall at Sentinel, Arizona, one of its habitats, is 4.2 inches; at Yuma 3.1. The maximum temperature for 1919 at Sentinel was 120°F and the minimum 22°F.

Hall and Long (30) report that some preliminary experiments conducted at Bard, California, tended to show that vegetative reproduction could be practiced without great difficulty.

O. F. Cook reported in the 1927 Yearbook of the Department of Agriculture (77-'27), experiments on A. subulata in progress at field stations in California and Florida. A. subulata has been prominent in experiments conducted at the Department of Agriculture gardens, but reports on progress are not issued frequently, partly because of lack of general interest in the projects, and partly because of the long time required to obtain satisfactory data. In 1935 Beckett and Stitt (8) reported that plants harvested in January and April ratooned rapidly and produced a greater number of stems, while those harvested in July ratooned slowly. Plants harvested in October died or recovered very slowly. (At Bard Gardens).

Rubber: Nearly all analyses of A. subulata are reported on stems. This is due to the fact that the leaves are so small and often so sparse at time of collection as to be negligible. The laticiferous tissue of the stems take over the rubber-holding properties of the leaves of other species, just as they also assume the photosynthetic activities.

Hall and Long found considerable fluctuation in rubber content. They attributed this to seasonal variation, environmental conditions, presence of genetic strains, and sampling errors. They concluded that all of the plants were higher in rubber-content during the autumn than in the early spring.

high: Sentinel, Arizona, Sept. 29, 6.5 per cent rubber in the young stems.

low : Sentinel, Arizona, May, 0.8 per cent in young stems.

The mean for 22 analyses from various locations and on different dates was 2.9 per cent. Hall and Long were concerned only with wild growing plants. With the wide variations possible for many reasons, estimation of acreage yield is not possible from their data.

Beckett and Stitt (8) in 1935 reported on wild growing plants as well as the plantings at the gardens at Bard. It was shown that harvested plant material when stored for a period of two years showed no appreciable loss in rubber-content, but plant material left exposed to the weather after being harvested lost practically all of its rubber within 90 days. In Arizona and California and in Sonora and Baja, California, Mexico, the rubber percentage of the wild plants examined ranged from 0.5 to 6.0 with a mean of 2.86. Seeds selected from high yielding wild plants and grown under cultivation at Bard had a maximum rubber content of five per cent in three and four year plants, the age at which the plants reached maximum size. Beckett and Stitt confirmed the conclusion of Hall and Long that the rubber content of both wild and cultivated plants is highest during the dormant period, which usually occurs in the fall and winter. New growth and rubber produced by plants 2-1/2 to 3 years after ratooning, often exceeds that of the original plants. Closely spaced plants produce larger yields of total rubber than wide-spaced plants. Unthinned 2-year old plants in rows of one foot apart were found to produce rubber at the rate of 212 pounds per acre, as compared with a rate of 71 pounds to the acre for plants spaced 3 to 4 feet apart.

The Department of Agriculture (70) considered no member of the milkweed group promising as a source of rubber. In regard to A. subulata it was stated: "Methods of cultivation have been worked out, and the plant could be grown in large quantities in the desert districts. In cultivation tests it has never been possible to demonstrate more than 80 to 90 pounds of rubber per acre per year. Processes of extracting the rubber and utilizing it commercially have not been developed."

Asclepias erosa

Description: (9) This species is also primarily a desert milkweed. A herbaceous perennial, with 8 to 20 stems that average about four feet in height when mature. Leaves whorled.

Distribution and Ecology: (9) The natural distribution of A. erosa is limited to the arid regions of the Southwest. It is known to extend from Kern to Ingo counties in California, south through the Mohave desert to San Diego county, east to north-central Sonora, Mexico, and north to Utah.

The plant is confined to dry gravelly stream beds, where water runs for short periods after rains, and to borrow pits along highways and railways. Usually scattered in groups of ten or more.

Rubber: Although Hall and Long (30) analyzed three samples of this plant from various locations, they found it of no importance and did not list it among the important species. These investigators classed it among "species with low rubber-content". Their highest test gave 2.5 per cent rubber in the leaves.

Investigations with A. erosa were conducted at the United States Acclimatization Garden near Bard, California, from 1931 to 1934 (9). Beckett, Stitt and Duncan report some analyses of wild plants. The rubber content of the leaves of wild plants collected in Yuma County, Arizona, ranged from 2.45 to 13.08 per cent rubber, with a mean of 8.57 per cent. The leaves represent over 50 per cent of the dry weight of the plants, and contain approximately 90 per cent of the total rubber. These investigations also state that a higher rubber content was obtained from the leaves of A. erosa than from any of the other milkweeds, and in habits of growth and ease of culture it compared favorably with other natural and introduced rubber-plants.

The plant produces new stems in March, and makes rapid growth in the spring and early summer, reaching maturity and maximum rubber content in autumn. Leaves of A. erosa were stored for 18 months without appreciable loss in rubber-content. (9). Seeds germinate readily, and seedlings make rapid growth, either in pots or directly in the field, attaining a mean height of 14.8 inches the first season. Progenies from plants with high, medium, and low yields of rubber were grown and analyzed; many of the one-year old plants had a rubber content equal to 75 per cent of that of the parents, and some of the progeny individuals, even the first season, had a higher rubber content than that of the parents.(9)

Asclepias sullivanti

Description: (30) A stout, erect perennial herb, two to five feet high. Occurs as clumps of stems at irregular intervals. Leaves numerous to the top, 7 to 12 pairs on each stem, 4 to 6 inches long, 1.5 to 3 inches wide. Leaves are thick and smooth.

Distribution and Ecology: (30) The range of this species is from southern Ontario and Ohio to Kansas, Nebraska, and Minnesota. While it may be expected almost anywhere throughout this region where soil and moisture conditions are suitable, there are but few records of its occurrence in abundance.

A. sullivanti grows only on low land where soil is moist. It seems abundant along streams and lake-shores, where the land is overflowed at certain seasons. Possibly it was at one time more common on better drained and drier soil, but was crowded out by agricultural practice. Its distribution indicates that it can endure very low winter temperatures (at least 30°F). Fairly high summer temperature and humidity are suitable. It is probably not suited to arid conditions.

Robust stems are sometimes 3/4 inch thick. The leaves constitute approximately 50 per cent of the weight of the plant. The tonnage to be grown per acre is probably the greatest of any of the milkweeds.

<u>Rubber</u>: <u>A. sullivanti</u> yielded the highest rubber content of any of the species tested by Hall and Long (30). One plant tested by these investigators gave 5.0 per cent in the leaves and 8.2 per cent in the stem; another gave 8.1 per cent in the leaves and only a trace in the stem. The average of 19 lots of leaves analyzed was 3.7 per cent. Stems except for a few exceptions averaged well under 1 per cent.

<u>Asclepias syriaca (Common milkweed)</u>
Synonym: A. cornuti

<u>Description</u>: (30) A stout, erect perennial herb, three to six and sometimes seven feet high. Stems usually several at a place, often very numerous and crowded to form thickets. Leaves numerous to the top, usually 20 or more on each stem, opposite, lance-oblong, or broadly elliptic, five to eight inches long, two to four inches wide.

<u>Distribution and Ecology</u>: (30) This is the most abundant milkweed in the eastern United States and Canada. It grows from New Brunswick, Canada, to North Carolina and west as far as Kansas and Saskatchewan. It is located especially in fields and waste places, commonly coming in where the soil has been disturbed. Railroad rights-of-way are often lined with it. The climate of southern Michigan is apparently well suited to the plants, since they are reported as very abundant in that region. This species is probably unsuited to the arid districts of the West and Southwest.

<u>Rubber</u>: Up to the investigations of Hall and Long, the common milkweed was the specie to receive the most attention as a rubber plant. The examinations of Saunders in 1875 and Fox in 1911 have already been discussed

in the introduction to the milkweeds, page 35 . These investigators demonstrated the presence of rubber in small amounts. Hall and Long believed these poor results to be due either to chance gathering of poor strains or to harvesting at the wrong season from plants grown under conditions unfavorable to the formation of rubber.

Hall and Long, in the analyses of ten leaf samples, obtained a maximum of 4.4 per cent rubber, a low of 0.53 and a mean of 2.71 per cent. Their results also indicate that mature leaves contain the highest percentage. Large robust plants may carry as high or higher percentage of rubber in the leaves as average or small ones. The amount of rubber in the stems is almost negligible (30).

Fisk Gerhardt reported in 1929 (27) the results of some work on the plant. He studied the seasonal variation of rubber as well as other constituents of the plant. "---sucrose is stored in the leaf of the milkweed, translocated in the form of hexoses through the stem to the root and stored as starch during the late summer only to be converted back to sucrose at the inception of winter". Ash and rubber were found to be stored in the leaf. Latex gave a rubber content of 3.5 per cent while gums and resins were present in large amounts. Freezing destroyed more than 4/5 of the normal rubber content. The relationship of rubber to the other constituents was not found. The seasonal variation in rubber content as found by Gerhardt is of interest: (benzene extract after acetone extraction is reported as rubber)

	leaves per cent	stems per cent
May 15	0.49	0.30
June 5	0.60	0.27
June 23	0.81	0.47
Aug. 5	1.50	0.40
Sept. 7	2.55	0.30
Oct. 6	2.85	0.31
Nov. 10 (freeze)	0.88	0.30

In all cases the rubber in the roots was found to be negligible.

Studies of the common milkweed as a rubber producer were conducted at the Iowa State College (1934 - 1939) by Messrs. Vilbrandt, Bates, and others. (Unpublished theses, Iowa State College)

T. K. Matzurevich (42) has made an extensive analysis of the sap of <u>A. syriaca</u>. The composition is given as:

1) a colloidal solution of rubber.
2) inorganic salts.
3) substances having a reducing action on Fehling solution (cannot be accepted as saccharides)
4) mixture of esters:
   acetic   cerotic
   butyric   erutic acids, and other fatty acids
   palmitic
5) high M.W. inactive resin alcs. with melting points of 180-181°C, 135-136°C
6) Lecithin is probably also present in the sap
7) the major part of the resins is probably composed of alpha and beta amyrins.

The same observer reports the rubber from <u>A. syriaca</u> to resemble ordinary kind in that it forms a bromide, iodide and a nitrosate.

<u>Asclepias californica</u>

<u>Description</u>: (30) A rounded perennial herb, two to three feet high and about as broad; roots exceptionally large, branching near the surface

of the soil to form a broad crown of usually four to ten stems. The stems are unbranched, straight, not erect, but spreading or ascending; leaves, four to eight pairs on each stem, ovate or oblong, acuminate, 2.5 to 5 inches long, 1.5 to 3 inches wide.

Distribution and Ecology: (30) This milkweed grows only in western California, from the latitude of San Francisco south to the Mexican border and on the westerly slope of the Sierra Nevada from Mariposa County to Tehachepi Pass. The plant grows scattered on the inner Coast Ranges, where it reaches its northern limit on Mount Diablo, and is common only in southern California. It nowhere forms pure stands over large areas.

A. californica requires a light, somewhat sandy soil, a very moderate amount of moisture, and this only during the early spring, and warm, clear days during the growing period. The annual rainfall in its natural habitat does not exceed 16 inches, most of this during January to April. The temperature of this location varies between 20 and 100°F.

Rubber: Hall and Long obtained from six leaf analyses, a high of 4.1 per cent rubber, a low of 0.9 and a mean of 2.76 per cent. They also tested some latex with the result of 10.0 per cent rubber and 58 per cent acetone extract in water-free latex. Lack of erect growing habit was thought by these investigators a disadvantage to commercial harvesting. Each plant requires considerable space.

Asclepias latifolia
(Broad-leaf milkweed)

Description: (30) A stout, very leafy perennial herb, usually one to two, but sometimes three feet high; roots coarse and woody; several stems, smoetimes much crowded and forming bush-like plants, unbranched, either erect or spreading, 12 to 20, and often 30 leaves on each stem, oval to orbicular, four to six inches long, and nearly as wide, very thick.

Distribution and Ecology: (30) A. latifolia is an inhabitant of the plains and lower foothills from Nebraska and Colorado south and west to Kansas, Texas, and northwestern Arizona. The plant grows in small, widely separated clumps, occupying several square feet and with stems probably all from one root. Along the eastern slopes of the Rocky Mountains it usually occupies the summits of low, rounded hills, or grows scatteringly over warm, dry southerly slopes where the soil is well drained. At one location where the species is abundant, the annual rainfall is 17 inches, and the temperature range - 28 to 101°F.

Rubber: Hall and Long obtained from a series of seven leaf analyses from different locations: high 3.7, low 1.0, mean 2.63 per cent. A study of weight of foliage and probable yield per acre was also made:

Average number of leaves per stem:	24
Average dry weight single leaf:	0.037 ounce
Average stems per square foot:	4
Computed weight dry leaves per acre:	9,392 pounds
On the basis of 3 per cent rubber:	281 pounds per acre

Asclepias Mexicana

Description: (30) An erect perennial herb, woody at the base, two to four feet high, and in moist situations over six feet high. Usually narrow and slender stemmed, but up to eight feet in diameter in vigorous forms, especially in alkaline soil. Stems usually few at one place, but under favorable conditions as many as 80 or 100 are crowded into a single clump. Stems straight, erect, and mostly unbranched. Forty to 60 leaves on each stem, arranged in whorls of three to six each, linear, tapering to the apex, 2.5 to 6 inches long, 1/4 to 1/2 inch wide.

Distribution and Ecology: (30) This species ranges from Mexico, whence came the original specimens, to Arizona, Nevada, California, northern Idaho, and southern Washington. It grows in greatest abundance and to the largest size in the hot interior valleys of California, but many vigorous plants are also to be found in the more elevated valleys of western Nevada.

The largest plants are always found in moderately alkaline soil. An ecological feature especially noticeable in this species is the promptness with which new stems are sent up after the old ones have been removed. It is certain that under ordinary conditions two crops could be harvested in a year, and this probably without any reduction in the rubber content. With a reasonable amount of moisture, a third crop seems possible.

Rubber: Hall and Long found a wide range of variation in rubber content among the samples tested. Twelve leaf samples gave a high of 4.8, a low of 1.4 and a mean of 3.34 per cent rubber. The foliage is more sparse than in most other milkweeds, and is only a minor portion of the whole weight. Some stems were found to contain 2.3 per cent with leaves of the same plant at 4.4 per cent. Several second growths after cutting gave over 4 per cent rubber.

<u>Asclepias galioides</u>

(Whorled milkweed)

<u>Description</u>: (30) An erect perennial herb, sometimes slightly woody at the base, 1 to 3 feet high. Roots erect and much branched just below the surface. Varying number of stems at one place, straight, unbranched, green. Leaves 20 to 60 on each stem, in whorls of three to six each or some of the lower only in pairs, linear, tapering up to the apex, two to four inches long and about 0.8 inches wide, green and smooth on both sides.

<u>Distribution and Ecology</u>: (30) A species of the southern Rocky Mountain region, from middle Utah and middle Colorado south into Mexico and Central America. It seems most abundant in Arizona and New Mexico. The natural habitat is on the dry plains and foothills, often in sandy soil. It is abundant in overgrazed areas, where it often replaces the original grasses and leguminous plants, and also in fallow fields. It responds quickly to the influence of cultivation or irrigation, as along ditch-banks.

The downy seeds are carried both by wind and irrigation water. Broken roots give rise to new plants. The plant is poisonous to stock.

<u>Rubber</u>: Hall and Long only analyzed three samples of this species and report as follows: Leaves, high 5.2, low 0.62 per cent; whole plant 1.5 per cent.

<u>Asclepias brachystephana</u>

<u>Description</u>: (30) A comparatively slender leafy herb, one to two feet high, roots thick and woody, producing clusters of stems. Stems

usually branched near the base, but otherwise mostly simple and straight, erect, very smooth. Leaves numerous to the top, usually 15 to 30 on each shoot, all opposite, narrowly lanceolate, 2 to 5 inches long, 1/4 to 1/2 inch wide, rather thin, smooth, veiny.

Distribution and Ecology: (30) Most abundant in New Mexico, but ranges west almost throughout Arizona, where it is much less common, and southeast into western Texas. Also found in northern Mexico. Grows on dry mesas and foothill slopes. Especially common in overgrazed or otherwise disturbed areas. The small size of the plant is somewhat compensated for by the abundant, crowded foliage, but the leaves are so narrow that a large yield of herbage can scarcely be expected.

Rubber: Hall and Long analyzed plants from one locality only. Three out of four samples were found to have almost an equivalent percentage of rubber in both leaves and stems. Mature plants gave the highest yields. One whole plant gave 3.0 per cent, leaves from another 2.7, stems up to 2.9 per cent.

Asclepias speciosa

(showy milkweed)

Description: (30) A robust, erect perennial herb, four to six feet high, several to numerous stems from each crown, sometimes forming clumps five feet or more in diameter. Stems simple and straight. Leaves numerous to the top, 10 to 20 or more on each stem, mostly in pairs, broadly lanceolate or oblong-ovate, four to six inches long and two to three inches wide, thick.

Distribution and Ecology: (30) This is the most widely distributed of all of the milkweeds of western North America. Ranges from Alberta and Minnesota to Iowa, Texas, Arizona, California, and British Columbia. It grows from the hot, low interior valleys, to the moderately cool mountain meadows in the lower part of the pine belt, where it is more abundant, reaching altitudes of over 8,000 feet in New Mexico. It is always partial to moist soil and is therefore found in seepage areas along ditches and creeks and in moist meadows.

Rubber: Hall and Long in seven leaf analyses from different localities and at different times, obtained a high of 3, a low of 0.99, and a mean of 2.10 per cent rubber. Stems gave consistently very low rubber contents, less than one per cent.

RABBIT-BRUSH

Botanical name: *Chrysothamnus* (over six species)

The work of Hall and Goodspeed: The outstanding and almost exclusive work on rabbit-brush was done by Hall and Goodspeed (29) and reported in 1919. The information presented in this section is therefore largely taken from the publication of these authors. While these investigators touched on quite a variety of plants (title of the report is "A Rubber Plant Survey of Western North America"), by far the major portion of the work was done on one specie of rabbit-brush, *Chrysothamnus nauseosus*. The work was fostered by the Committee on Scientific research of the State Council of Defense of California and by the University of California.

Hall and Goodspeed found it necessary to give considerable attention to the botanical relationships of the species and varieties of this genus of shrubs. There seems to have been considerable confusion among botanists as to nomenclature and characteristics which define the different species and varieties. This was due to the high complexity of the different forms. The first part of the work of Hall and Goodspeed was devoted to the investigation and classification of the botanical characteristics and to nomenclature.

Chrysothamnus nauseosus: (Over 22 recognized varieties) This species was divided into a number of varieties, each one receiving separate consideration. A brief description of the group in general follows:

All of the species of *Chrysothamnus* are shrubs. Some are merely dwarfs, but those which Hall and Goodspeed found of interest as rubber producers are usually of good size, from three to eight feet high, and about as broad. They all grow from deep taproots which have normally but few materials. There are usually several trunks from a single base and these are clothed in age with loose, fibrous brown bark which peels off in strips. Straight clear stems are the exception. The branches are numerous, and often are distorted and irregular. The young shoots are long, straight, and erect in some varieties, short, branched and twiggy in others. The narrow, entire leaves are rather sparse and vary from green to dull green to gray. The plants are highly ornamental during the flowering season, which extends from August to October. The average age of sull sized shrubs is about eight years for plants weighing five or six pounds growing in ordinary alkaline soil without attention or disturbance by man. Plants seldom reach full size before they are five years old and often increase in size and weight up to ten years and older.

Distribution and Ecology: Rabbit-brush is widely distributed in western North America. The plants are most abundant and of maximum size in the Great Basin area. The northern limit is reached in British Columbia, Alberta, and Saskatchewan. The easterly limits of the genus are reached in South Dakota and western Nebraska; the southerly limits in western Texas, southern New Mexico, and southern Arizona, with some possible extensions into Mexico, or at least Lower California.

The densest stands and largest plants in the Great Basin area are found in the alkaline deserts of Nevada and eastern California, and in southern Colorado and Utah. In general, the plants will not tolerate very strongly alkaline soil. Where alkali is somewhat less, but still too abundant for upland plants certain varieties of Rabbit-brush covers areas of considerable extent.

Cultural requirements are such that Chrysothamnus could be grown on many alkaline plains of the West without irrigation; certain varieties endure winter temperatures of -20° F; others would withstand summer temperatures anywhere in the Western states except possibly in the hottest valleys. Plants grow readily from seed. Vegetative reproduction is also possible. Plants cut above the stem-root boundary will ratoon rapidly; if cut below this line, the remaining portion dies.

Rubber: Rubber occurs in individual cells much as in guayule, and is not of the latex variety.

Hall and Goodspeed adopted the name "Chrysil" for the rubber from C. nauseosus, and found it to be a high grade rubber, vulcanizing without difficulty. The discovery of rubber in Chrysothamnus was made in 1904. Previous to this time it had been known that Indians prepared a sort of chewing gum from the plant. Steps were taken about 1908 to erect a rubber-extraction plant at Salida, Colorado, the intention being to use rabbit-brush but the plan fell through.

Rubber occurs in the plants in greatest amount at about the soil line. It is present only in the upper part of the root. Young leaves and twigs have only small amounts. The richest tissues are in the cortex and medullary rays, the former carrying much more than the latter. In view of this fact, Hall and Goodspeed recommended the inclusion of about four inches of the roots in harvesting to obtain maximum rubber.

A survey of the total amount of rubber that might be obtained was made by districts:

		pounds
1)	East Central California and adjacent Nevada	3,280,000
2)	Mojave Desert, California	400,000
3)	Northeastern California and adjacent Nevada and Oregon	1,000,000
4)	West Central Nevada	7,680,000
5)	Northern & Central Nevada	23,700,000
6)	Utah	20,000,000
7)	Colorado	24,300,000
	Total	80,360,000

After various allowances for areas not included, it was stated as probable that the total amount in all of the western states was not less than 300,000,000 pounds.

The results of the chemical analyses of C. nauseosus are tabulated:

	Variety of C. nauseosus	Number samples	Rubber % of dry weight High	Low	Mean
1)	consimilis	69	6.57	0.39	1.97
2)	viridulus	36	5.66	0.44	2.52
3)	gnaphalodes	18	3.60	0.26	1.61
4)	speciosus	17	2.77	0.16	1.18
5)	graveolens	10	3.19	0.07	0.83
6)	pinifolius	5	3.98	1.11	2.95
7)	hololeucus	4	4.10	1.06	2.83
8)	mohavensis	4	1.08	0.30	0.63
9)	occidentalis	3	1.54	0.71	1.07
10)	leiospermus	2	1.17	0.84	1.00
11)	frigidus	1	—	—	1.86
12)	nauseousus (typical)	2			traces

It should be stated that sometimes individual plants were devoid of rubber. Other species of Chrysothamnus are included in the tabulation on page 69.

Hall and Goodspeed refrained from drawing conclusions on any but the first five of these. Individual variation is an important factor and only after a large number of samples from widely separated localities have been analyzed are conclusions justified. It was thought significant that C. viridulus and C. consimilis were inhabitants of alkaline flats, C. gnaphalodes, and C. speciosus of non alkaline soil. The apparent parallel between rubber content and botanical varieties may be due to environmental factors.

A study in seasonal variation indicated that during the resting period (September through December) acetone-soluble substances increase in amount while rubber decreases.

Young plants, four years old or less, are almost always low in rubber content (per cent). Deposition of rubber is small until about the third year and the ratio of rubber-bearing tissue to the whole plant is low. Decay sets in with over-maturity, reducing the weight of the rubber-carrying parts.

The bulk of the harvested shrub may be materially reduced without much loss in total rubber content by discarding all growth less than three years old. This would take with it all the leaves, but these, like the twigs themselves, carry only traces of rubber.

Estimation of Acreage Yield. (by H. Kress) After weighing numerous samples, Hall and Goodspeed estimated the weight of the woody (main rubber-carrying) parts to be, on the average:

C. viridulus:	6 pounds
C. consimilis:	4 pounds
C. pinifolius	4-5 pounds

These plants are described as from three to eight feet high and about as broad. Each plant will occupy or require about 40 square feet area. This amounts to about 1,000 plants per acre. The mean of the analyses for C. viridulus was 2.52 per cent rubber, for C. consimilis 1.97 per cent; sufficient samples of C. pinifolius were not tested to place reliance on the mean given. We have therefore,

for C. viridulus: 1,000 x 6 x0.0252 = 151 pounds per acre
for C. consimilis: 1,000 x 4 x0.0197 = 78.8 " " "

The average age for this weight of plant was given as eight years; the yield in pounds per acre per year is therefore:

C. viridulus: 151/8 = 19
C. consimilis: 79/8 = 10

Haplopappus: Hall and Goodspeed also found rubber in ten species of a closely related genus of shrub, Haplopappus. This genus does not warrant a special description and rubber percentages are included in the tabulation on page 69.

THE SPURGE FAMILY

Botanical name: Euphorbia (many species)

This group contains innumerable species of latex-bearing plants closely related to the true Para rubber tree. (70)

In 1928 an expedition to Madagascar led by Charles F. Swingle of the Bureau of Plant Industry, explored this island for plants likely to be of value to American agriculture. (77 - 30) The expedition spent several weeks in the extreme southwestern part of the island, where tree Euphorbias flourish, notwithstanding the extreme aridity of the region. The annual rainfall in this section is frequently below ten inches, and droughts lasting six months occur every year. The expedition returned with 23 lots of potential rubber producing plants, including ten species which had actually been commercially used in the past. Most of these plants were propogated for future trial in the United States.

Euphorbia intisy: One of the species obtained by the above mentioned expedition was Euphorbia intisy. The plant was almost extinct because of ruthless exploitation for rubber in the past. This plant, almost leafless, has a unique water storing system, enabling it to withstand drought. It was thought that the plant would thrive on the worthless arid soils of the United States.

In 1930, this "intisy" was reported as being propogated from cuttings, though special treatment was required. (68) Many of the cuttings failed to root. The behavior of the plant was being studied at field stations in California and Florida. It was regarded as probable that the very slow rate of growth excluded profitable commercial cultivation.

A further report in 1932 (68) states that the "intisy" plants were found to grow better in southern Florida and near the coast of California than under desert conditions in the Colorado Valley. A large shipment of seed from Madagascar in the spring of 1932 failed entirely to germinate.

The Department of Agriculture in 1942 (70) reports cultivation experiments disappointing. It was impossible to obtain seeds and reproduction by cuttings was very slow. After the many years required to grow the plant, it would have to be destroyed to obtain the rubber.

Poinsettia: The Poinsettia is also a member of the Euphorbia group, and appears as an ornamental in Florida. The plant has been promoted and tested for rubber production. (70) Reliable tests have demonstrated that the rubber content of this plant is very low.

Other Euphorbias: Various other Euphorbias are found in the United States, some of those appearing as ornamentals. One of these is the so-called "Snow on the mountain". These plants have been examined in Germany where they have also been considered as rubber producers. Scheermesser (60) draws attention to the technical difficulties in the way of rubber recovery and to the unprofitableness of such a venture. Further species appear in the tabulation on page 69 .

MISCELLANEOUS

Colorado Rubber Plant: (*Hymenoxys floribunda utilis*) (30) In 1902 and 1903 considerable interest fell on a rubber plant from Colorado and New Mexico, commonly called "pinguay". Small mills were erected in southern Colorado and experiments were undertaken in the cultivation of the plant. It was soon abandoned as unprofitable. Roots were stated at that time to contain from 5 to 12 per cent of crude rubber. Analyses by Hall and Long gave 3.6 per cent in the roots, main stems and leaves, 0.84 and 0.9 per cent for one whole plant.

The 1904 report by W. P. Cockerell (17) gives the name of the plant as *Picradenia odorata utilis*.

Osage Orange: (*Maclura pomifora*) (70) Because of its milky juice osage orange or hedge apple had attracted attention as a source of rubber. Interest in the plant dates back to before 1910, and studies have been conducted. Department of Agriculture laboratories failed to show even one per cent rubber in the fruits and other parts of the plant.

China Rubber Tree: (*Eucommia ulmoides*) (68) One of the hardiest species of rubber-producing plants that can be grown in the United States is the Chinese rubber-bark tree. It produces a gum with qualities somewhat intermediate between rubber and gutta-percha. The tree is not affected by winter temperatures in the vicinity of Washington, D. C., though the flowers may be killed by late frosts, so that seed is not set every year. The tree grows as far north as Massachusetts (77-'27). Rubber is formed in leaves and seed coats as well as in twigs and bark. Not a latex plant.

Other Rubber trees: All of the principal types of tropical rubber trees including American, African, and Asiatic species, have produced vigorous individuals in Florida, and most of these have flowered and fruited (68).

The African Rubber tree (Funtumia elastica) has grown at the U. S. Plant Introduction Garden at Chapman Field, south of Miami, Florida. The tree grows well, and has possibilities as an ornamental as well as a rubber producer. (68).

The Assam Rubber Tree (Ficus elastica), a native of northern India, is well known in household cultivation in the form of cuttings known as "rubber plants". It is also planted as a shade tree and grows to large size in the coast districts of California and in southern Florida as far north as Bradenton and Fort Pierce. The mature trees produce rubber of good quality, but not so readily obtainable by tapping as from Hevea (77-'27).

The Hevea or Para rubber tree has made good growth in Florida (1928) and many trees attained 15 feet or more. Evidently the Hevea is more resistant to cold than supposed (68). One small Hevea survived for more than 20 years in the open air in southern Florida, in an unfavorable location (77-'27).

Three species of the Ceara rubber tree can grow in southern Florida:

Manihot glaziovii
Manihot heptaphylla
Manihot dichotoma

Chitte trees (19) occur on the west coast of Mexico and can be grown in California, yielding a fair quality of rubber.

OTHER RUBBER PLANTS

Numerous other rubber-bearing plants are mentioned in the literature. Information on distribution and ecology is usually lacking entirely, and rubber is either merely mentioned as being present or the results of one or two analyses are given. These do not warrant a separate section, therefore, and are included in the tabulation on page 69.

SPECIES WITH NO RUBBER

Frequently erroneous reports of the discovery of a new rubber plant finds its way into the literature. In some instances these have been used to lure investors into fraudulent commercial enterprises. Ocotillo (*Fouquieria splendens*) has been reported a number of times as a rubber plant and money invested in its utilization for this purpose. Very careful chemical examination by Hall and Long showed beyond a doubt that no rubber is present. Various species of cactus are stated as containing rubber, but no evidence presented. *Opuntia vulgaris* is one of these, rubber supposedly having been obtained from it in Arizona. Claims as rubber producers have been made for certain ocean kelps, especially *Macrocystis pyrifera*, and companies formed in southern California to exploit them for this purpose. The one reported most frequently, probably because of its resemblance to guayule is the brittlebush (*Encelia farinosa*). Analysis proved that no rubber was present.

Hall and Long (30) list 63 species which they examined and in "which no rubber could be detected with certainty." Their list contains one each of guayule, goldenrod, osage orange, and rabbit-brush. It is entirely possible that some of these species may yield rubber under conditions or in locations different from those of the single chance-gatherings. For example, Hall and Goodspeed found some individual samples of rabbit-brush entirely devoid of rubber although the mean of all samples of the given specie showed a good rubber content.

Hall and Goodspeed (29) also list 74 species in which rubber could not be detected with certainty. The same qualifications should be applied.

WILD LETTUCE

(Prickly Lettuce)

Botanical name: Lactuca (several species)

Lactuca scariola

Description: (56) This plant closely resembles the common garden lettuce, especially the Cos varieties. The plant is an annual, coming from seed each year. Occasionally the seed germinates in the fall, the plant making some growth before cold weather. In this form it passes the winter, thus becoming a winter annual.

The height of the plant is from a few inches in poor soil up to five or six feet or more in rich soil. The stems are erect and branched only above. The lower half or two-thirds of the stems are clothed with sessile leaves, opposite, oblong and armed, four to six inches long and one to two inches wide. The upper half or third of the stalk sends out spreading, rather bare branches, much subdivided, and ultimately bearing inconspicuous yellow flowers. Each flower gives rise to about a dozen dark brown seeds of similar shape to those of the garden lettuce, but somewhat shorter. Each seed bears a slender rigid stalk as long as itself, in turn supporting a white, filmy parachute, which serves in wind distribution. Flowering time is from July to September.

The whole plant is a pale, pea-green color. Its specially characteristic feature is the presence of a row of soft prickles along the edges of the leaf and a row down the midrib beneath. There are also a few prickles scattered over the stem, particularly the lower portion. The juice of the plant is milky.

Wild Lettuce as a Weed: Although regarded as an unimportant weed by Darlington in his "American Weeds and Useful Plants", published in 1847, it is now regarded as one of the most troublesome weeds. (26) The Department of Agriculture lists it among the 50 worst weeds in the United States (22), and states it as injurious to all crops from Ohio to Iowa, and Utah to California.

It is a weed not only because it is a plant out of place, but because it possesses certain attributes that enable it to maintain itself wherever a seed finds moisture and soil enough to gain a foothold (56). Among these are:

1) Large number, hardiness, and excellent distribution of seeds.

2) Protective devices against animals and insects. (Prickles, and bitter, milky juice.)

3) Adaptability to rather extreme soil and climatic conditions.

4) Rapid recovery upon injury or destruction of the upper portions.

The manner in which the seeds ripen is of interest. The small flowers only open a short time on clear days, and then close up until the seed is ripe, and in the meantime look almost like young, unopened buds. This deceptive appearance may lead one to think he is cutting the weed in the bud before it has blossomed, when in reality it is loaded with seeds which will ripen as the plant dries, and be discharged almost as effectively as if the plant had been left standing.

Regarding germinating power of the seeds, one report states (56) that an average of 10 per cent of the seeds of one plant had the power of growing soon after ripening; the remaining 90 per cent remain dormant until the coming spring, and doubtless longer.

Distribution and Ecology: The plant is a native of southern Europe, northern Africa, and the temperate part of eastern Asia. It found its way into the United States about 1863, gaining a foothold in some Atlantic ports (56). It was distributed by both railroads and waterways to most parts of the country. Its present range is from Vermont to Georgia, and westward to the Pacific coast, and includes the greater portion of the pluvial area of the United States (69,26).

The plant will grow and produce seed in a great variety of soil and surrounding conditions. Stone heaps, weed-choked corners of fences and yards, alongside gutters and roadways, a crevice in the pavement, beaten paths, are all acceptable places in which to flourish. (56). In favorable locations it will make rapid growth to overtop many of its competitors, and in less favorable locations it will grow where few other plants could live.

Rubber: In 1913, Fox (26) tested two species of wild lettuce for rubber, one of which was Lactuca scariola. Fox reports the latex of the plant to contain 1.58 per cent rubber and 12.85 per cent resin or acetone soluble material. The rubber was said to be of exceptionally good quality. During the war (1914018) the Germans attempted to manufacture rubber from certain weeds. The most important weed used was a species of Lactuca (30). Hall and Long (30) report analyses as follows:

Place of collection	date	part	per cent resin	per cent rubber
Manitou, Colo.	July 19	leaves	10.4	0.86
Manitou, Colo.	Aug. 18	whole	5.4	0.20
Lawrence, Kans.	Aug. 28	whole	13.0	0.64
Madison, Nebr.	Sept. 24	whole	10.8	0.71

LACTUCA CANADENSIS

Description: (26) A vigorous, robust, biennial plant, three to twelve feet high; stems stout, hollow, purple; leaves large, irregularly cut and toothed, dull green; flowers small, numerous, yellow to white; seeds small with usual cottony appendages which aid in its distribution; odor strong, acrid. All portions of the plant, especially the stem, secrete when bruised, an abundance of thick latex which rapidly coagulates to a yellowish semi-solid.

Distribution and Ecology: This plant is native to the United States, and is found growing everywhere across the continent from Oregon to the Carolinas. (26)

The plant is usually found in damp situations, growing upon rich soil, especially on newly cleared lands.

Rubber: In 1913, (26) Fox reported the latex of this plant to contain 2.19 per cent rubber and 11.42 per cent resins. Quality of the rubber was exceptionally good.

Lactuca Virosa

Description: This plant is very much like Lactuca scariola in appearance and habit. (69) The lower leaves are somewhat larger than in L. scariola, and the stems are smooth throughout or hairy at the base.

Distribution and Ecology: The plant occurs in fields and waste places as L. scariola, and has the same range.

Rubber: Hall and Long (30) report one analysis of L. virosa, with leaves containing 0.7 and stems 0.5 per cent rubber.

Other Species: Descriptive material on the other species of Lactuca is lacking. Several analyses appear in the tabulation on page 69.

Non-rubber Constituents of Lactuca: At least three of the species of Lactuca are known to contain Lactucarium, a recognized drug of the Pharmacopoeia. This drug is classified as a sedative and diuretic, and known as "lettuce opium" on account of its medicinal action which is due to lactucin or lactucic acid. (26) Lactucarium is an imported drug originating in Scotland, Rhenish Prussia, and France. In Scotland its production is an industry. Lactuca virosa is listed among "American Medicinal Plants of Commercial Importance" by the Department of Agriculture (69). In Europe L. scariola is said to be substituted for the official plant L. virosa, its extract having to an inferior degree the anodyne and calming properties of opium. (56). Lactuca canadensis also contains a bitter principle pronounced equal to Lactucarium of German origin (26). (Fox suggested the combined production of rubber and Lactucarium as a possible industry for the North Temperate Zone.)

In his analyses of the latices of L. canadensis and L. scariola, Fox (26) discovered a substance of acid nature, insoluble in acetone, and soluble in weak alkalies. In preparing the rubber from the latex, Fox found it necessary, on account of this acid substance, to heat the crude acetone precipitate with boiling alcoholic potash or to precipitate directly the benzene rubber solution with this reagent.

TABLE R.

RUBBER CONTENT OF PLANTS

Plants Which are Native to, or Which Have Been Introduced Into the United States

Botanical Name	Common Name	No. Anal.	Part	Rubber per cent high	low	mean	Ref.
Abractylis gummifera		1	-	-	-	rep	77(27)
Acerates angustifolia		1	sf	-	-	0.70	30
auriculata		1	f	-	-	2.9	30
"		1	s	-	-	0.5	30
viridiflora		1	sf	-	-	1.0	30
Actinella Richardsonii	Pingue plant	-	r	-	-	7	34
Agoseris aurantiaca		2	sf	0.22	0.16	0.19	30
gauca		1	sf	-	-	0.6	30
Alstonia	Devil tree	-	-	-	-	rep	68(25)
Apocynum androsaemifolium	Spreading dogbane	3	f	1.2	0.62	0.84	30
"		1	s	-	-	0.22	30
cannabinum	Indian hemp	7	f	5.1	0.79	3.34	30
"		6	s	1.1	0.22	0.80	30
Asclepias :	Milkweeds						
albicans		12	sf	4.42	0.68	2.11	8
arenaria		1	f	-	-	0.70	30
"		1	s	-	-	0.53	30
brachystephana		4	sf	3.0	2.1	2.5	30
californica		6	f	4.10	0.90	2.76	30
"		2	s	0.75	0.70	-	30
cordifolia	Purple M.	1	sf	-	-	0.70	30
"		1	f	-	-	1.5	30
eriocarpa		2	f	2.4	2.2	-	30
"		2	s	0.70	0.50	-	30
erosa	Desert M.	3	f	2.5	1.54	2.01	30
"		4	s	1.39	0.48	0.82	30
"		50	f	13.06	2.45	9.57	9
galioides	Whorled M.	2	f	5.20	0.62	-	30
halli		3	f	1.4	0.8	1.07	30
"		3	s	1.0	0.6	0.8	30
latifolia	Broad-leaf M.	7	f	3.70	1.0	2.63	30
"		6	s	0.7	0.5	0.64	30
linearis		2	sf	0.85	0.40	-	8
mexicana		12	f	4.80	1.40	3.34	30
"		12	s	2.30	0.50	0.82	30
pumila		2	sf	1.6	0.86	-	30
speciosa	Showy M.	7	f	3.00	0.99	2.10	30
"		5	s	2.6	0.14	0.82	30
subulata	Desert M.	22	s	6.5	0.8	2.9	30
"		393	sf	6.00	0.50	2.86	8
sullivanti		19	f	8.1	1.2	3.75	30
"		18	s	8.2	0.1	0.36	30
syriaca	Common M.	8	f	4.4	0.8	3.1	30
"		-	f	2.85	0.49	-	27
"		-	s	0.47	0.27	-	27
"		-	l	-	-	3.5	27
verticillata		1	sf	-	-	2.4	30
Asclepiodora decumbens		1	sf	-	-	1.3	30
viridis		1	f	-	-	1.4	30
"		1	s	-	-	0.3	30
Aster spinosus		2	sf	0.9	0.2	-	30
Campanula pyramidalis	Chimney bellflower	1	f	-	-	1.0	30
"		1	s	-	-	0.1	30
rotundifolia	Harebell	1	sf	-	-	1.2	30
Carissa (sev. species)	Hedge thorn	-	-	-	-	rep	68(25)
Carpodinus "		-	-	-	-	rep	68(25)
Castilla elastica	Mexican rubber tree	-	-	-	-	rep	68(25)
Cerbera (sev. species)		-	-	-	-	rep	68(25)
Chrysothamnus :	Rabbit brush						
linifolius		2	t	1.0	0.0	-	29
nauseosus, var:							
consimilis		69	t	6.57	0.39	1.97	29
frigidus		1	t	-	-	1.86	29
gnaphalodes		18	t	3.60	0.26	1.61	29
graveolens		10	t	3.19	0.07	0.83	29
hololeucus		4	t	4.10	1.03	2.83	29
leiospermus		2	t	1.17	0.84-	1.00	29
mohavensis		4	t	1.08	0.30	0.53	29
occidentalis		3	t	1.54	0.71	1.07	29
pinifolius		5	t	3.98	1.11	2.95	29
speciosus		17	t	2.77	0.16	1.18	29
viridulus		36	t	5.56	0.44	2.52	29
paniculatus		2	t	3.24	1.20	-	29
teretifolius		5	t	4.51	1.67	2.70	29
turbinatus		1	t	-	-	4.88	29
Crepis taraxicifolia	Hawks beard	1	sf	-	-	0.6	30
Cryptostegia :	Madagascar rubber vines						
grandiflora		1	f	-	-	5.1	30
"		1	s	-	-	1.0	30
"		-	f	3.34	-	3.13	52
"		20	f	2.94	-	1.90	68(32)
madagascariensis		-	f	3.14	-	2.94	52
"		20	f	3.51	-	2.22	68(32)
(hybrid)		-	f	8.60	-	5.97	52
"		20	f	6.98	-	4.97	68(32)
Eucommia ulmoides	China rubber tree	-	-	-	-	ref	68(27)
Euphorbia albomarginata		1	sf	-	-	0.6	30
arkansa		2	sf	2.0	0.19	-	30
californica		-	-	-	-	rep	48
calyculata	Chupire	-	l	-	-	21	48
cyparessias	Cypress spurge	-	-	-	-	rep	49
"		-	-	(20 Kg. per acre)			75
"		-	l	3.0	1.0	-	75
elastica		-	l	-	-	10.85	57
fulva	palo amarillo	-	l	15.7	7.3	-	48
glyptosperma		1	sf	-	-	0.66	30
helioscopia	sun spurge	-	-	(17.4 Kg. per acre)			75
hindsiana		-	-	-	-	rep	48
intisy		-	-	-	-	rep	77(30)
lathyris	Caper spurge,	1	f	-	-	0.1	30
"	Mole plant	1	s	-	-	0.1	30
lorifolia		-	l	-	-	15.88	44
marginata	Snow-on-the -	4	f	0.85	0.40	0.64	30
"	mountain	4	s	0.32	0.21	0.28	30
montana		1	f	-	-	0.4	30
"		1	r	-	-	0.46	30
"		1	sf	-	-	0.2	30
nutans		2	sf	0.43	0.30	-	30
ocellata		1	sf	-	-	0.6	30
pulcherrima	Poinsettia	-	-	-	-	rep	70
"		1	sf	-	-	0.9	30
tirucalli	Milk bush	-	l	-	-	27	4
Ficus carica	Fig	1	f	-	-	0.4	30
elastica	Assam rubber tree	-	-	-	-	rep	77(27)
Funtumia elastica	African rubber tree	-	-	-	-	rep	68(25)
Grindelia nuda	Gum plant	1	sf	-	-	1.1	30
robusta		1	sf	-	-	0.77	30
squarrosa		2	sf	0.8	0.5	-	30
Haplopappus :							
arborescens		1	sf	-	-	rep	29
brachylepis		2	sf	0.81	0.16	-	29
cervinus		4	sf	4.03	2.21	2.85	29
ericoides		3	r	-	-	1.5	29
laricifolius		1	sf	-	-	5.16	29
"		2	s	2.32	2.01	-	29
"		2	r	3.37	2.87	-	29
linearifolius		6	sf	1.32	0.03	0.75	29
monactis		1	sf	-	-	0.38	29
nanus		4	sf	9.46	4.61	7.30	29
palmeri		3	sf	0.91	0.0	0.30	29
pinifolius		1	s	-	-	1.61	29
Hymenoxys:							
floribunda utilis		1	rsf	-	-	0.9	30
"		1	r	-	-	3.6	30
"		1	sf	-	-	0.84	30
odorata	Colorado rubber plant	1	sf	-	-	2.0	30
Jatropha cardiophylla		1	s	-	-	3.0	30
urens		-	-	-	-	rep	48
Lactuca :	Wild Lettuce or						
canadensis	Prickly lettuce	-	l	-	-	2.19	26
ludoviciana		1	sf	-	-	0.30	30
pulchella		1	sf	-	-	0.43	30
scariola		1	f	-	-	0.86	30
"		3	sf	0.71	0.20	0.52	30
"		-	l	-	-	1.58	26
viminea		1	sf	-	-	0.6	28
virosa		1	f	-	-	0.7	30
"		1	s	-	-	0.5	30
Landolphia	"the creeper"	-	-	-	-	rep	20
"		-	-	-	-	rep	68(25)
Lygodesmia spinosa		1	s	-	-	0.21	30
"		2	r	0.43	0.32	-	30
"		1	sf	-	-	0.54	30
Maclura pomifera	Osage orange	-	f	(below 1%)			70
Malacothrix californica		2	sf	0.5	0.5	-	30
Mascarenhasia		-	-	-	-	rep	68(25)
Manihot dichotama		-	-	-	-	rep	77(31)
heptaphylla		-	-	-	-	rep	77(31)
glaziovii	Ceara rubber tree	-	-	-	-	rep	77(31)
Papaver rhoeas	Corn poppy	1	f	-	-	0.3	30
Parthenium argentatum	Guayule			(range many observations)			
			for	28	1		
incanum	Mariola	-	-	-	-	rep	30
Pedilanthus		-	-	-	-	rep	68(25)
Philibertia linearis		3	sf	1.9	1.7	1.8	30
"		1	s	-	-	0.1	30
Plumeria		-	-	-	-	rep	68(25)
Ptiloria tenuifolia		2	sf	1.4	0.3	-	30
runcinata		1	s	-	-	0.42	30
"		1	sf	-	-	0.56	30
"		1	r	-	-	0.21	30
virgata		1	sf	-	-	0.48	30
Pyrrhapappus multicaulis		1	r	-	-	1.5	30
Rhabdadenia		-	-	-	-	rep	68(25)
Schinus molle	Californian pepper tree,	3	f	0.63	0.22	0.49	30
"	or Peruvian mastic "	2	s	0.16	0.10	-	30
Scorzonera tau-sagyz	Salsify	-	-	-	-	rep	70
"		(1-yr. root)		8	1	-	55
"		(2-3-yr. ")		30	8	-	55
Silphium laciniatum	Rosin weed, or	2	f	1.8	1.6	-	30
"	Compass plant	1	s	-	-	0.2	30
Solidago:	Goldenrod						
altissima		12	f	6.34	1.38	3.45	50
arguta		1	f	1.02	-	-	50
bicolor		3	f	1.20	0.89	1.03	50
caesia		1	f	2.46	-	-	50
erecta		1	f	0.80	-	-	50
fistulosa		4	f	4.48	2.08	2.99	50
flexicaulis		2	f	3.46	1.47	-	50
graminifolia		2	f	1.07	1.03	-	50
juncea		2	f	1.38	0.93	-	50
leavenworthii		-	f	12	6.5	-	10
monor		5	f	3.53	2.63	3.00	50
neglecta		1	f	3.36	-	-	50
nemoralis		2	f	1.38	0.93	-	50
puberula		4	f	2.35	1.20	1.62	50
racemosa		1	f	0.92	-	-	50
rigida		1	f	3.10	-	-	50
rugosa		7	f	3.54	2.63	2.95	50

Botanical Name	Common Name	No. Anal.	Part	high	low	mean	Ref.
lorifolia		-	l	-	-	15.88	44
marginata	Snow-on-the -	4	f	0.85	0.40	0.64	30
"	mountain	4	s	0.32	0.21	0.28	30
montana		1	f	-	-	0.4	30
"		1	r	-	-	0.46	30
"		1	sf	-	-	0.2	30
nutans		2	sf	0.43	0.30	-	30
ocellata		1	sf	-	-	0.6	30
pulcherrima	Poinsettia	-	-	-	-	rep	70
"		1	sf	-	-	0.9	30
tirucalli	Milk bush	-	l	-	-	27	4
Ficus carica	Fig	1	f	-	-	0.4	30
elastica	Assam rubber tree	-	-	-	-	rep	77(27)
Funtumia elastica	African rubber tree	-	-	-	-	rep	68(25)
Grindelia nuda	Gum plant	1	sf	-	-	1.1	30
robusta		1	sf	-	-	0.77	30
squarrosa		2	sf	0.8	0.5	-	30
Haplopappus :							
arborescens		1	sf	-	-	rep	29
brachylepis		2	sf	0.81	0.16	-	29
cervinus		4	sf	4.03	2.21	2.85	29
ericoides		3	r	-	-	1.5	29
laricifolius		1	sf	-	-	5.16	29
"		2	s	2.32	2.01	-	29
"		2	r	3.37	2.87	-	29
linearifolius		6	sf	1.32	0.03	0.75	29
monactis		1	sf	-	-	0.38	29
nanus		4	sf	9.46	4.61	7.30	29
palmeri		3	sf	0.91	0.0	0.30	29
pinifolius		1	s	-	-	1.61	29
Hymenoxys:							
floribunda utilis		1	rsf	-	-	0.9	30
"		1	r	-	-	3.6	30
"		1	sf	-	-	0.84	30
odorata	Colorado rubber plant	1	sf	-	-	2.0	30
Jatropha cardiophylla		1	s	-	-	3.0	30
urens		-	-	-	-	rep	48
Lactuca :	Wild Lettuce or						
canadensis	Prickly lettuce	-	l	-	-	2.19	26
ludoviciana		1	sf	-	-	0.30	30
pulchella		1	sf	-	-	0.43	30
scariola		1	f	-	-	0.86	30
"		3	sf	0.71	0.20	0.52	30
"		-	l	-	-	1.58	26
viminea		1	sf	-	-	0.6	28
virosa		1	f	-	-	0.7	30
"		1	s	-	-	0.5	30
Landolphia	"the creeper"	-	-	-	-	rep	20
"		-	-	-	-	rep	68(25)
Lygodesmia spinosa		1	s	-	-	0.21	30
"		2	r	0.43	0.32	-	30
"		1	sf	-	-	0.54	30
Maclura pomifera	Osage orange	-	f	(below 1%)			70
Malacothrix californica		2	sf	0.5	0.5	-	30
Mascarenhasia		-	-	-	-	rep	68(25)
Manihot dichotama		-	-	-	-	rep	77(31)
heptaphylla		-	-	-	-	rep	77(31)
glaziovii	Ceara rubber tree	-	-	-	-	rep	77(31)
Papaver rhoeas	Corn poppy	1	f	-	-	0.3	30
Parthenium argentatum	Guayule			(range many observations)			
			for	28	1		
incanum	Mariola	-	-	-	-	rep	30
Pedilanthus		-	-	-	-	rep	68(25)
Philibertia linearis		3	sf	1.9	1.7	1.8	30
"		1	s	-	-	0.1	30
Plumeria		-	-	-	-	rep	68(25)
Ptiloria tenuifolia		2	sf	1.4	0.3	-	30
runcinata		1	s	-	-	0.42	30
"		1	sf	-	-	0.56	30
"		1	r	-	-	0.21	30
virgata		1	sf	-	-	0.48	30
Pyrrhapappus multicaulis		1	r	-	-	1.5	30
Rhabdadenia		-	-	-	-	rep	68(25)
Schinus molle	Californian pepper tree,	3	f	0.63	0.22	0.49	30
"	or Peruvian mastic "	2	s	0.16	0.10	-	30
Scorzonera tau-sagyz	Salsify	-	-	-	-	rep	70
"		(1-yr. root)		8	1	-	55
"		(2-3-yr. ")		30	8	-	55
Silphium laciniatum	Rosin weed, or	2	f	1.8	1.6	-	30
"	Compass plant	1	s	-	-	0.2	30
Solidago:	Goldenrod						
altissima		12	f	6.34	1.38	3.45	50
arguta		1	f	1.02	-	-	50
bicolor		3	f	1.20	0.89	1.03	50
caesia		1	f	2.46	-	-	50
erecta		1	f	0.80	-	-	50
fistulosa		4	f	4.48	2.08	2.99	50
flexicaulis		2	f	3.46	1.47	-	50
graminifolia		2	f	1.07	1.03	-	50
juncea		2	f	1.38	0.93	-	50
leavenworthii		-	f	12	6.5	-	10
monor		5	f	3.53	2.63	3.00	50
neglecta		1	f	3.36	-	-	50
nemoralis		2	f	1.38	0.93	-	50
puberula		4	f	2.35	1.20	1.62	50
racemosa		1	f	0.92	-	-	50
rigida		1	f	3.10	-	-	50
rugosa		7	f	3.54	2.63	2.95	50

Botanical Name	Common Name	No. Anal.	Part	high	low	mean	Ref.
sempervirens		3	f	3.94	2.22	3.02	50
serotina		5	f	5.64	2.40	3.92	50
speciosa		2	f	3.12	2.50	-	50
squarrosa		1	f	0.56	-	-	50
stricta		1	f	2.87	-	-	50
suaveolens		3	f	3.31	2.26	2.68	50
tenuifolia		1	f	2.91	-	-	50
ulmifolia		2	f	1.84	1.28	-	50
Sonchus congestus		1	f	-	-	0.54	30
"		1	s	-	-	0.18	30
oleraceus		-	-	-	-	rep	77(27)
pinnatus		1	s	-	-	0.63	30
Stephanomeria virgata	Chicory	-	-	-	-	rep	70
Taraxacum:							
kok-sagyz	Russian dandelion	-	r	5	1	1.5	70
"		(1-yr.roots)		10	5	-	55
krim-sagyz		-	-	-	-	rep	70
"		(wild roots)		6	5	-	55
"		(1-yr.roots)		0.8	0.7	-	55
officinalle	Common dandelion	1	sf	-	-	0.4	30
Tragopogon porrifolius	Oyster plant	1	sf	-	-	0.75	30
pratensis		1	sf	-	-	0.40	30
Urceola		-	-	-	-	rep	68(25)
Viscum album	Mistletoe	-	-	-	-	rep	68(25

Number of Analyses: refers to the number of different samples tested, not to duplicate analyses of the same sample. A blank indicates that the number was not stated.

Part: The part of the plant for which the analysis is reported, where

r = root
s = stems
f = foliage (leaves)
l = latex
t = main trunk
rsf indicates a combined sample of roots, stems, and leaves

Rubber: percentages are reported to the number of significant figures as in the given reference.
rep indicates that rubber was reported present, but no definite percentages were given.

In nearly all cases, "rubber" as reported is per cent of the dry weight, and pertains to acetone insoluble - benzene soluble material (see literature review on Analysis)

TABLE V

Cultivation Characteristics

of Rubber-bearing Plants in the United States

Name	Poss. Area of U.S. %	Propagation	Conditions	Labor req.	Quality	Rubber lbs./acre/yr. High	Rubber lbs./acre/yr. low
Dandelion	25	quick	irrigated land	high	fair	200	150
			dry land			60	30
Euphorbia							
sun spurge	20	-	-	-	-	38	-
cypress spurge	20	-	-	-	-	44	-
Goldenrod	25	easy, quick	first year	low	poor	100	50
			fifth year			500	-
Guayule	2	easy, quick	5-yr. plan	low	good	-	400
			1-yr. plan			1000	-
Madagascar Vines	3	slow	mature	high	good	100	60
Milkweed							
desert	10	fair	2-yr. old	med.	fair	90	80
common	25	fair		med.	fair	80	-
Rabbit brush	10	slow	6-8 yr.	high	good	19	10

The above table includes those plants for which actual acreage yields were given in the literature, or could be estimated from the information given.

For comparison, the Hevea or Para rubber tree, as grown in the Far East, yields 800 to 1000 lbs./acre/year.

Factors Affecting the Rubber-Content of Plants

Specie and Strain: The species of any one family, and also the various strains within the species, seem to vary considerably in their inherent rubber-producing capacities. In all cases where a sufficiently large number of analyses were made to obtain a reliable mean, it was possible to group the species into high and low rubber-producers. Whenever rubber-producing plants are studied under cultivation, the selection and breeding of high yielding strains and species is one of the primary objectives.

Ecological Conditions: These conditions undoubtedly have a profound influence on the amount of rubber formed in plants. Much of the variation reported for a given specie is attributed to the growing conditions. Guayule, for example produces high percentages of rubber when grown in its native, arid habitat, and almost no rubber when grown in humid places. Other plants produce large growths in rich soils, but very little rubber; when grown in poor soils, growth is much less, but rubber-production higher. It is known that the usual high yielding species of goldenrod when grown in the shade, produce almost no rubber.

Ecological conditions also largely determine the distribution of the various species. An apparent difference between two species may therefore be the result of ecological conditions rather than any inherent difference in rubber-producing capacity.

Seasonal variation: All plants examined to any extent show seasonal variation in rubber-content. The variation in the common milkweed found by Gerhardt (27) has already been pointed out. In the case of guayule a variety of evidence to the fact that there is a striking seasonal variation in rubber-content. It has been found that during the active season of growth only negligible quantities of rubber are deposited while during the following resting period rubber makes its appearance in new tissues. The two periods are correlated with the duration of the rainy season in the desert region where guayule grows wild. In rabbit-brush, a condition in reverse to that of guayule was found (29). During the resting period the amount of rubber diminished.

The age of plants or their stage in growth is therefore important in noting the rubber content of plants. In the case of shrubs or trees, the total age of the plant or of the part in question should also be known.

Conditions Following Harvesting: The marked deterioration of rubber in guayule under certain conditions of storage has already been pointed out. Exposure to sunlight seems to have an especially deleterious effect. One report brings this out very clearly:

Samples of goldenrod leaves were exposed to sunlight in cellophane envelopes of different colors for different periods of time. Three species were included in the test. Leaves were exposed in red, blue, green and clear envelopes. Check samples in black paper envelopes were also exposed. The leaves in the red, green, and blue envelopes showed notable losses in rubber content, and those in the clear envelopes lost most of their rubber. Material in the black ones showed no loss. Results with all species were consistent.

THE DETERMINATION OF RUBBER IN RUBBER-BEARING PLANTS

Much has been written on the various methods which have been proposed for the determination of rubber (the pure hydrocarbon $(C_5H_8)_X$) in both crude rubber and in plants. In general, the quantitative methods may be divided into two classes:

1) Advantage is taken of the solubility properties of rubber. Selective solvents are applied to separate the rubber from the other materials, and the rubber is then weighed as such.

2) A derivative of the rubber is prepared, separated, and weighed, and the rubber calculated.

Solubility Methods: The usual rubber solvents employed are: benzene, carbon tetrachloride and other chlorinated solvents, and petroleum ether. Rubber is insoluble in, and can be precipitated from, solution by acetone and methyl and ethyl alcohol. Rubber becomes insoluble in mixtures of 45 volumes of alcohol to 100 of benzene and in 80 volumes of acetone to 100 of benzene (15).

Plant materials contain many acetone soluble materials such as chlorophyll, fats, resins, and similar substances, which are also soluble in benzene. Therefore, the plant material is first treated with acetone to remove these substances, and then with benzene to remove the rubber.

Fox (23) in 1909 proposed a method for the analytical determination of rubber in guayule by solvent extraction. Whittlesey (76) described a similar method in the same year. Hall and Goodspeed (29) used acetone and benzene as solvents in their method of chemical analysis which is summarized as follows:

The Baily-Walker extraction apparatus was employed.

1) Sample ground to pass a 30-mesh sieve.

2) Five-gram sample extracted three hours, boiling acetone.

3) Acetone flask dried eight hours, cooled in desiccator and weighed.

4) Material in extraction thimble or siphon tube dried, placed in a second flask, and subjected to the action of boiling benzene for three hours.

5) Flask containing benzene extract dried four hours, cooled in desiccator, and weighed.

Hall and Goodspeed point out that the periods of extraction as well as the length of the periods of drying to constant weight were definitely determined after a large number of preliminary efforts.

Hall and Long (30) employed the procedure of Hall and Goodspeed in their analyses, with a modification in the preparation of the sample. The material was ground to pass a 30-mesh sieve, and a small amount of 10-mesh included in each sample to prevent tight packing in the extractors.

Polhemus, in analyses of goldenrod (50) employed a modification of the method of Hall and Goodspeed, in which the extraction time was extended to six hours.

An extensive study of the analytical determination of rubber in rubber-bearing plants was made by Spence and Caldwell (66). These investigators point out that the methods described by Fox and Whittlesey gave either incomplete extraction with losses from several sources, or contamination of the rubber with impurities in the shrub. Fox's method gave in some cases, on alcohol precipitation, rubber contaminated with as high as 25 per cent of benzene insolubles. Factors affecting the accuracy of analysis, that had been largely overlooked by previous investigators, were studied by Spence and Caldwell. Although the primary consideration of these investigators was the analysis of guayule, their findings may be applied to other rubber-bearing plants. The factors are as follows:

1) Respiration changes occuring in the plant tissue after harvesting and before analysis.

Under certain storage conditions plants may evolve carbon dioxide and water vapor, with consequent loss in dry weight. This may result in fictitiously high values of rubber content. Losses of more than 15 per cent in the dry weight of the original plant were found to occur in a few days between pulling and analysis of guayule.

2) Influence of colloidal, protective materials in the plant structure upon extraction of the rubber.

Complete extraction of rubber is not as easily accomplished as it would seem from the procedure of Hall and Goodspeed. Hemicellulose, pectins, proteins, etc., have a profound influence on the completeness of extraction. Extraction of guayule with benzene in the older ways showed incomplete rubber extraction even after 240 hours.

3) Effect of the type of solvent used.

Carbon tetrachloride and other chlorinated solvents were found entirely unsuited for accurate analysis. With these solvents, three sources of error are encountered, namely, decomposition of the solvent, chlorination of the rubber, and formation of non-volatile residues from the solvent itself.

4) Oxidation which occurs during the drying of films of extracted rubber.

The rubber films which result from evaporation of the benzene extracts, being free of the protective agents in the plant, are extremely susceptible to oxidation. A 10 per cent increase in weight is not unusual due to oxidation.

Spence and Caldwell have worked out a procedure which includes steps to correct these errors. The corrective measures are as follows:

1) Prompt desiccation of guayule shrub to less than nine per cent moisture or storage of the freshly ground material, ready for analysis, in tightly packed and stoppered jars, eliminates the respiration loss.

2) Materials which hinder extraction are decomposed as follows:

   a) Boiling the sample for three hours in a one per cent solution of sulphuric acid.
   b) Then, steaming for three hours in an autoclave at 30 pounds per square inch pressure.
   c) Leaching for three hours with fresh water at 60°C.

3) Benzene is used as a solvent. None of the effects mentioned for chlorinated solvents are encountered with benzene.

4) Before evaporation of the benzene extract, 5 ml of a 0.1 per cent solution of dimethyl-p-phenylenediamine in benzene is pipetted into the solution. This compound prevents oxidation. A correction based on a blank determination is made in calculating the results.

Hall and Long (30) pointed out a possible error involved in the use of acetone. They state that rubber is partially soluble in boiling acetone when fats are present, but considered the error due to this effect as negligible.

Derivative Methods: Two common derivatives of rubber used in analysis are the tetrabromide and the nitrosate. The tetrabromide is by far the simplest and easiest derivative to prepare. Both are used in the analysis of crude rubber, but this author is not aware of any instance in which the nitrosate has been employed in analyzing plants. The so-called "tetrabromide" referred to in the literature is the compound of the formula $(C_{10}H_{16}Br_4)x$. It may also be expressed as a dibromide of the formula $C_5H_8Br_2)_x$. It represents the addition product of rubber and bromine, two bromine atoms adding at each of the unsaturated linkages of the rubber molecule. The pure tetrabromide is a white powder.

The formation and stability of the tetrabromide have received considerable attention. The compound has a tendency to split out hydrogen bromide, especially at elevated temperatures. Harries observed that the evolution of HB_r always accompanied the formation of the tetrabromide. He stated that the tendency to liberate HB_r increases with the purity of the starting material, and that the evolution proceeded more readily on warming (45). Memmler stated that the evolution of HB_r could be eliminated by preparing the compound in the cold. On heating the bromide to 50 to 60°C, a lively evolution of HB_r takes place, and the white compound becomes discolored.

It is apparent that any formation of HB_r will affect the analysis. The extent of this formation varies greatly with conditions of time, temperature, and concentration.

One procedure was described to this author by F. W. zur Burg (78). An outline follows:

1) 200 milligrams of finely powdered sample is placed in a test tube with 6 ml of benzene and allowed to soak for one hour with occasional stirring.

2) The solution is filtered and the powder washed with nine ml of benzene.

3) One ml of brominating solution* is added to the filtrate, and after one hour, the bromide is precipitated with 25 ml of anhydrous ethyl alcohol.

* Brominating solution: two grams of iodine are dissolved in 100 ml of carbon tetrachloride, the solution filtered, and four ml of bromine added. (The iodine acts as a carrier in the reaction.

4) The precipitate is filtered into a tared Gooch crucible, dried at a temperature not exceeding 110°F., desiccated, and weighed.

Microscopic Analytical Methods: Microscopic analytical methods are largely qualitative, although they are employed to estimate rubber content in plant tissues. It is probable that these methods are better adapted to the non-latex type of plant in which the rubber occurs in individual cells. Two instances of application are guayule and rabbit-brush, both of which are of the non-latex type.

Hall and Goodspeed (29) found such a method of advantage in their analyses of rabbit-brush. These investigators used the microscopical method largely as a preliminary step to determine whether subsequent chemical analysis was warranted. Their method is outlined as follows:

1) Sections are cut from the tissue to be examined and dropped into water.

2) Sections from water to 95 per cent alcohol; five minutes.

3) Boiling acetone; 15 to 30 minutes.

4) Sudan III; 18 hours.

5) Wash off excess stain in 50 per cent alcohol as rapidly as possible.

6) Mount in pure glycerine.

The cell inclusions of rubber appear stained a brilliant scarlet.

III. EXPERIMENTAL

Purpose: The purpose of this investigation is to obtain information necessary to establish the place of wild lettuce, as a source of natural rubber, among the other rubber-bearing plants in the United States.

Plan: The plan to be followed in order to accomplish the above purpose includes the following steps:

1) A preliminary survey to determine the distribution and amounts of the wild-growing plant material available in the vicinity of Blacksburg, Virginia.

2) Collection of, and germination tests on seeds.

3) Planting of an experimental plot.

4) Observations on the growing characteristics of the plant.

5) Development of a satisfactory method of laboratory analysis.

6) Determination of the rubber, resin, and moisture content of the plants at various stages of growth.

7) Collection of data to allow estimation of yields per acre.

8) Drying at several temperatures and humidities to determine rates.

9) Semi pilot plant tests to determine possible commercial extraction methods.

Materials

Wild Lettuce: Wild lettuce of the specie *Lactuca scariola* was obtained from the vicinity of Blacksburg, Virginia.

a) nearly pure stands of wild-growing plants

b) separate scattered plants

c) plants from the experimental plantings

Acetone: Technical grade acetone, distilled at 131-2°F before use; no residue on evaporation.

Alcohol: Special alcohol for scientific use; 190 proof ethyl alcohol; no residue on evaporation.

Benzene: Technical grade benzene, distilled at 174-5°F before use; no residue on evaporation.

Bromine: C.P. bromine; maximum limits of impurities stated as follows: non-volatile matter 0.015 per cent, sulphur compounds 0.002 per cent, iodine 0.05 per cent, organic bromide compounds to pass test.

Carbon tetrachloride: Technical grade carbon tetrachloride, distilled at 167-70°F before use; no residue on evaporation.

Iodine: C.P. Iodine; maximum limits of non-volatile matter stated as 0.020 per cent.

Apparatus

Air Conditioned Dryer: This dryer is not of standard construction or design. Complete structural details appear in a B. S. thesis in Chemical Engineering by M. L. Ellison, "The Redesign, Construction and Operation of an Air Conditioned Dryer" (1941). This thesis appears in the library of the Virginia Polytechnic Institute (378.755 VPO E 479). The drying chamber is approximately three feet cube. Heating coils and spray nozzles allow adjustment of temperature and humidity of the inlet air stream. (Dry bulb 70 to 180°F, humidity 5 to 100 per cent.) screen trays: 3' x 2'

Atmospheric Dryer: Proctor 12-Tray Dryer

serial number:	H - 8122
overall size:	6' x 3'6" x 5'
heat	supplied through steam coils
tray size:	33" x 18"
power:	0.5 HP General Electric type SCR motor
air circulation:	fan; (adjustable vanes allow adjustment of inlet and outlet air streams)
manufacturer:	Proctor & Schwartz, Inc., Phila.,Pa.

Extraction Apparatus: Soxhlet-Allihn Extraction Assembly.

material:	"Pyrex" glass, cork stoppers
capacity of flask:	250 ml
length of condenser jacket:	250 mm
extraction thimble:	paper; 40 mm diam., 120 mm long.

<u>Hydraulic Press</u>: Carver hydraulic laboratory press.

number:	4905 - 20
pressure:	maximum of 20,000 pounds between faces
pressing basket:	3.5" diameter
manufacturer:	Fred S. Carver, New York, N. Y.

<u>Laboratory Electric Drying Oven</u>:

volume:	one cubic foot
shelves:	three
control:	thermostatic control
manufacturer:	Will Corporation, Rochester, N. Y.

<u>Rod Mill</u>: Patterson Rod Mill

internal diameter:	1'0"
internal length:	1'7"
rods:	16 rods, 1'5" long, and varying in diameter from 1/2" to 1-1/4"
power:	1 HP General Electric type K motor
manufacturer:	Patterson Foundry and Machine Co., E. Liverpool, Ohio.

<u>Miscellaneous Laboratory Apparatus</u>:

"Pyrex" filtering crucibles: (fused-in, fritted glass filter disk)

capacity:	35 ml
disk diam.:	26 mm
disk thickness:	2.5 mm
height:	48 mm
porosity:	medium

Dry bulb-wet bulb thermometer set, aspirator, electric hot plates, desiccators, flasks, condensers, funnels, "Mason" screw-cap preserving jars with rubber rings (one pint size), etc.

Methods of Procedure

Collection of Seeds: Seeds for the planting of an experimental plot were collected from mature plants showing the white bloom of seed "parachutes". The tops of the plants were shaken above a cardboard box, so that the seeds, together with the "parachutes" fell into the box. Quite a number of the seeds are lost, of course, due to slight air currents. The seeds were separated from extraneous material by repeated screening through 20 and 30-mesh screens.

Other seeds were obtained from mature plants which had been harvested for other purposes. After partial drying of the plants, and opening of a large number of the seed heads, the plants were shaken over canvas spread on the laboratory floor. The seeds were then separated by screening as above.

Harvesting of Plants: The larger plants with stems were cut with a knife, between one and three inches from the ground level. When harvesting from the nearly pure stands, a definite area was marked off, and the plants within this area cut.

Drying: Plants harvested as above were transported as quickly as possible to the laboratory. The particular dryer to be used was set in operation to allow attainment of the desired conditions while the plants were being weighed and prepared. The plants were cut into lengths corresponding to the width of the trays, a layer of the material put on each tray, and then placed into the dryer.

During the drying, simultaneous readings of dry and wet-bulb temperatures in the drying chamber and weight of the material, were taken at timed intervals. Adjustments necessary to maintain the desired conditions were made as required.

The dried material was stored in a dry place in the laboratory for future use.

Some plants were also dried atmospherically by spreading out on a laboratory table. Data were taken as above.

Sampling Plants for Analysis: For purposes of analyzing large groups of plants at one location, five representative plants selected at random were taken for a sample. The sample thus obtained was weighed, and then dried in a dryer to a point where the leaves were crisp enough to remove by crumpling. The leaves were removed, the stems cut into short sections, and drying of leaves and stems completed in a laboratory oven, and final weights taken. The material was stored in moisture-proof jars, until ready for analysis.

The leaves and stems on some 5-plant samples were separated immediately after cutting, to allow separate determination of moisture in leaves and stems. These were not retained for other analyses.

Analysis with Soxhlet-Allihn Apparatus: In those cases where the purely solvent extraction method was used in analyzing plant samples for rubber and resin, the following procedure was used:

1) Sample is dried thoroughly, and ground to approximately 20-mesh.

2) A five gram sample is weighed out and transferred to the extraction thimble. The thimble is placed into the extractor.

3) 50 ml. of acetone are put into the tared flask, and heat applied from a hot plate. Heat is adjusted so that the apparatus siphons once every 15 minutes.

4) The extraction is continued for seven hours or longer, until the liquid in the siphon-leg is perfectly clear.

5) The acetone extract in the flask is evaporated on the hot plate, nearly to dryness, and then placed in an oven at 110°F. for 8 hours. The flask is desiccated and weighed.

6) After extraction with acetone, the sample, together with the thimble, is also placed in the oven and dried for 8 hours at 110°F.

7) The thimble is again placed into the extractor, 50 ml of benzene placed in a second tared flask, and the sample extracted for seven hours.

8) The benzene extract is evaporated and dried as with the acetone extract; flask is desiccated and weighed.

The percentage of acetone soluble (resin) and rubber are calculated from the weights of the residues.

<u>Analysis by Developed Method</u>: The procedure of the method developed by this investigator follows:

1) A five-gram portion of the sample obtained as described in a previous paragraph (Sampling Plants for Analysis) is ground to a fine powder in a mortar. Approximately 1.5 grams of this powder is weighed out on the analytical balance, and transferred to a 125 ml Erlenmeyer flask (a).*

2) The balance of the five-gram portion is taken for a moisture determination.

3) 25 ml of acetone are added to flask (a) and the mixture boiled gently under reflux for 30 minutes.

4) Flask (a) is removed, the solids allowed to settle for five minutes, and the solution filtered into a tared blask (b).

5) 25 ml more acetone is added to (a) and the mixture boiled as before for 30 minutes.

6) Flask (a) is removed, the solids allowed to settle for five minutes, and the solution filtered as before into flask (b).

* (a, b, and c, refer to 125 ml Erlenmeyer flasks)

7) The solids are washed twice or more with 5 ml portions of acetone, shaking and settling each time, and filtering the washings successively into flask (b).

8) The filter paper and solids retained by it are washed clean with acetone, all the filtrate and washings being collected in flask (b).

9) The filter paper is removed from the funnel and placed into flask (a) with the solids; solids and filter paper are dried in (a) under vacuum at 110°F for one hour.

10) The solution in flask (b) is boiled down nearly to dryness on the hot plate, flask and residue dried at 110°F for two hours, desiccated, and weighed.

11) 25 ml benzene are added to the solids in flask (a) and the mixture boiled gently under reflux for four hours. The solids are allowed to settle and the solution is filtered into flask (c).

12) 25 ml more benzene are added to flask (a), and the mixture boiled as above for two hours, settled, and the solution filtered into (c).

13) The solids in (a) are washed with two 5 ml portions of benzene, and washings filtered successively into (c).

14) The total benzene extract in (c) is evaporated to 25 ml, and cooled to 68°F. One ml bromine solution* is added.

15) After one hour (eight hours maximum) 50 ml of ethyl alcohol is added to (c) to precipitate the bromide, and allowed to stand one hour with occasional shaking.

16) Contents of (c) is filtered through a tared, fritted-glass filtering crucible. The precipitate is washed with three-5 ml portions of ethyl alcohol.

17) Crucible and bromide are dried in an oven at not over 110°F to constant weight, desiccated, and weighed.

<u>Notes on Procedure of the Developed Method:</u> These notes are numbered to correspond to the steps in the procedure.

3) Since corks usually contain acetone soluble material, those used should be boiled in acetone previous to use.

4) With proper settling, very little of the solids reach the filter paper. This step is largely a decantation.

8) The total volume in (b) should be about 80 to 90 ml.

11) The filtration here is also to be mainly a decantation.

14) The benzene extract must be practically colorless, and contain no suspended matter of any kind.

15) Temperature during bromination must not exceed 68°F. The alcohol used in precipitation must not contain suspended matter of any kind. (Ethyl alcohol of denatured formula No. 1 may be used.)

Bromination is complete after one hour. However, for convenience, up to eight hours may elapse before addition of the alcohol.

16) T he precipitate must be pure white after washing.

17) One hour is sufficient for the drying.

* Brominating solution: two grams of iodine are dissolved in 100 ml carbon tetrachloride. The solution is filtered, and four ml bromine are added. (Iodine acts as a carrier in the reaction). Store in a dark glass container, with ground-glass stopper, in a cool place.

DATA AND RESULTS

Location of Plant Material: A preliminary survey of Blacksburg and vicinity was made on July 25, 1942, to determine the amounts and location of wild lettuce available for the research. Abundant plant material was located. Nearly all of the plants were found along the sides of roads and in waste places where the ground had been broken. Common milkweed was frequently noticed in the same locations as the wild lettuce. The stage in development was noted by the presence of:

a) true buds

b) small yellow flowers

c) "deceptive" buds of ripe seeds, not ready to discharge

d) white tufts, or cottony seed "parachutes"

All four of these conditions were often combined in a single plant. The plants along the roadways ranged from four to eight feet in height. A number of the lower leaves of each plant had died. The upper third of the stalk which bore the buds, flowers, and seeds, was usually found to be much branched, and devoid of leaves except for a few very small ones at the axils. All parts of the plants, except the lower woody parts of the stems and the roots, showed a milky latex on injury.

Description of the Nearly Pure Stands: Several nearly pure stands up to approximately 600 square feet in area were found both during the survey of July 25, and on later dates. In following parts of the report, these are designated by letters as they appear below:

A) Located 7-29-42, at the intersection of the road passing to to the south of the V.P.I. campus lake, and the road branching to the south a short distance east of the lake dam. Distributed along 50 feet of the road, and from two to eight feet deep. Very robust plants, with some at least ten feet high. Buds, flowers, and seeds were all in evidence. A number of the lower leaves were dead, especially on the larger plants. The plants were not very leafy. The upper parts of the stems were much branched, and some of the larger ones were branched the entire length.

B) Located 8-11-42, on the southeast corner of an empty lot between the property of French Pack and of the Blacksburg Lutheran Church. The lot had evidently been mowed previously, and the lettuce plants severed about three inches from the ground level. The plants had ratooned, producing from four to eight stems from each root near the base. The stems were not branched, and ranged from two to three feet in height. The clusters of flower heads were just beginning to appear.

C) Located 7-30-42, along the road passing Davidson Hall on the west, and directly northwest of the Toske residence. Similar to (A), though somewhat smaller in area.

D) Located 8-28-42, in an unused garden in back of the house adjoining the Teaching and Administration Building on the northeast. Similar to (B), but more advanced because of the two weeks difference in time of location.

Experimental Planting: (E): Data on the later stages in development of the plants could be obtained from the above stands. To obtain data on the early stages, an experimental planting was undertaken on July 28, 1942. A plot was selected in a waste field west of Davidson Hall, a short distance to the north of the location of (C). Seed was gathered from the mature plants in the vicinity. The selected plot measured 17 x 10 feet. A heavy growth of quack grass with some milkweed was present. The ground was spaded to a depth of from six to eight inches, and most foreign plant tops and roots removed. After smoothing the spaded ground, 13,140 seeds were distributed over the plot broadcast, raked into the soil, and rolled down. A chronological development follows:

7-28-42: Planting as described above

8-5-42 : First rain since planting

8-9-42 : First seedlings observed

8-14-42: Small plants, three-leafed, each leaf approximately 0.15 inches long and 0.1 inches wide.

9-16-42: 2,200 plants were counted. Leaves spatulate to oblong, six to eight inches long and 1.5 to 1.7 inches wide, all springing from the root crown. Plants standing alone lie spread out, close to the ground; those crowded together, send out leaves almost perpendicular to the ground. Roots show latex on injury, leaves very little or none.

9-30-42: Very little growth since 9-16-42. The leaves on most plants have become more jagged or lanced in shape than described under 9-16-42. Tap roots four to six inches long and 1/4 inch thick, with many fine, hairy branches. Both roots and leaves show latex on injury. One representative plant was removed:

weight:	12.8	grams (as removed)
Moisture:	86.0	per cent
resins:	6.47	per cent (dry basis)
rubber:	0.049	per cent (dry basis)

10-24-42: No further growth above ground noticeable. Latex in both leaves and roots. One plant:

weight:	19.7	grams (as removed)
moisture:	83.2	per cent
resins:	6.64	per cent (dry basis)
rubber:	0.013	per cent (dry basis)

10-27-42: Temperature the preceding night dropped to 28°F. Latex still in both leaves and roots.

The plants remained nearly static during the winter, all of the larger leaves on each plant gradually dying away.

3-24-43: 1890 plants were counted. This represents a decrease of 310 from last fall. A small part of the area on a slight slope was severely erroded, and devoid of plants. The whole plot showed large cracks. Latex near the base of the leaves and in the roots, none in the extremities of the leaves.

3-27-43: Two plants were removed:

	(1)	(2)
Length of root, inches	9.0	5.5
Length of leaves, inches	3.0	3.0
Av. diam. of bush, inches	3.0	3.0
Leaves, wet, grams	13.6	8.9
Root, wet, grams	9.3	6.8
Root, dry, grams	1.46	1.13
Root, percent moisture	84.3	83.4
Rubber, percent of dry root	0.092	---

4-13-43: New leaves have grown out from the crown; long, slender, uniform. Latex in leaves and roots. Prickles along the under side of the midrib and along the edges of the new leaves.

5-7-43: Plants making rapid progress, many leaves coming out. Stems have started on many plants.

5-13-43: Plants were removed and the following determined:

a) Two whole plants, including roots:

	(1)	(2)
weight, wet, grams	17.1	33.0
weight, dry, grams	2.03	3.95
moisture, per cent	88.2	88.2
root, inches	5.3	4.6
leaves, number (over 2")	10	15
resins, per cent of dry weight	5.42	5.34
rubber, per cent of dry weight	0.339	0.239

(Main top roots with many fine branches)

b) Single leaves:

	(1)	(2)
grams, wet	1.134	2.057
moisture, per cent	87.1	87.3
length, inches	6.75	8.0
witch, inches	1.75	2.0

(tips of all leaves obtuse; irregularly toothed, dentate margins; elliptical to oblont)

c) One plant:

total wet leaves, grams	20.4
per cent moisture in leaves	87.3
wet root, grams	8.1
per cent moisture in root	85.3

Beginning on 5-7-43, a record of the growth of three separate plants was begun. This record appears in Table I. The data entered in the table are those available at this writing. Additions will be made as further data are obtained.

Further analytical data will also be added as obtained.

5-25-43: The leaves are from five to eight inches long. While approximately the lower five on each plant are spatulate to elliptical in shape, the upper ones are jagged and armed as is characteristic of the leaves on mature plants. The bottom two to three leaves have died. A remarkable fact is that the leaves, by a half twist near the stems, are arranged so that the flat surfaces face east-west. Some of the larger plants are 18 to 24 or more inches high, with stems 5/16 inch thick. The latex is very abundant in all parts. Leaf midribs are hollow near the axils, as are the lower stems.

TABLE I

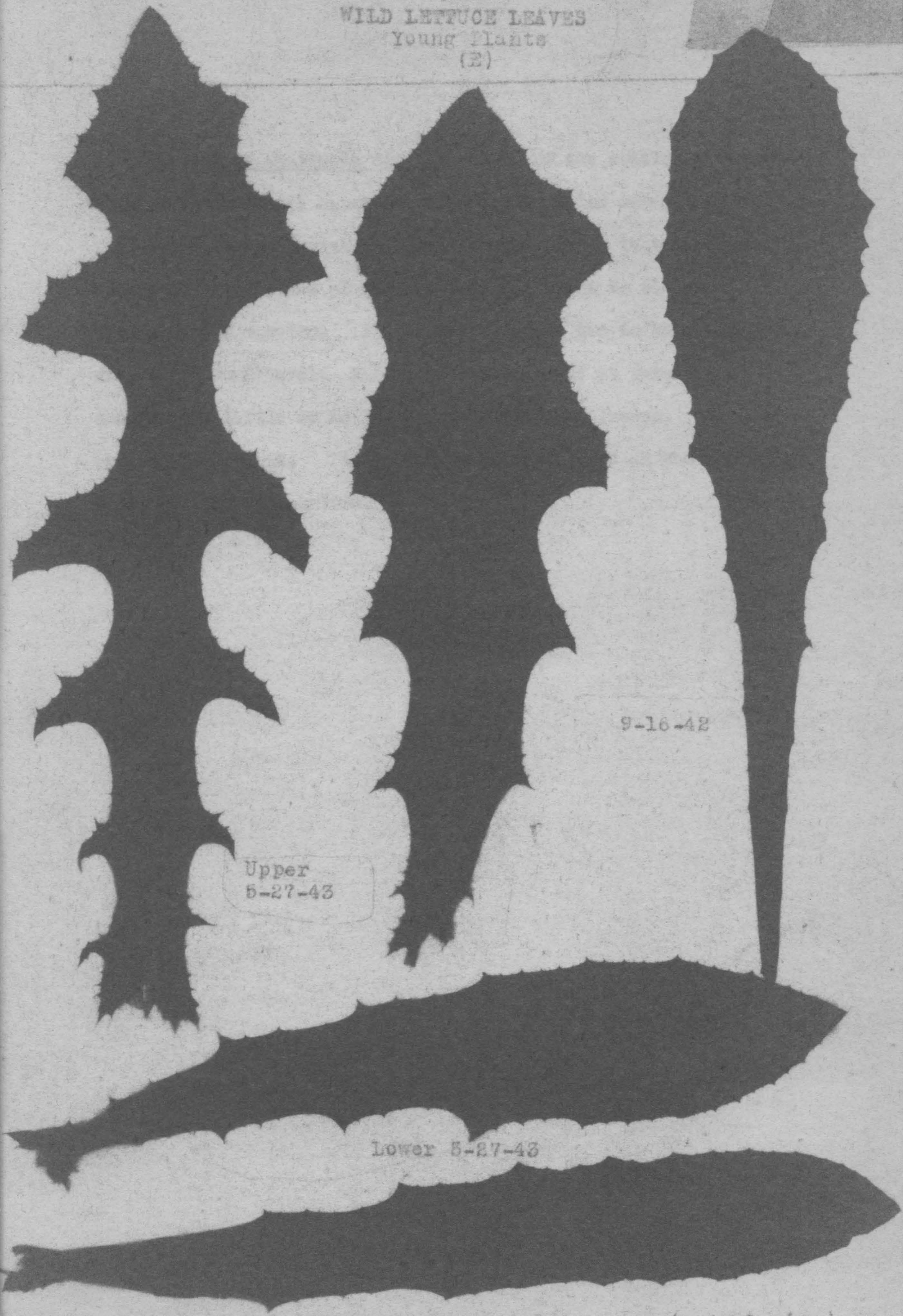
GROWTH RECORD OF WILD LETTUCE PLANTS

Three Separate Plants From the Experimental Plot (E)

	E-1			E-2			E-3		
Date	total height inches	length stem inches	number* of leaves	total height inches	length stem inches	number* of leaves	total height inches	length stem inches	number* of leaves
5- 7-43	8.2	3.4	-	8.3	2.9	-	7.9	3.4	-
5-10-43	10.2	4.0	-	9.1	3.4	-	8.4	3.9	-
5-13-43	11.0	4.5	-	9.5	4.0	-	10.3	5.2	-
5-17-43	12.0	6.5	15	11.5	5.6	13	12.7	7.3	11
5-25-43	16.2	9.7	17	16.2	10.2	16	15.4	10.9	13
5-31-43	20.5	14.0	19	20.5	14.0	18	17.5	12.6	14

* total number over 2 inches long, including those which have died. (on 5-31-43, an average of 3 leaves per plant had died)

WILD LETTUCE LEAVES
Young Plants
(E)



(actual size)

Harvesting Available Stands: Parts of the available stands of wild lettuce were harvested in order to allow estimation of yields of plant material. It was thought likely that in commercial harvesting the plants would be cut close to the base, as with a mowing machine. All plants were cut two to three inches from the ground level. The stems, being woody at this point, showed very little or no latex at the severed tissues. The data appear in Table II. Yields have been calculated on the per acre basis to allow comparison.

TABLE II

HARVESTING OF WILD LETTUCE

Yields of Leaves and Stems

Date:	7-29-42	7-30-42	7-31-42	8- 7-42	8-12-42	8-16-42	8-21-42	8-28-42
Stand	A	C	A	C	B	B	B	D
Area cut, sq. ft.	18	18	63	18	30	49.5	31.2	45
Total weight								
wet, lbs.	16.0	17.5	55.5	11.3	11.8	13.9	10.8	16.2
dry, lbs.	3.56	3.55	12.40	2.30	2.22	2.52	2.30	3.60
Leaves								
wet, lbs.	5.0	6.28	16.5	-	5.77	6.89	4.7	6.45
H_2O, %	81.3	81.3	81.0	-	81.8	81.6	79.0	78.2
dry, lbs.	0.94	1.17	3.20	0.80	1.05	1.27	1.0	1.41
Stems								
wet, lbs.	11.0	11.22	39.0	-	6.03	7.01	6.1	9.75
H_2O, %	73.0	78.5	76.7	-	80.5	80.8	79.0	78.2
dry, lbs.	2.62	2.38	9.20	1.50	1.17	1.35	1.30	2.13
Lbs./acre (calc.)								
Total								
wet	38,700	42,400	38,400	27,400	17,130	12.230	15,570	15,700
dry	8,630	8,590	8,580	5,570	3,220	2,300	3,310	3,420
Leaves								
wet	12,100	15,200	11,400	-	8,380	6,060	6,770	6,250
dry	2,280	2,830	2,210	1,940	1,520	1,120	1,440	1,360
Stems								
wet	26,600	27,200	27,000	-	8,750	6,170	8,600	9,450
dry	6,350	5,760	6,370	3,630	1,700	1,180	1,870	2,060

__Drying:__ If harvested plant material is to be stored before processing, drying is necessary to prevent deterioration. Extraction with organic solvents would also require preliminary drying.

Drying in the open field, in the manner of hay, was considered. It was known that when goldenrod leaves were exposed to sunlight, practically all of their rubber was destroyed in a short time. There was obviously reason to suspect a similar effect in wild lettuce. Two samples were taken from (E), the first dried in a dryer at 110°F, and the second allowed to dry over a period of 46 hours, exposed to the sun during the day. The leaves were then tested for rubber:

Sample	Per cent rubber
110°F dried	0.140
roof dried	trace

It is seen that exposure to sunlight after harvesting destroyed nearly all of the rubber present. Drying in the field is therefore eliminated as a possibility.

Artificial drying was next considered. In order to determine the effect of drying temperature on rubber content, the following test was conducted: Two samples of (B) were placed in ovens at 180 and 110°F respectively, and a third was dried on a laboratory table, shielded from light (75-80°F). The samples, after drying, were analyzed for resins and rubber. Percentages are given on the dry weight basis.

Drying temp.	Leaves resins %	Leaves rubber %	Stems resins %	Stems rubber %
180°F	10.05	0.116	5.51	0.024
110	10.30	0.103	4.60	0.013
75-80	9.42	0.104	5.56	0.000

The 110° Sample retained the most brilliant and natural green color. The table dried sample had some brown discoloration, and the 180° sample still more brown discoloration. This color effect was accentuated by the acetone extracts of these samples. It is to be noted that the 180° sample gave the highest rubber analysis in both leaves and stems. It seems that temperatures up to 180°F at least may be employed without decreasing the rubber content. It should be kept in mind, however, that although the amount of rubber is not decreased by the higher temperature, the effect on the quality must also be considered. Slow drying at atmospheric temperature is also possible, provided the material is not exposed to sunlight.

Drying rates under different conditions of temperature and humidity were studied. The data together with the calculated rates are presented in the following tables. The method of calculation appears in the Appendix, page 154.

TABLE III

DRYING OF WILD LETTUCE

(C), harvested 8-4-42. Spread out as whole plants on laboratory table 10' x 3'.

dry bulb: $81^{\circ}F \pm 1^{\circ}$

wet bulb: $66^{\circ}F \pm 2^{\circ}$

Area: 30 square feet
Air velocity: negligible
Relative humidity: 43%

	Drying time, hours cum.	net	net lbs.	av. lbs.	H_2O av. lbs.	H_2O loss lbs.	av. lbs. H_2O per lb. of dry material	Drying rate lbs./hr./sq.ft
	0	-	7.91	-	-	-	-	-
	17	17	5.71	6.81	5.25	2.20	3.37	0.00431
	23	6	5.25	5.48	3.92	0.46	2.51	0.00255
	26	3	4.94	5.09	2.53	0.31	2.26	0.00345
*	39	13	4.13	4.53	2.97	0.81	1.91	0.00208
	42	3	3.98	4.05	2.49	0.15	1.60	0.00167
	47	5	3.70	3.84	2.28	0.28	1.46	0.00180
	61.5	14.5	3.24	3.47	1.91	0.46	1.22	0.00106
	65	3.5	3.14	3.19	1.63	0.10	1.04	0.00095
	71	6	2.98	3.06	1.50	0.16	0.96	0.00089
#	93	22	2.62	2.80	1.24	0.36	0.79	0.00055
**	114 discontinued	21	2.34	2.48	0.92	0.28	0.59	0.00045

Weight, totally dry: 1.56 lbs.
Moisture remaining at end of run: 0.78 lbs.
* leaves start to become crisp, but do not drop off on handling
\# leaves crisp enough to remove by crumpling
** leaves 11.2% moisture, stems 41.0% moisture

TABLE IV

DRYING OF WILD LETTUCE

(B), harvested 8-21-42. Whole plants, cut to two foot lengths; 3 trays, 1.5 inch layer on each tray, in Air Conditioned Dryer

dry bulb: 120 ± 1°F
wet bulb: 88 ± 1°F

Area: 36 square feet
Air velocity: 80 feet per minute
Relative humidity: 28%

Drying time, hours CUM.	NET	net lbs.	av. lbs.	H_2O av. lbs.	H_2O loss lbs.	av. lbs. H_2O per lb. of dry material	Drying rate lbs./hr./sq.ft.
0	-	10.80	-	-	-	-	-
0.17	0.17	10.40	10.60	8.44	0.40	3.89	0.0666
0.67	0.5	9.23	9.81	7.65	1.17	3.54	0.0646
1.16	0.46	8.45	8.84	6.68	0.78	3.09	0.0470
1.66	0.5	7.80	8.12	5.96	0.65	2.76	0.0360
2.16	0.5	7.26	7.53	5.37	0.54	2.48	0.0300
2.92	0.76	6.61	6.93	4.77	0.65	2.21	0.0237
3.42	0.5	6.35	6.48	4.32	0.26	2.00	0.0144
4.42	1.0	5.81	6.08	3.92	0.54	1.81	0.0149
4.92	0.5	5.55	5.68	3.52	0.26	1.63	0.0144
discontinued							

weight totally dry: 2.16 lbs.
moisture remaining at end of run: 3.39 lbs.

DRYING OF WILD LETTUCE

(B), harvested 8-16-42. Whole plants, cut to two feet lengths; 3 trays, 1.5 inch layer on each tray, in Air Conditioned Dryer

dry bulb: 120 ± 1°F
wet bulb: 88 ± 1°F

Area: 36 square feet
Air Velocity: 80 feet per minute
Relative Humidity: 19%

Drying time hours cum.	net	net lbs.	av. lbs.	H_2O av. lbs.	H_2O loss lbs.	av. lbs. H_2O per lb. of dry material	Drying rate lbs./hr./sq.ft.
0	-	14.00	-	-	-	-	-
0.5	0.5	12.80	13.40	10.10	1.20	3.06	0.0670
1.[illegible]	0.5	11.88	12.34	9.04	0.92	2.74	0.0510
2	1	10.43	11.16	7.86	1.45	2.48	0.0402
3	1	9.34	9.88	6.58	1.09	1.99	0.0303
4	1	8.40	8.87	5.57	0.94	1.69	0.0216
5.5	1.5	7.40	7.90	4.60	1.00	1.39	0.0185
6.5	1	6.80	7.10	3.80	0.60	1.15	0.0166
7.5	1	6.30	6.55	3.25	0.50	0.985	0.0139
8.6	1.1	5.75	6.02	2.72	0.55	0.824	0.0131
9.5	0.9	5.23	5.49	2.19	0.52	0.664	0.0172
11	1.5	4.69	4.96	1.66	0.54	0.503	0.0100
12	1	4.38	4.53	1.23	0.31	0.372	0.0068
13	1	4.14	4.26	0.96	0.24	0.291	0.0061
14	1	3.92	4.03	0.73	0.22	0.223	0.0061
15	1	3.78	3.85	0.55	0.14	0.168	0.0039
16	1	3.62	3.70	0.40	0.16	0.121	0.0043
17	1	2.50	3.56	0.26	0.12	0.079	0.0033
18	1	3.39	3.44	0.14	0.11	0.042	0.0030
19	1	3.33	3.36	0.06	0.06	0.018	0.0017

TABLE VI

DRYING OF WILD LETTUCE

(B), harvested 8-28-42. Whole plants, Atmospheric Dryer

dry bulb: 156 ± 2°F
wet bulb: 97 ± 2°F

Air velocity: 80 feet per minute
Area: 7.1 square feet
Relative humidity: 12%

Drying time hours cum.	net	net lbs.	av. lbs.	H_2O av. lbs.	H_2O loss lbs.	av. lbs. H_2O per lb. of dry material	Drying rate lbs./hr./sq.ft.
0	-	2.12	-	-	-	-	-
0.5	0.5	1.72	1.92	1.47	0.40	3.37	0.113
1	0.5	1.37	1.54	1.09	0.35	2.42	0.0985
1.5	0.5	1.12	1.24	0.79	0.25	1.75	0.0705
2.08	0.58	0.90	1.01	0.56	0.22	1.24	0.0535
2.5	0.42	0.77	0.83	0.38	0.13	0.845	0.0436
3.83	1.33	0.50	0.63	0.18	0.27	0.400	0.0286
4.91	1.08	0.46	0.48	0.03	0.04	0.068	0.0052
6.01	1.10	0.45	0.455	0.005	0.01	0.011	0.0013

TABLE VII

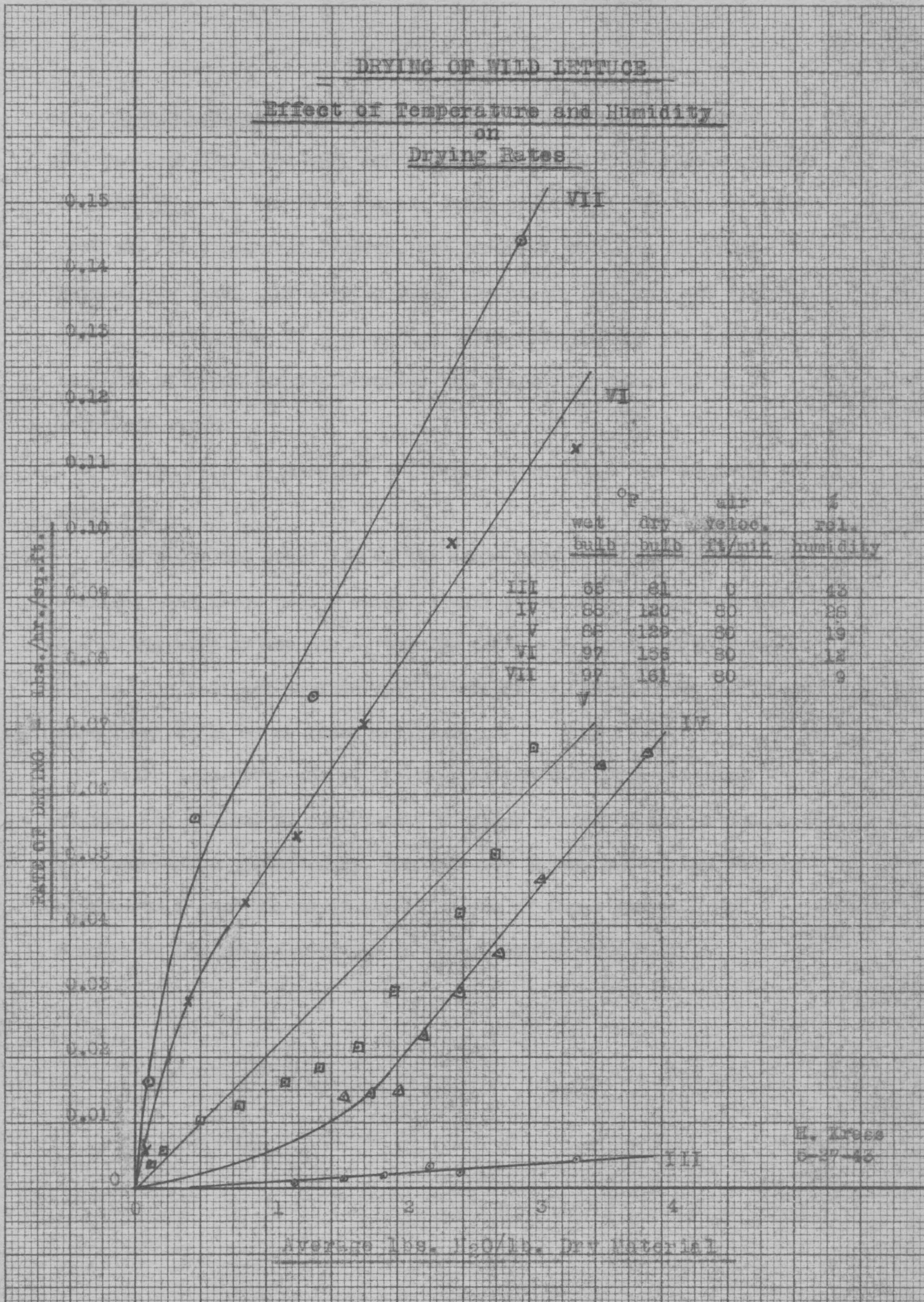
DRYING OF WILD LETTUCE

(B), harvested 8-12-42. Whole plants, Atmospheric Dryer

dry bulb: 161 = 4°F
wet bulb: 97 = 5°F

Area: 7.1 square feet
Air velocity: 80 feet per minute
Relative humidity: 9%

Drying time hours cum.	Drying time hours net	net lbs.	av. lbs.	H_2O av. lbs.	H_2O loss lbs.	av. lbs. H_2O per lb. of dry material	Drying rate lbs./hr./sq.ft.
0	-	1.69	-	-	-	-	-
0.67	0.67	1.00	1.34	1.00	0.69	2.94	0.144
1.25	0.75	0.60	0.8	0.46	0.40	1.35	0.075
1.75	0.5	0.40	0.5	0.16	0.20	0.47	0.0564
2.25	0.5	0.34	0.37	0.03	0.06	0.09	0.0169


DRYING OF WILD LETTUCE
Effect of Temperature and Humidity
on
Drying Rates
RATE OF DRYING = lbs./hr./sq.ft.
Average lbs. H2O/lb. Dry Material
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
1
2
3
4
VII
VI
V
IV
III
°F
wet bulb
dry bulb
air veloc. ft/min
% rel. humidity
III 65 81 0 43
IV 83 120 80 26
V 86 129 80 19
VI 97 156 80 12
VII 97 161 80 9
H. Kress
6-27-43

Development and Description of (B): The nearly pure stand (B) was located on 8-11-42, and a description as of that date appears on page 90 . As has been stated, these plants had been cut at some previous time, and when located, had produced from four to eight ratoons per root. The date on which the plants had been cut could not be ascertained. By a comparison with other plants not so cut, it seems that the cutting retarded the stage of development by at least one month.

Yields of plant material from harvesting of (B) are included in Table II.

The roots and lower 1/3 of the stems were woody in character on 8-11-42. The stems became progressively woody from the bottom up, and on ripening of the seeds, totally woody and hollow part of the way up. As had been noticed with other plants, these woody portions show very little or no latex on injury.

Being less developed at the time of location than the other stands, (B) offered an opportunity to study a wider range in the stages of development. Accordingly, samples were taken, and analyses made, at intervals over the remaining life-span of these plants. The results of the analyses appear in the following tabulation.

TABLE VIII

ANALYSES OF (B)

Date	Moisture Leaves %	Moisture Stems %	Leaves * Resins %	Leaves * Rubber %	Stems Resins %	Stems Rubber %
8-11-42	81.8	80.5	9.31	0.069	5.74	trace
8-16-42	81.6	80.8	10.23	0.094	5.85	none
8-18-42	81.6	80.8	10.30	0.103	5.22	0.013
8-29-42	76.4	76.8	11.03	0.122	-----	none
9-11-42	72.0	-----	11.26	0.140	-----	none
9-15-42 #	16.8	73.8	10.43	0.048	-----	none

* per cent of the dry weight of the green leaves

\# dead, brown leaves, still clinging to stem

One root sample showed no trace of rubber and further roots were not analyzed. The traces of rubber in stem samples are presumably from the younger parts of the stems.

The leaves become brown and wilt progressively from the bottom up. This condition was found with all plants, whether they were standing singly and free, or crowded close together. However, the dying commenced sooner in those plants crowded close together. Since this effect is accompanied by loss of most of the rubber, its extent is of importance. Observations on the number of dead leaves were made.

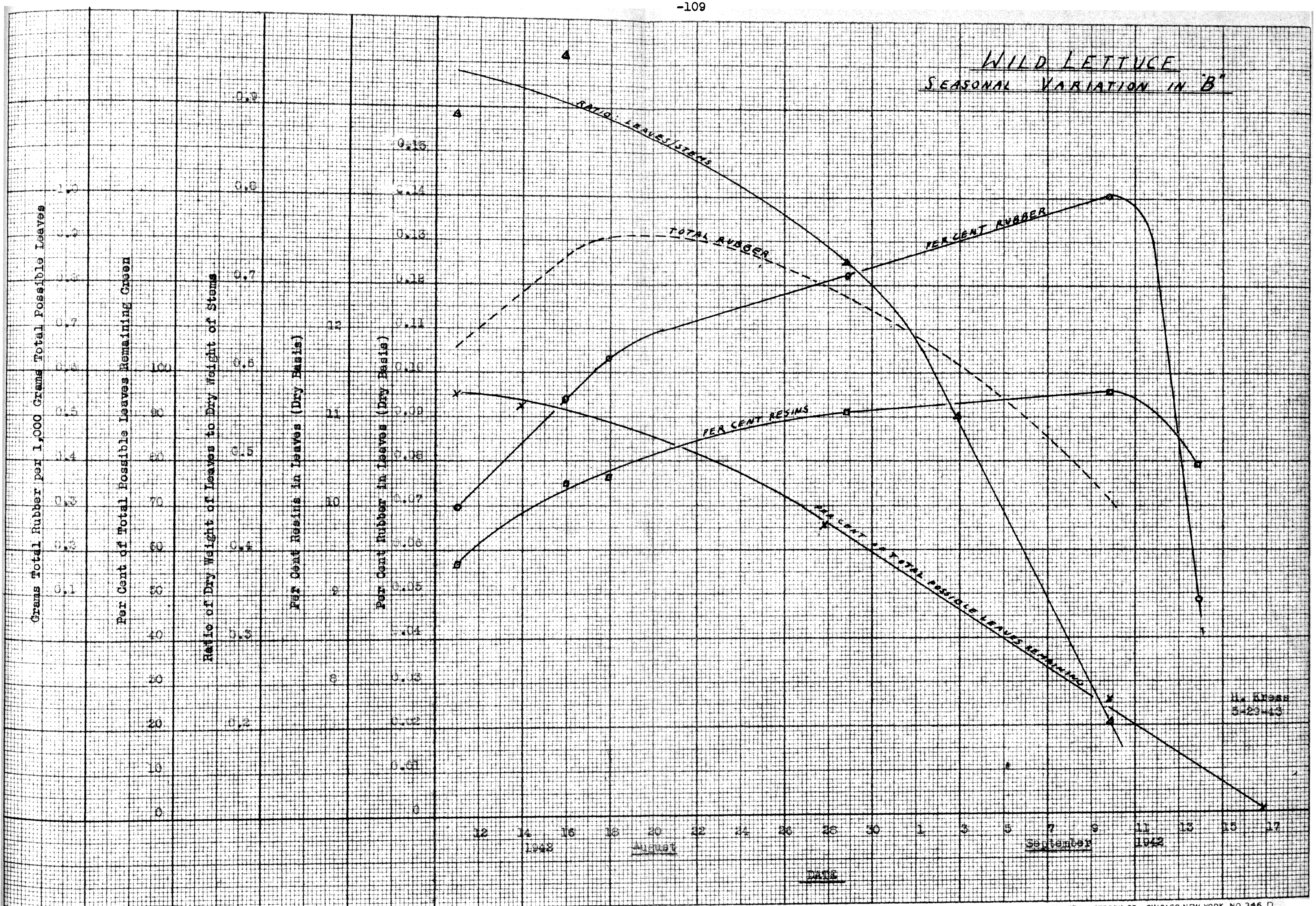
Date	Number of dead leaves per stem*	Notes
8-11-42	0 - 2	—
8-14-42	1 - 3	A few flowers appearing.
8-28-42	6 - 8	Flowers, some white tufts.
9-11-42	14 -16	Abundant white tufts.
9-18-42	all	Most seed discharged

* For average stems of 20 total leaves

Increasing per cent rubber and decreasing total leaves available are opposing factors in the total amount of rubber. Assuming that all leaves have attained maximum weight by August 11, and that 1000 grams of dry leaves are available on that date, we may estimate the total rubber available from this given weight of leaves:

Date	Leaves Available %	Grams leaves available from original 1000	Rubber %	Total rubber grams
8-11-42	95	950	0.069	0.655
8-18-42	88	880	0.103	0.904
8-25-42	74	740	0.116	0.860
9- 1-42	56	560	0.125	0.701
9- 8-42	33	330	0.136	0.450
9-11-42	23	230	0.140	0.322

The following curves will help to illustrate the seasonal variations in (B).


WILD LETTUCE
SEASONAL VARIATION IN "B"
RATIO: LEAVES/STEMS
TOTAL RUBBER
PER CENT RUBBER
PER CENT RESINS
PER CENT OF TOTAL POSSIBLE LEAVES REMAINING
Grams Total Rubber per 1,000 Grams Total Possible Leaves
Per Cent of Total Possible Leaves Remaining Green
Ratio of Dry Weight of Leaves to Dry Weight of Stems
Per Cent Resins in Leaves (Dry Basis)
Per Cent Rubber in Leaves (Dry Basis)
H. Kress
3-23-43
12
14
16
18
20
22
24
26
28
30
1
3
5
7
9
11
13
15
17
1942
August
September
1942
DATE

The percentage of rubber in the green leaves increased uniformly the first week. Flowers began to appear on August 14, but were not in abundance till August 18. From the time of abundant flowering, through to the discharge of the sees, there was a uniform increase in rubber content, though at a slower rate than in the first week. The rubber analysis of September 15, showing a rapid drop, is for the brown, dead leaves; nearly all of the leaves were in this condition. The highest total rubber available is seen to be on August 18, and indicates that harvesting for maximum total rubber should be done a few days after the appearance of the first flowers.

The percentage of resins varied in a manner similar to that of per cent rubber.

There is a continuous decrease in the leaf-stem ratio, the rate of decrease becoming greater with age.

By 9-6-42, the stumps from harvested (B) had developed numerous ratoons up to one foot in length, with small leaves, and flower buds at the axils. With proper cutting, three crops per year are therefore a possibility.

WILD LETTUCE LEAVES

(actual size)

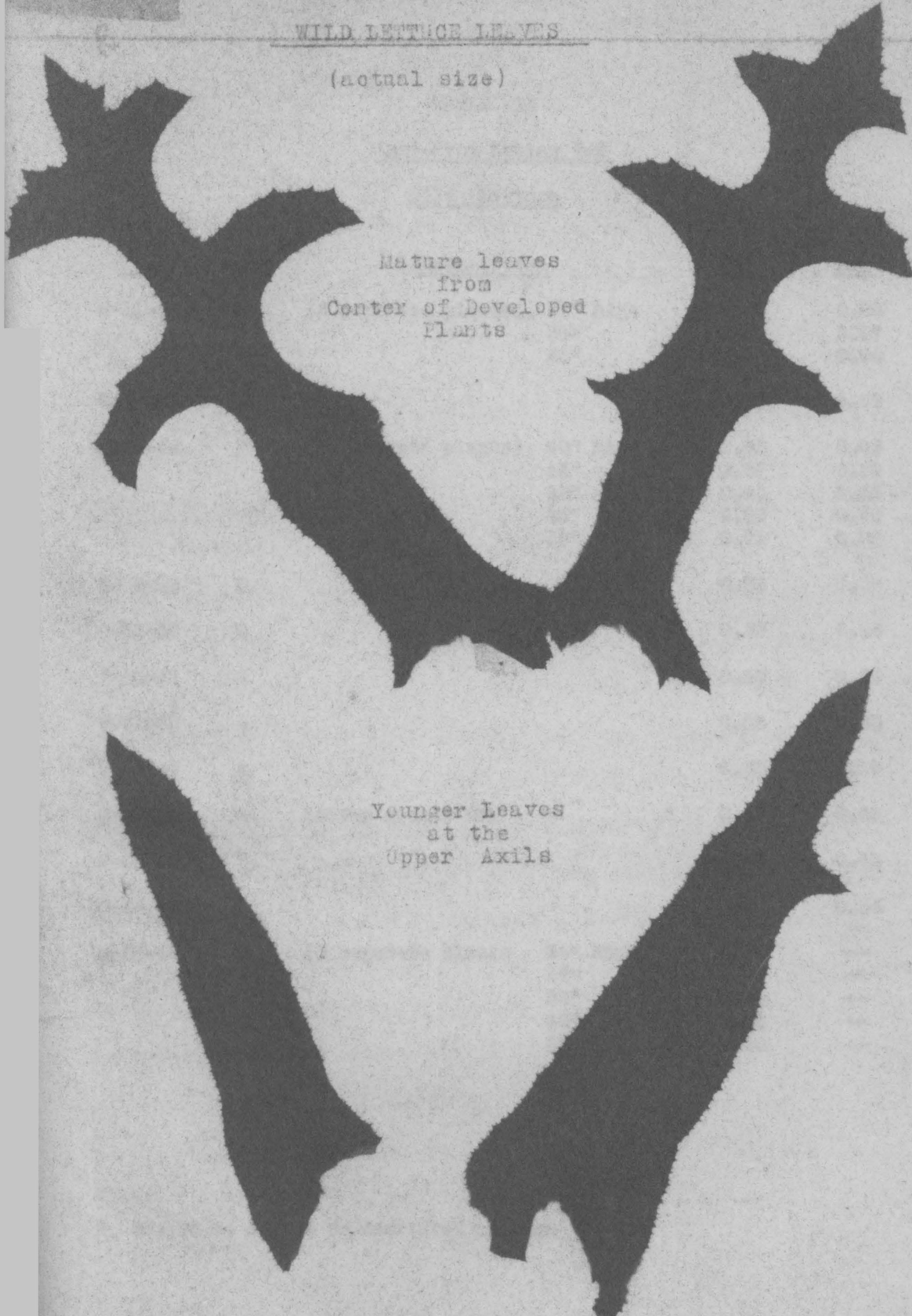


TABLE IX

Leaf-Stem Ratios for

Wild Lettuce

Date	*	Description		Ratio Wet	Ratio Dry
8-11-42	B	(3 separate plants),	31" high	0.95	0.88
			34"	0.92	0.87
			23"	1.03	0.94
8-18-42	B			0.98	0.96
8-29-42	B	(5 separate plants),	40" high	0.93	0.95
			41"	0.57	0.58
			42"	0.66	0.66
			43"	0.69	0.70
			49"	0.71	0.73
9- 4-42	B			0.55	0.55
9-11-42	B			0.20	0.20
7-29-42	A			0.45	0.36
7-31-42	A			0.42	0.35
8- 1-42	A			0.35	0.30
8-20-42	A	leaves nearly dry		0.07	0.23
7-30-42	C			0.56	0.48
8-4- 42	C			—	0.54
8-28-42	D	(5 separate plants	24" high	0.68	--
			27"	0.73	--
			36"	0.63	--
			40"	0.63	--
			42"	0.66	--

* Refers to source as described on page 90 .

<u>Leaf-Stem Ratio</u>: Since stems yield very little or no rubber, it is obviously desirable to obtain a type of growth which will yield a maximum weight of leaves. The ratio of the weight of leaves to the weight of stems will serve as an indication of the type of growth; a high ratio indicating a leafy plant, and a low ratio indicating a plant with robust stem and small leaves. These ratios as obtained are given in Table IX.

It will be seen that for (B) the ratio decreased with increasing maturity. It was observed that the leaves seemed to have attained maximum size by 8-11-42, and that subsequent growth was confined mainly to the upper stem and flower-carrying parts. Also, as has been noted, the leaves died progressively and were lost. These two effects are explanation for the decrease in the ratio. In comparing those growths of the ratoon type (B,D), with the uncut, single stem type, the former have a much higher ratio. This would indicate that the ratoon type is more desirable from the standpoint of leaf production.

<u>Results of Other Analyses</u>: Several isolated plants, not located near any of the stands previously described, were tested. The results are of little value so far as comparing them with the other results. One analysis is of interest: a few of the remaining small, green leaves in the upper axils of a plant that had discharged nearly all its seed, were tested.

resins: 11.26 per cent, rubber: 0.191 per cent

These percentages are higher in both resins and rubber than any found in the larger pure stands considered.

Date	Leaves resins %	Leaves rubber %	Leaves Moisture %	Stems Moisture %	Whole Plant Moisture %
8- 1-42 A	8.40	0.042	76.4	72.4	-
8- 4-42 C	9.50	0.120	-	-	83.3
8-28-42 D	9.65	0.040	-	-	78.2

Extraction by Pressing: Since the plants contain free-flowing latex together with a large proportion of plant juices, it was thought possible to separate the rubber by expressing the wet plant material, and subsequently processing the liquid so obtained.

Three such pressings were made in a hydraulic laboratory press.

I. Fresh, green leaves from (B), 8-12-42, 461 grams

Pressure psi	Grams Liquid Expressed Cum.	Grams Liquid Expressed Net.
301	36.7	36.7
426	68.8	32.1
770	103.2	34.4
850	125.0	21.8

Final cake: 299.0 grams
Loss 37.0 grams

The liquid so obtained (turbid and dark) was diluted with an equal volume of water. Twenty ml of 50 per cent acetic acid were added to coagulate, filtered into tared Gooch crucible, washed with acetone, and dried at 110°F.

0.689 grams

The cake from above was made up to 773 grams with water, and allowed to soak for several hours, then pressed a second time.

Pressure psi	Grams Liquid Expressed Cum.	Grams Liquid Expressed Net.
426	497	497
850	531	34
1,100	541	10
1,280	541	0

Final cake: 206 grams
Loss 26 grams

The liquid was treated as above: 0.251 grams

Total from two pressings: 0.940 grams

The product is a brittle, dark material, insoluble in acetone, benzene, alcohol, acetic acid, and water; burns slowly in Bunsen flame, decomposed slowly by HCl, H_2SO_4, and more rapidly by HNO_3.

II. Leaves from (B), 9-4-42, 382 grams.

426 psi: few drops
1,280 psi: 25 grams

Four pressings were made, the cake being soaked with water each time. The liquid was coagulated with a small amount of dilute acetic acid. The fourth pressing gave very little precipitate. Filtered and dried as under I.

Acetone extracts a small amount of chlorophyll from the product. Several days standing in benzene also brings out a faint green color. The material dries to brittle flakes similar to that under I.

III. Young shoots from (B), 9-17-42, 144.8 grams.

The pressings as under II were repeated, and identical results and observations on the product obtained. The filtrate was boiled down to a tarry, dark brown residue, similar to solvent extracted resins.

It is obvious that other materials besides the rubber are obtained in the coagulation with acid. It is not known how much of the rubber was separated by the pressing. If pressing were to be employed as a method of separation, a method of procedure other than the one used above must be developed.

Larger Batch Extractions: Several methods were tried in order to obtain rubber in larger quantities.

3.5 pounds of leaves, stored from the drying runs, were placed in a rod mill with 16 pounds of water and 50 grams of caustic, and the mill operated for three hours. The mash so obtained was transferred to a 25 gallon crock, and made up to about 20 gallons with water. It was thought that the rubber would float to the top and could be skimmed off as in the process used with dandelion. About half of the solids floated to the top, the other half settling to the bottom. No rubber could be separated.

This maceration process with caustic added, was repeated on several occasions, with slight variations in technique; in all cases, the results were equally disappointing.

Application of acetone and benzene to larger batches was also dried. In one test, 100 grams of finely ground leaves were extracted with acetone. The solids were then dried and extracted with benzene. The benzene extract was evaporated to 75ml, and 100 ml of ethyl alcohol added. The precipitate settled to the bottom, was separated by filtration, and washed with alcohol. A tacky gum was obtained on drying, which was not elastic. This gum was dissolved in benzene and reprecipitated with alcoholic caustic, filtered, and washed with alcohol. The color of this precipitate was somewhat lighter than the first, but the properties were the same. It is probable that materials having the same solvent properties as rubber were obtained together with the rubber. The entire lack of elasticity would indicate that the rubber was obtained in a much deteriorated form.

<u>Collection of Latex</u>: It was early discovered that by drying a few drops of latex between the finger tips, a ball or string of rubber could be obtained which, though tacky, was very elastic. The young plants (spring, 1943) show an abundant latex. About six ml of latex was collected by breaking such plants, and sucking the latex into a small bottle. The wet latex washed by shaking with acetone, and filtering. The residue was boiled with benzene, the benzene solution filtered, and the filtrate precipitated by the addition of acetone. The precipitate, on drying, gave a small ball of rubber, not tacky, and of high elasticity and strength. The insoluble residue from the benzene extraction yielded a white powder on drying. A drop of iodine gave no blue coloration to the powder as it would have if starch was present.

In breaking of the plants above for the collection of latex, it was noticed that most of the latex could be removed by one break at the middle of the stem. After the exuded latex had been removed, rupture of other parts of the plant showed very little or no latex.

<u>Seed</u>: In the cleaning of collected seeds by screening, it was found that nearly all of the seeds passed a 20-mesh screen, and were

retained on a 30-mesh. (U. S. Standard Screens) In one collection, 13,140 air dried seeds were found to weigh 6.385 grams, or 2,060 seeds per gram.

Regarding germinating power, one report appears in the literature review in which it is stated that ten per cent of the seeds had the power of growing soon after ripening, the rest remaining dormant. The seeds used in the planting of the experimental plot (E), were planted on the same day as collected from plants. A total of 2,200 plants were counted, coming from a planting of 13,140 seeds.

$$2,200/13,140 = 16.7\%$$

Therefore, at least 16.7 per cent of the seeds had the power of germinating, and surviving the infancy.

Two sets of seeds were tested in a laboratory planting:

e-1 : collected 8-7-42
e-2 : collected 9-13-42

Both were stored during the winter in one pint Mason jars. Soil was obtained adjoining the experimental plot (E), screened through ordinary window screen, and placed in a 21 x 21 inch wooden box to a depth of six inches. Approximately 2,340 seeds of each sample were soaked in water for two days at 70°F. Each portion was sown in five 21-inch rows, 1/3 inch deep, covered, and rolled down (3-27-43). The first plant counts were as follows:

Date	e-1	e-2
4-3-43	323	192
4-5-43	346	148

The soil was kept moist by watering daily. The plants did not have much sunlight, and some plants of both sets, especially e-2, were dying off or wilting at the ground level. On 4-6-43, the box was placed outside in a sunny place on a roof, and all the plants that were up died by 4-9-43. On the same day, 4-9-43, new plants began coming up, and on 4-13-43, quite a number of these were up. These plants stayed much closer to the ground, were darker green, and stronger. Several roots were 1.3 to 1.5 inches long, sprouting from the opposite end of the seed from that which had the seed "parachute" attached. Further plant counts follow: ("new" only)

Date	e-1	e-2	
4-19-43	854	393	
5- 4-43	1,245	960	(maximum reached)

On 5-4-43, many of the plants showed from three to six leaves, the larger of which were 0.4 inches long, and 0.3 inches wide.

The first sets in the laboratory planting, which came up much more rapidly than the rest, possibly belong to that group having germinating power soon after ripening. The percentages of these would be:

e-1 : 346/2340 = 14.8 per cent
e-2 : 192/2340 = 8.2 per cent

The total germination in the laboratory planting:

e-1 : 1591/2340 = 63 per cent
e-2 : 1152/2340 = 49 per cent

It should be noted that the seeds e-2 were darker in color than e-1, though collected and stored under the same conditions, the only difference being in date of collection.

<u>Development of the Analytical Method</u>: (The reader should refer to the literature review on Analysis.) The first analytical method tried was that of solvent extraction with the Soxhlet-Allihn apparatus, and the procedure given on page 85 was followed. Leaves from the drying run of (B), 8-12-42 were tested. Duplicate analyses gave rubber percentages of 1.05 and 0.753 respectively. The product, or residue from the benzene extract (taken as rubber in this method of analysis) possessed no elasticity and was dark in color, and tacky. Acetone washings removed chlorophyll from the mass. The first conclusion was that acetone extraction had not been complete. The extractions were repeated, with the time of acetone extraction extended to 24 hours. Samples of (B) 8-18-42 were used. Triplicate analyses gave 0.691, 0.795, and 0.676 per cent rubber respectively. The evaporation of the benzene extract gave a nearly clear, transparent residue. This residue was not elastic, and also not tacky, having more of a waxy or greasy feel. A material other than rubber, but with the same solvent properties was suspected.

A bromination method, as described on page 78 of the literature review was also tried. Several analyses, using this procedure were made. Two difficulties with this method became apparent:

1) The resins which are present during the bromination interfere. In some instances, the bromine on addition was immediately used up, producing a tarry mass.

2) The precipitated bromide was so small as to be scarcely noticeable. Obviously no accuracy could be attained with a procedure involving the filtration and weighing of a few tenths of a milligram.

It was alwo hard to see how standing in cold benzene for one hour could accomplish complete rubber extraction, when the Soxhlet-Allihn extraction method required seven hours of extraction with boiling benzene.

In order to test the bromination method as far as formation and stability of the bromide was concerned, the following tests were made:

I. Samples were cut from a sheet of raw crepe rubber.

a) 0.0141 grams
b) 0.0123 grams
c) 0.0147 grams

These were placed in separate 8-inch test tubes, and dissolved in 13 ml benzene. (A fine reticulation remained, even after four hours. This was assumed to be the protein structure usually found in raw rubber.) One ml of the usual bromine solution was added to each, and after 2.5 hours, precipitation accomplished with 25 ml ethyl alcohol. The precipitate was filtered, washed, dried at 110°F, desiccated, and weighed. On the basis of two Br atoms per C_5H_8 unit, the calculated percentages were: (factor 0.2986)

a) 91.74 per cent rubber
b) 88.70 per cent rubber
c) 91.74 per cent rubber

Raw crepe usually contains from three to six per cent resins, and some protein and moisture. Therefore, it seems safe to assume that a bromide of the composition $(C_5H_8Br_2)_x$ is actually formed.

II. A rubber solution was prepared by dissolving raw crepe (previously acetone extracted) in benzene, and filtered to remove the reticulated structure. Six 25 ml samples of this solution were pipetted into 125 ml Erlenmeyer flasks, and one ml of bromine solution added to each at the same time. The temperature was kept at 68°F, and the time of bromination varied. At different times, the bromide was precipitated with 50 ml alcohol, filtered, washed, dried at 110°F., desiccated and weighed.

Hours in bromination	grams bromide
1	0.0079
3	0.0078
5	0.0078
12.5	0.0075
16.5	0.0073
24	0.0081
(no bromine, alcohol ppt.)	0.0022 rubber
50 ml of the solution evaporated	0.0048 rubber

The above procedure was repeated with the same solution:

Hours in bromination	grams bromide
1	0.0076
4	0.0076
8	0.0075
36	0.0094
(no bromine, alcohol ppt.)	0.0023 rubber

The precipitates up to eight hours bromination time are floculent, filter easily, and on washing are pure white. The 24 and 36 hour precipitates are more granular, settle with difficulty, are hard to filter, and retain a brown discoloration even after prolonged washing.

These experiments indicate:

1) Bromination is complete after the first hour, or at some time before.

2) The decrease in weight from 0.0079 to 0.0073 from one to

sixteen hours may be attributed to the slow splitting out of HBr.

3) The subsequent increase to 0.0081 and 0.0094 for 24 and 36 hours, may be attributed to the addition of more bromine at the place of splitting of HBr, giving three or more Br units per C_5H_8.

4) Using the factor 0.2986 for conversion of the bromide to isoprene, for the one hour brominations:

$$(0.2986)\ (0.0076) = 0.00227 \text{ grams rubber}$$
$$(0.2986)\ (0.0079) = 0.00236 \text{ grams rubber}$$

The pure alcohol precipitates gave 0.0022, and).0023 grams which is in close agreement with that calculated from the bromide. The evaporated sample shows 0.0048/2 or 0.0024 grams per 25 ml of the original solution, which is also in close agreement.

It was apparent, that the determination of very small percentages was involved. In the solvent extraction method the effect of the foreign material with solvent properties similar to rubber would have to be overcome. In the bromination method, the interference of the resins would have to be corrected. The method devised to overcome these two difficulties involves the following steps:

1) acetone extraction to remove resins
2) benzene extraction
3) bromination of the benzene solution
4) precipitation of the bromide formed

After numerous trials, the final details of time, amounts, etc., were standardized, and in final form appears under Methods of Procedure, page 86.

That none of the acetone-insoluble, benzene-soluble material, which interferred in the solvent extraction method, was precipitated with the bromide is indicated by the pure white, powdery character of the bromide obtained in all cases. The bromination method also allows the weighing of a precipitate nearly four times as heavy as the rubber hydrocarbon being determined.

All filtration was done with the fritted-glass filtering crucibles. The bromide from at least six determinations could be allowed to accumulate on these filters before removal was necessary. The final weight of one determination was taken as the tare weight for the succeeding one. Several blanks were run with bromide on the filters. In no case was a change in weight obtained, indicating that washing in the manner described in the procedure was complete, and that intermediate heating to 110°F caused no decomposition of the bromide.

Bearing in mind the facts brought out by Spence and Caldwell in their study of analytical methods, it was decided to make a determination following the procedure prescribed by these authors. The procedure was modified somewhat, since their apparatus could not be duplicated. A 2.000 gram sample of leaves (B), 8-18-42 was used. Acid hydrolysis was accomplished by boiling the sample in the one per cent sulphuric acid solution in a 125 ml Erlenmeyer flask, under reflux for three hours. Steaming was done with 15 psi steam for three hours, and leaching with cold water.

It is perhaps significant, that after acetone and benzene extractions, the remaining solids weighed only 0.60 grams (from the original two gram sample). The final analysis showed

0.0996 per cent rubber in the sample

The analysis by the method developed by this author gave for the same sample,

.013 per cent rubber

The rigorous method of treatment in the Spence and Caldwell method assured complete rubber extraction. Since results of the developed method agree closely with that of Spence and Caldwell, it can be assumed that the extraction times as stated in the procedure of the developed method are sufficient for complete rubber extraction.

The agreement in duplicate and triplicate analyses by the developed method justified reporting the rubber percentages to three significant figures. Duplicate analyses were made in all determinations of rubber content. The single values of per cent rubber throughout this report represent the mean of duplicate analyses, using the method and procedure developed by this author.

The resin percentages are in each case to be considered as the acetone soluble constituents.

Estimation of Yield Per Acre: Since stems show very little or no rubber in the developed plants, the total rubber yield must be based on the leaves. An estimate for (B) follows:

If harvested at the time of maximum total rubber as indicated by the curve on page 109, the percentages are as follows:

	per cent resins	per cent rubber
leaves	10.4	0.103
stems	5.2	---

Three harvestings of (B) gave an equivalent high yield of 1,520 pounds of dry leaves per acre and a low of 1,120 pounds. The yields are :

Per Acre:	High	Low
Total pounds wet plant material	17,130	12,230
Total pounds dry plant material	3,220	2,300
pounds dry leaves	1,520	1,120
Pounds dry stems	1,700	1,180
Pounds resins from leaves	158	117
Pounds resins from stems	90	61
Total pounds resins	248	178
Total pounds rubber	1.57	1.16

While (A) and (C) yielded considerably more plant material in harvesting, the histories of these plants was not followed for a sufficient length of time to justify estimates on rubber yield per acre.

The yield indicated by the young plants of the experimental plot (E) are of special significance: (see page 92)

	(1)	(2)
Total dry weight of single plant (grams)	2.03	3.95
Per cent rubber	0.339	0.239
Number of plants per acre*	660,000	660,000
Pounds dry plants per acre	2,950	5,750
Pounds rubber per acre	10	13.7

* Based on a total of 2,200 plants counted on the 170 square feet of experimental plot.

IV. DISCUSSION

A. Discussion of Results

Rubber: It was necessary to determine the pounds of rubber per acre per year which could be obtained from the cultivation and processing of wild lettuce in order to allow comparison with other rubber-bearing plants. Since there is a seasonal variation in rubber content, as well as in total rubber, determinations had to be made to cover the whole growth cycle in order to establish the time and stage of maximum rubber content. For this purpose, the nearly pure stand of wild growing plants, (B), was utilized.

In the study of (B), it was early found that the stems contained very little or no rubber, and that rubber was primarily confined to the leaves, as shown by the analyses reported in Table VIII. The percentages of rubber in the leaves increased uniformly from 8-11-42 to 8-18-42, and the increase continued at a slower rate to 9-11-42. The increase over the entire period was from 0.07 per cent on 8-11-42 to 0.14 per cent on 9-11-42. The seasonal variation of rubber content, as well as the variation in resins, amount of leaves available, and leaf-stem ratios, are illustrated by the curves on page 109. The increasing rubber percentage, and the decrease in the amount of leaves available, are opposing effects in the total amount of rubber to be obtained. A maximum of total rubber, 0.9 grams per 1,000 grams of total possible leaves, was found to occur on 8-18-42, although the maximum rubber percentage was not attained until 9-11-42. This point of maximum total rubber coincides closely with the stage of development at which flowers first make their appearance. Combining this analytical data with the weight of plant material obtained by harvesting, allowed estimation of the pounds of rubber to be obtained per acre. This was found to be 1.57 pounds per acre.

The younger plants from the experimental planting (E) were also used to determine the yield in pounds per acre during the early stages of growth. One young plant yielded a rubber percentage of 0.339, which was much higher than that obtained for any of the more developed plants. The calculated yield for such young plants is 13.7 pounds of rubber per acre. These young plants which are in a stage of rapid growth have a very abundant latex, which explains the much higher rubber content.

The yield of 30 to 60 pounds of rubber per acre per year for dandelion is considered low (70). Even the yields of 80 to 100 pounds per acre which may be obtained from milkweeds and goldenrod (70) are not very promising from the standpoint of commercial utilization. In view of these facts, the calculated yields from wild lettuce are not very encouraging. It should be kept in mind that the yields calculated for wild lettuce are based on analytical data and not on batch extractions, the yield by extractions assumed to be 100 per cent.

Resins: The seasonal variation in resins content of leaves closely paralleled the trend of rubber (see curve, page 109). The highest resin content found in (B) was 11.26 per cent. At the point of maximum rubber, the resin content was 10.30 per cent. The resin content of the stems varied from 5.22 to 5.85 per cent. The combined yield of resins from both leaves and stems amounts to 287 pounds per acre.

Cultivation: Natural stands of wild lettuce can not be considered for commercial utilization. Therefore, the cultivation characteristics of the plant must be known. Some of these characteristics can be deducted from the wild-growing plants; others must be determined by experimental plantings. For this reason, the experimental planting (E) was undertaken.

Seed from the wild-growing plants was available in the latter part of July. At first it was thought that if this seed were planted at this time, the plants coming therefrom would make good progress during the remaining summer and fall, and data on the early stages hereby be obtained. As was discovered, the seed planted soon after ripening produces only the winter annual type of plant, that is, the plants grow only to a certain stage and then remain static until the coming spring. It is probable that during the "static" period, the roots become more developed.

Wild lettuce seed was found in abundance, a well branched plant of medium size yielding about 8,000 seeds. Of the seeds collected soon after ripening, and planted on the experimental plot (E), 16.7 per cent germinated and survived infancy, in contrast to a report in the literature (56) that only ten per cent of such seeds had germinating power soon after ripening. Two samples of seed collected in the fall were found to have germinations of 68 and 49 per cent respectively. Of these last two samples, 14.8 and 8.2 per cent respectively germinated much more rapidly than the rest, and it is believed that these were of the type capable of forming the winter annuals. Harvested seed could not be used in plantings for a period of at least half a year because of the dormancy of at least 80 per cent of the seed for this time. Broadcast or drill sowing seems entirely possible.

A decided advantage of wild lettuce is that the plants require no attention between sowing and harvesting time. If the stands are uniform, weeds will be largely crowded out by the lettuce. Its adaptability to a wide range of ecological conditions, as indicated by its natural range and distribution, would make it a possible crop in most of the rainbelt area of the United States, whereas many of the other rubber-bearing plants such as the desert milkweeds, guayule, rabbit brush, and Madagascar rubber vines, are confined to a limited area. The dandelion could be grown over a wide range, but requires rich soil and extensive care during growth. Poor soils could be utilized for wild lettuce, though its rubber producing capacity under less favorable conditions is not known. That moisture requirements for wild lettuce are not high is indicated by its habit of thriving in places receiving and retaining very little moisture. (For an outline of cultivation characteristics, of the more important rubber-bearing plants, see Table Y, page 70).

Harvesting: The ratooning habit of wild lettuce makes three harvests per year possible from the same plants. If three crops could be successfully harvested, the yield of rubber could be considerably increased above that calculated for the single stands. The time at which (B) had been cut previous to its location is not known. The yield obtained from the first ratoons of (B), (the second harvesting) is shown in Table II. Data on the second ratoons (third harvesting) was not obtained, but it is likely that the weight to be obtained from these would be less than from the first ratoons. As is shown in Table II, the highest yield of dry leaves obtained from any harvesting was 2,830 pounds per acre. This high yield was obtained from (C), which had exceptionally robust plants. Comparison of this yield with those obtained from (B) is hardly justified, since the history of (C) was not followed as it was in (B). However, this high yield may serve as an indication of the amount of leaves to be obtained under very favorable conditions.

As was noted in the history of the experimental plot (E), the young plants contain an abundant latex in all parts, including the roots. The cutting of young plants is accompanied by a loss in latex, unless special precautions are taken to collect the exuded latex. If the entire young plants, including the roots, are to be harvested, this would probably necessitate planting in rows, and removal with a machine similar to a beet-lifter. Harvested plants that were dried in sunlight lost nearly all of their rubber, while plants dried quickly in a dryer gave 0.140 per cent rubber in the leaves. In any harvesting, therefore, plants must be removed from the field soon after cutting.

Leaf-stem Ratio: Since stems yield very little or no rubber, it is desirable to obtain a type of growth which will yield a maximum weight of leaves. The ratio of leaves to stems is an indication of the type of growth, a high ratio indicating a leafy plant, and a low ratio indicating a plant with robust stem and small leaves. These ratios appear in Table IX. The leaf-stem ratio of (B) was found to decrease from 0.92 on 8-11-42 to 0.20 on 9-11-42. Evidently the younger plants have a better ratio. The best ratio for the single-stem type of growth, represented by (A) and (C) was 0.48. These results would indicate that the ratoon type of growth produces more leafy plants, and is therefore desirable.

Extraction: Extraction of the rubber will undoubtedly present the greatest difficulty in processing in the analytical extractions with acetone and benzene, between 0.691 and 1.05 per cent of an acetone-insoluble, benzene-insoluble material was obtained. The physical nature of this material indicated that it was not rubber. Therefore, solvent extraction with acetone and benzene is not satisfactory.

Since the plants contain free-flowing latex together with a large proportion of plant juices, it was thought possible to separate the rubber by expressing the wet plant material, and subsequently processing the liquid so obtained. The juice from 461 grams of green leaves gave a coagulum of 0.940 grams, which is about 1.1 per cent on the dry basis. This is much above the rubber content obtained by analysis. The material also exhibited no rubbery qualities. Materials other than rubber are also coagulated by addition of acid to plant juices. If pressing were to be employed as a method of separation, a method of procedure other than the one used in these experiments must be developed.

Larger batch extractions were attempted as described on page 116. These methods involved a maceration with alkali, similar to that used for dandelion (11). No rubber could be separated in any of the attempts. It seems that nothing short of an elaborate technique, involving solvents in addition to acetone and benzene, is necessary to extract the rubber.

Mr. R. Colee of the Florida Chamber of Commerce, has suggested that in the case of *Cryptostegia* latex could be collected by cutting the plant tips and allowing the latex to drop into a small cup, one man being capable of collecting about one pound of rubber per day in this way. (Nov. 15 issue, Roanoke Times). Direct collection of latex would eliminate subsequent handling of plant material, but in the case of wild lettuce, would still necessitate the extraction of the rubber from the latex. The same acetone insoluble, benzene soluble which interfered with the solvent extraction of rubber from the leaves, was found present in the latex (page 117). Though the latex can be made to flow very easily from wild lettuce, and the bulk of the rubber be obtained in this way, this author does not consider such a method a possibility, mainly because of the enormous amounts of labor involved.

Drying: If harvested plant material is to be stored before processing, drying is necessary to prevent deterioration. Extraction with organic solvents would also require preliminary drying.

As has already been stated under "Harvesting", drying in the field can not be considered because of the rapid deterioration of the rubber when exposed to sunlight. Data on artificial drying at various temperatures and humidities was obtained. The data on page 99 indicated that drying temperatures up to 180°F may be employed with no decrease in rubber content, and also that slow drying at lower temperatures may be used, provided that the material is not exposed to sunlight. It should be kept in mind that although the amount of rubber is not decreased by the higher temperatures, the effect on the quality must also be considered. Tables III through VII, and the curves following, show that all the moisture in the green plants is "bound", and all drying is confined to a falling-rate period. The rapid increase in drying rate with decreasing humidity is illustrated by the curves.

<u>Analysis</u>: None of the procedures found in the literature for the determination of rubber in plant material were found satisfactory in the analysis of wild lettuce. It is probable that none of the methods can be, or were intended to be, universally employed. Each plant has its own characteristics, which call for variations in procedure. For example, the bromination method as described by zur Burg (78) was designed for the analysis of goldenrod leaves. The rubber in goldenrod occurs in an entirely different manner and quantity than does rubber in wild lettuce. Different plants also vary greatly in amounts and nature of other materials such as resins, proteins, etc., which may all in some way affect the analysis. The results of any one method, when applied to a series of the same plants, are of value in comparison within themselves, even though they are not correct in the quantitative sense.

(See the section on "Development of the Analytical Method", under Data and Results.) Solvent extraction methods and bromination methods were first tried. The difficulties encountered and observations made are described in the above section. Because of conflicting views in the literature (53,45) regarding the formation and stability of the bromide of rubber, tests on the bromination were conducted. The average of three analyses of raw crepe rubber was 90.1 per cent pure isoprene, using the factor for a dibromide. Since raw crepe usually contains from three to six per cent resins, and some protein, moisture, and oxidized matter, it seems safe to assume that a bromide of the composition of $(C_5H_8Br_2)_x$ is actually formed. Studies on the conditions of time, temperature, and concentration during bromination are presented on pages 121-123. These show conclusively that under the conditions of time, temperature, and concentration, used in the method developed by this author, only the dibromide is formed, and is stable.

There can be very little confidence in results obtained by the purely solvent extraction methods, when the percentages involved are below one per cent. In the case of wild lettuce, such a solvent extraction method would have overstated the actual rubber content by five to ten times. Hall and Long (30) in reporting the lower percentages were always careful to point out that what they obtained as rubber by solvent extraction, may not have been rubber at all. Obviously when high percentages are involved, the presence of small amounts of non-rubber constituents in the rubber extract does not cause much error, and the solvent method may be safely employed.

The rigorous treatment of hydrolsis used in the method of Spence and Caldwell (66) assures the elimination of interfering materials, and also complete rubber extraction. Their method was developed primarily for use with guayule. One analysis of wild lettuce by the method of Spence and Caldwell (66) gave 0.099 per cent, the developed method giving 0.13. It seems probable that such a rigorous hydrolysis treatment is not required for wild lettuce.

In the developed method, direct boiling of samples with solvents in 125 ml flasks was used. It is not intended to imply that this particular procedure should be substituted for the regular extraction apparatus involving some of the many variations of the Soxhlet type. The treatment in flasks, though requiring less time, is more laborious. The only advantages claimed for it are complete extraction in a much shorter time, and the use of simplified, inexpensive laboratory equipment.

Hall and Long (30) in using the solvent extraction method, report one analysis of the leaves of Lactuca scariola with 0.86 per cent rubber. Analyses performed by this author, using the solvent method, gave percentages of 0.69, 0.79, and 0.67 for one sample. Evidently the same effect of interfering materials was encountered by Hall and Long (30). Fox (26) by his treatment in which he prepared pure rubber from wild lettuce latex, obtained about one per cent rubber in the latex. The 0.86 per cent on the dry basis would be about 0.17 per cent on the wet basis. The leaves would therefore have to be 17 per cent latex to make the 0.86 figure correct, and this is highly improbable.

Sampling: One difficulty in sampling plants for analysis was experienced with wild lettuce, which will be found in any latex-bearing plant. Cutting of the plants and separation of leaves from green plants results in the loss of latex from the severed parts, and must give erroneous analytical results. Other authors make no mention of how this loss was avoided. In the case of wild lettuce, the removal of a single leaf from a young plant would result in loss of the major portion of the rubber. The procedure used for wild lettuce involved cutting of the plants at the woody portions which exude no latex, and subsequent drying of the whole plant before separation of the parts. This also involves some error, since during drying latex may flow to the extremities and be concentrated there, but at least there is no loss, and the total rubber in the plant can be ascertained. In sampling young plants, the complete plant including roots must be removed, and dried before separation of the parts. The method of quick drying and storage used probably eliminated most of the respiratory changes in the plants subsequent to harvesting.

Advantages of the Developed Method: This author believes the developed method of analysis, coupling solvent extraction with bromination, to be especially adapted to plant material having very low rubber content, accompanied by high rosin contents. With it, duplicate analyses can be obtained when only three grams of plant material, of very low rubber content, are available; three significant figures being justified in the results obtained.

B. Recommendations

The following recommendations for future study on the subject are made:

Cultivation: Fall sown plants far outdistance those coming from seed in the following spring, therefore fall-planting should receive considerable attention. The lowest desirable winter temperatures would need to be known for a plan of fall-planting. Time of planting, requirements in soil preparation, and the necessity of seed pre-germination, require further research.

Harvesting: The possibility of three harvests per year seems one of the most promising features of the wild lettuce. The amount of plant material which can be obtained from three such harvests should be investigated. The proper time for cutting, as well as the level of cutting for the production of abundant ratoons needs to be determined. Methods of harvesting without the loss of latex should also be investigated.

Extraction: Before wild lettuce can be considered for its rubber, a workable extraction method must be found. Large scale extraction presents the greatest difficulties, and also offers the best opportunity for further research. A combination mechanical and solvent extraction method is indicated. Properties of the rubber obtained by different treatments are important, since solvent extraction methods usually result in an inferior quality product.

Resins: Since the resins are abundant, a possible use for these would be important. Determinations of composition and physical properties would be steps in such a development.

Lactucarium: Since this constituent of wild lettuce is already a commercial product, further study as to amounts available and means of extraction and separation are justified.

C. Limitations

The Growth Cycle: Due to limitation in time, the complete one-year cycle from seed to mature plant could not be covered. The young plants, showing special promise as to rubber production, should have received much more extensive study.

Ecology: The effect of ecological conditions on rubber production were not studied, because of time limitations and the localized character of the research.

Cultivation: Much of the data had to be obtained from wild growing plants and the experimental planting was confined to a relatively small area. For more reliable results, larger plantings would have to be undertaken.

V. CONCLUSIONS

1. The maximum rubber percentage (0.14 per cent of the dry weight) in the leaves of the natural growing wild lettuce of one nearly pure stand in Blacksburg, Virginia, was attained on 9-11-42, just previous to the total discharge of seed.

2. The maximum total rubber content of the natural growing pure wild lettuce stand referred to in (1) occured on 8-18-42, at the time of the appearance of the first flowers. The calculated yield on this date was between 1.16 and 1.57 pounds of rubber per acre.

3. The rubber content of young plants of an experimental planting was between 0.239 and 0.339 per cent of the dry weight of the whole plant on 5-13-43. This amounted to a calculated yield of from 10.0 to 13.7 pounds of rubber per acre.

4. The resin content of the leaves of the natural growing pure wild lettuce stand referred to in (1) was 10.3 per cent on 8-18-42. The stems contained 5.22 per cent on this date. The calculated yield on 8-18-42 was between 176 and 248 pounds of resins per acre from leaves and stems combined.

5. The rubber in mature wild lettuce plants was confined largely to the leaves; woody stems and roots showed only traces of rubber.

6. The largest yield of dry plant material obtained from natural growing plants was equivalent to:

leaves:	2,830 pounds per acre
stems :	5,760 pounds per acre

7. Drying of plants at 180°F gave no decrease in rubber content

during drying.

8. Drying of plants at 70 to 80°F, exposed to sunlight for 48 hours, decreased the rubber content of the leaves from 0.14 per cent to 0.0 per cent.

9. Drying plants at 80°F, not exposed to sunlight, gave no decrease in rubber content during drying.

10. A minimum of 16.7 per cent of the seeds collected from mature plants on 7-31-42 and sown on the same day germinated and survived infancy.

11. Two wild lettuce seed samples, collected on 8-7-42 and 9-13-42, gave germinations of 68 and 49 per cent respectively the following spring.

12. On 5-31-43, plants sown on 7-31-42 had attained a mean height of 20 inches. Plants sown on 3-27-43 had not produced stems on 5-31-43.

13. Acetone-benzene extraction of one sample of leaves gave a mean of 0.72 per cent rubber, the developed method of analysis, combining solvent extraction and bromination, giving 0.103 per cent for the same sample.

14. Direct boiling of finely ground wild lettuce leaves, previously acetone extracted, in benzene for a period of six hours gave complete extraction of rubber.

VI. SUMMARY

A literature review of rubber-bearing plants in the United States was made, and the essentials of distribution, ecology, and rubber content presented in condensed form. Wild lettuce of the specie Lactuca scariola was investigated to determine its place among the other rubber-bearing plants.

Nearly pure stands of natural growing wild lettuce were harvested and the weights of plant material determined. Yields up to 2,830 pounds of dry leaves together with 5,760 pounds of dry stems per acre were obtained. The seasonal variation in rubber content and resins of one natural growing wild lettuce stand was studied from the time of the appearance of flower buds to the end of the growth cycle. At the time of maximum rubber content of this stand the calculated yield was between 1.16 and 1.67 pounds of rubber per acre.

An experimental planting was undertaken to determine rubber content, resin content, and growth and cultivation characteristics of the earlier stages of growth. Young plants gave up to 0.339 per cent rubber and a calculated yield of 13.7 pounds of rubber per acre.

Drying temperatures up to 180°F gave no decrease in rubber content during drying. The rubber content of harvested plants was found to decrease rapidly on exposure to sunlight.

At least 16.7 per cent of the seeds were found to have the power of germinating soon after ripening. Seeds ripened in the fall were found to have between 49 and 68 per cent germinating power.

An analytical method adapted to the accurate determination of low percentages of rubber in wild lettuce, was developed.

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1923	Possibilities of Rubber Production	49
1924	Rubber Investigations Pushed	74
1925	Rubber Possibilities in the U.S.	51
1926	Demand for Rubber Information	68
1927	Rubber Possibilities of Many Kinds Exist in the U.S.	562
1930	Madagascar Expedition Finds Rubber Plants Possibly Suited to U.S.	370
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APPENDIX

Drying Calculations (see Table V)

Consider the first period of drying, from 0 time to 0.5 hours:

time, net : 0.5 - 0 = 0.5 hours

net lbs. : The net weight of the material,

0 hours - 14.000 lbs.
0.5 hours - 12.80 lbs.

average lbs.: (14.00 + 12.80)/2 = 13.40 lbs.

H_2O av. lbs.: (the net dry weight by moisture determination = 3.30 lbs.)

13.40 - 3.30 = 10.10 lbs.

H_2O loss, lbs.:

14.00 - 12.80 = 1.20 lbs.

Av. lbs. H_2O/lb. dry material:

10.10/3.30 = 3.06 lbs.

Drying Rate: (Area in all cases is assumed to be the area of the trays used) Area: 36 sq.ft.

1.20/(0.5 x 36) = 0.0670 lbs/hr/sq.ft.

Bromination Calculations

Grams bromine per ml brom. soln.:

bromine soln, 4 ml bromine in approx 100 total
density bromine(liquid) : 2.98

4(2.98)/100 = 0.119 grams bromine per ml.

Grams rubber requiring 1 ml bromine solution:

bromide formed: $C_5H_8Br_2$ M.W. 227.89
C_5H_8 M.W. 68.06
Br_2 M.W. 160

68(0.119)/160 = 0.057 grams rubber

68.06/227.89 = 0.2986; weight bromide x 0.2986 = wt. rubber