RUBBER-CONTENT OF NORTH AMERICAN PLANTS

BY

HARVEY M. HALL AND FRANCES L. LONG

PUBLISHED BY THE CARNEGIE INSTITUTION OF WASHINGTON
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RUBBER-CONTENT OF NORTH AMERICAN PLANTS.

I. PURPOSE OF THE INVESTIGATION.

Rubber is now considered by every civilized community as one of its prime necessities. Since this important commodity is almost wholly a product of the tropics, those countries which lie entirely or mostly in the temperate zones are dependent upon importations, mostly from overseas, for their supply. This places the importing nation at a disadvantage, since it is subject at all times to labor and other economic disturbances in the rubber-producing countries, while in time of war it is dependent upon the good-will both of the producers and of whatever power happens at the moment to be in control of those seas over which the importations must travel. The United States is in a particularly hazardous position in this respect. The normal annual importation into this country is approximately 300,000,000 pounds. War-time conditions would make such increased and imperative demands that, unless this amount could be very materially augmented, it would be necessary greatly to restrict the use of rubber for ordinary commercial purposes. This inconvenience, however, would be trivial as compared with the perilous condition of the country in case importations from overseas should at the same time be seriously curtailed or stopped entirely by the enemy. It therefore behooves the United States and other countries so situated to discover some other method of supplying their needs, and it is possible that one such method lies in the improvement and cultivation of rubber plants suited to extra-tropical conditions. The responsibility for the initiation of such studies lies primarily with the botanist, since he is the one who should be the best qualified to recognize the kinds of plants most likely to yield results. It was with these considerations in mind that the present investigation was undertaken, although the general scientific interest which attaches to the formation and presence of rubber in plants was also an impelling motive.

The work described in this paper is to some extent a continuation of a survey of western North America for rubber-producing plants begun in 1917 as a war-emergency project under the State Council of Defense of California and of which there is more specific reference on p. 8. That project, however, centered around a study of the genus *Chrysothamnus* and related shrubs, plants in which the rubber occurs in the form of solid particles in the plant cell, whereas the present studies are concerned chiefly with the genus *Asclepias* (milkweeds) and similar herbaceous plants in which the rubber occurs somewhat as an emulsion in the latex, or milky sap, which in turn occupies the vessels of the highly specialized laticiferous tissues. Furthermore, while the prime object of that earlier search was to locate an emergency supply of rubber in native shrubs, the object of the present one is to discover, if possible, some latex plant sufficiently promising to justify experiments looking towards its cultivation as a rubber-producing crop. A second object is to extend the knowledge of the occurrence of rubber in plants, quite irrespective of any immediate practical results. During both of these investigations attention has been also given to many other plants than those of the two genera just mentioned, so that definite information is now available as to the presence or absence of rubber in about 225 species and varieties of west American plants.

II. EARLIER INVESTIGATIONS.

The most important studies thus far made on North American rubber plants have been those on *Castilla* and guayule, the former a tree of tropical America, the other a low shrub of northern Mexico and southwestern Texas. Investigations of latex plants native to the United States have been few and, at least so far as indicated by published reports, they resulted in no promising discoveries. This was due in some cases to chemical and other difficulties encountered in the analyses of the samples; sometimes to a lack of persistence in assembling samples from a large number of species and from a considerable variety of habitats; sometimes, and perhaps always in part, to the chance which resulted in the wrong botanical species as the object of study or to its examination at an unfavorable season. One of the outstanding results of the present inquiry is the discovery that not only do closely related species vary among themselves in their rubber-content to a surprising degree, but also that a remarkable range of variation may be expected within a single species. Even the different parts of the plant are usually found to carry very unequal percentages, and these proportions vary somewhat with seasonal and other ecologic conditions. It is therefore evident that, if one sets out to discover the best native rubber-producing species, he should not rest content until a very large series of examinations has been made. It will be seen from the following summaries of the results obtained by earlier workers that with the exception of *Castilla* and guayule the investigations were not carried far enough to give an adequate basis for judgment, and that in a number of cases the plants deemed as unworthy of further study have since been shown to possess considerable promise as rubber plants.

Central American Rubber Tree (*Castilla elastica*).—Since this is a tropical plant not suitable for cultivation in the United States, it will here receive but the briefest mention, and that only for the sake of making the list as nearly complete as possible. The most authoritative account of the plant is one by Cook (1903). The conclusions of this author are that the culture of *Castilla* has passed the experimental stage, but he emphasizes the fact that the regions in Mexico and Central America well adapted to its culture are much more limited than generally supposed. With no attempt to discourage rubber cultivation in those districts, he nevertheless urges caution in making investments. The rubber, which is carried by a latex obtained by the tapping process, is scarcely inferior to Para rubber and is obtained in some quantity from native trees in Central America.

Other Mexican latex plants.—Mexico is a very promising field for exploration with the object of discovering plants capable of yielding rubber in commercial quantities, both from the native growth and from plantations established for this purpose. This was the conviction of the late Dr. Pehr Olsson-Seffer, who, more than anyone else, had looked into the matter as an experienced student of rubber plants. In fact, Olsson-Seffer was preparing to take advantage of this knowledge when political disturbances in Mexico, and finally his own death in connection with one of these, put a stop to his plans. The plants which he considered as of greatest value are species of *Jatropha*, *Plumeria*, and *Euphorbia* which have, in addition to their qualities as rubber producers, the very desirable ability to reproduce from the base when the tops are removed, thus affording a perennial supply and avoiding the great expense of tapping by hand. The results of Olsson-Seffer's studies have not been published in detail, although some reference has been made to them by Dunstan (1910) in an article in which it is said that some species of *Plumeria* yield a latex averaging 14 to 16 per cent and sometimes with as much as 24 per cent of rubber, while the latex of *Euphorbia calyculata* yields 21 per cent of rubber of good quality.

A Mexican plant which has received some attention as a source of rubber is the palo amarillo (*Euphorbia fulva* Stapf, *E. elastica* Altamirano and Rose, not Jumelle). The best account of this species has been given by Rusby (1909), who states that it is a tree of the subtropical region, and especially of the hilly country, where the western edge of the Mexican table-land breaks down into the coastal slope, at an altitude mostly of 5,000 to 7,000 feet. It belongs principally to the States of Michoacan, Guanajuato, and Jalisco. The latex is obtained by tapping and that from the stems carries 7.3 to 15.7 per cent of caoutchouc. The rubber is about equal in value to that of guayule, but the amount collected has been so small that it has not entered into commerce to any appreciable extent. The chief interest in this plant lies in its possibilities if properly developed. It is very easily propagated by cuttings and full-sized trees are thus obtained in 5 to 7 years.

Other Mexican species mentioned by Dunstan (1910) as containing small amounts of rubber are *Jatropha urens*, *Pedilanthus tomentellus*, and *P. pringlei*.

Guayule (Parthenium argentatum).—The most extensive use thus far made of North American rubber plants has been that of guayule, a Mexican and Texan shrub that came into prominence about 1902. This plant was formerly very abundant in some parts of Mexico and the value of the exported product exceeded $10,000,000 in 1911. In recent years, however, the production has fallen off very markedly. As the native supply began to wane, attempts were made to bring the species under cultivation, at first with but little success because of difficulties encountered in the germination of the seed. It was also found that whereas the native shrub yielded an average of 10 per cent of guayule gum, or "rubber," the content of the cultivated plants fell in some cases to less than 2 per cent. After considerable experimentation a high rate of germination was finally obtained, and through the segregation and selection of superior strains the content of field-grown plants is said to have been increased to 18 per cent. In fact, a few strains carrying a considerably higher percentage have been developed, but it is understood that these have certain characteristics which render them unsuitable for commercial planting. Whether the 18 per cent just mentioned is for pure rubber or whether it includes a considerable amount of resin and other impurities, as in commercial guayule, is not known to the writers. It is now well established that the wild plants belong to a series of innumerable races, that these vary to a considerable extent, and that reproduction is parthenogenetic, at least in part. The method of improvement, therefore, has been to select the best strains as determined by analysis and cultural characters and to propagate from these plants without the introduction of cross-breeding. The rubber in guayule occurs as minute bodies in the cells, there being no latex as in *Hevea*, *Ficus*, and most other rubber plants. The planting of guayule on a large scale has been started in southern Arizona under the scientific direction of Maccallum, but the success of the industry is still a matter for the future to decide. The only extensive account of rubber as it occurs in guayule has been presented by Lloyd (1911). This author 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.

Chrysil and related rubbers.—Immediately upon the entrance of the United States into the great war in 1917, the State of California undertook a survey of the Great Basin and Pacific Coast areas for rubber-producing plants, the work being carried out under the direction of the State Council of Defense and the University of California. The results have been published by Hall and Goodspeed (1919). According to these authors, rubber of good quality has been found in 12 varieties of *Chrysothamnus nauseosus* or rabbit-brush, the best shrubs carrying as high as 6.5 per cent, while the average is about 2.5 per cent. These figures are for rubber obtained by the acetone-benzene method. In commercial extraction, such as is practiced for guayule, the amount would be increased because of the inclusion of anywhere from 10 to 25 per cent of resins and other impurities. The pure product was given the name of chrysil. A total of 300,000,000 pounds was estimated to be present in the native plants. Rubber was also found in various amounts in 4 other species of *Chrysothamnus* and in 10 species of the closely related genus, *Haplopappus*. Since the prime object was to locate an emergency supply of native rubber, the investigations were not extended to include cultural experiments, although some information is presented that could be used as a basis for such work and as a beginning in breeding and selection. Chrysil is not a latex rubber, but occurs as solid particles in the plant cells, much after the manner of guayule, as is indicated by detailed histological studies, the results of which are presented by these authors.

Colorado rubber plant.—In 1902 and 1903 considerable interest was manifested in a new rubber plant from Colorado and New Mexico, namely, the pinguay (*Hymenoxys floribunda utilis*) or Colorado rubber plant, as it soon came to be called. This was before the time of plantation rubber and when the crude product from the upper Amazon districts commanded high prices because of the rapidly increasing demand. Small mills were erected in southern Colorado and experiments were undertaken in the cultivation of the plant. It was soon learned, however, that profits could not be made by utilizing the wild plants, owing to their small size and scattered growth, and that the plants did not yield enough rubber to make their cultivation profitable. Very little has been published concerning this plant, but there is a note by T. D. A. Cockerell (1903) and another by W. P. Cockerell (1904). The latter states that the roots are said to contain 5 to 12 per cent of crude rubber, but apparently this includes a considerable proportion of impurities. Recent analyses have yielded only 3.6 per cent of pure rubber in the root and basal portions of the plant (p. 41). Hillier (1906) expresses the opinion that the product does not compare favorably with many of the lower grades of rubber already on the market.

Milkweeds (Asclepias spp.) and Indian hemp (Apocynum cannabinum).—The first recorded attempt to prepare rubber from any of the plants which grow north of the Mexican boundary was that of William Saunders (1875), who experimented with the common milkweed (*Asclepias syriaca* = *A. cornuti*). 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 allowing the coarse-ground material to ferment for several days, drying, then adding carbon bisulphide, he was able to obtain nearly 5 per cent of this substance, which evidently was a mixture of rubber and various other ingredients. No serious attempt was made to commercialize this discovery. A. T. Saunders (1910) reports the results of examinations made in 1900 of a milkweed the species of which is not given. Only a very small amount of rubber was prepared, but the physical properties are described as indicated later (p. 54).

Apparently the most extensive examination of the milkweeds hitherto made was that of Fox (1911), who carried on his experiments at Akron, Ohio. This worker obtained 2 to 3 per cent of rubber from *Asclepias 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 is so inferior, and its cost of production is so high, that a profitable industry is out of the question." A year later Fox (1912) reported more favorably concerning his work on *Apocynum cannabinum* or Indian hemp. The latex of this species was found to contain only 1.12 to 2.36 per cent of rubber, but the quality of the product was much superior to that obtained from *Asclepias*. Other characters of the rubber are given on p. 55) It is to the credit of this investigator that he carried his examination so far, although working with plants which gave such discouragingly low yields.

Widtsoe and Hirst, working at the Utah Agricultural College, made percentage determinations for several species and prepared a small amount of rubber for examination. The method consisted in extraction with benzene in a Soxhlet apparatus and precipitation with alcohol. The precipitate was in some cases treated with acetone to remove fats, etc. The best result was obtained with *Asclepias speciosa*, the leaves of which yielded about 2.25 per cent by this process. *A. incarnata* gave 3.15 per cent, but this includes at least a portion of the fats and resins. *Asclepiodora decumbens* yielded about 1 per cent, while no rubber was obtained from *Apocynum cannabinum* and *Lactuca scariola*. These results are here given from a manuscript report with the consent of the investigators.

Miscellaneous reports.—It is reported by Pearson (1916) that during the recent war the Germans, being unable to import freely, resorted to the manufacture of rubber from certain weeds, one of which, *Sonchus oleraceus*, or common sow-thistle, grows wild as an introduced species in the United States. Apparently the most important weed used was a sort of wild lettuce, or *Lactuca*.

No other accounts of studies on latex rubber in North American plants have been found in the literature, although it is possible that such exist. At any rate, the results did not indicate a commercial value nor did they lead to extensive experiments in the improvement of the plants. Not infrequently, however, erroneous reports of the discovery of new rubber plants find their way into the literature. These reports sometimes cause considerable trouble through the time consumed in establishing their falsity, and in some instances they have been used to lure investors into fraudulent commercial enterprises. The more persistent of these reports refer to the following plants:

Ocotillo (*Fouquieria splendens*), a tall shrub of the southwestern deserts, has been reported a number of times as a rubber plant and money invested in its utilization for this purpose. However, very careful chemical examination shows beyond doubt that no rubber is present. Analysis by the usual method as described later gives no return in the benzene extract. Furthermore, when the pulverized material is extracted with benzene, the residue after evaporation is entirely soluble in acetone, thus indicating again that no rubber is present. Ocotillo contains considerable amounts of waxes, resins, and similar substances, some of which are now being manufactured on a commercial scale, according to Pearson (1920).

Various species of cactus are stated to contain rubber, but no evidence of its presence has been found and the chemical nature of the plants does not encourage its expectation. *Opuntia vulgaris* was one of the species mentioned, with the statement that rubber was obtained from it in Arizona. This plant grows nowhere in the Southwest.

Claims also have been made for certain ocean kelps, especially *Macrocystis pyrifera*, as rubber plants, and companies formed in southern California to exploit them on this basis. A detailed chemical study of the organic constituents of kelps has been made by Hoagland (1915), who reports that carbohydrates or analogous bodies make up the principal portion of the organic matter and that these carbohydrates are complex colloidal substances which would ordinarily be classed among the vegetable gums or pectins. Thus the rubber present, even if it occurs at all, which seems extremely unlikely, would be so small in amount as to be negligible.

During the period of high rubber prices much effort was made to find plants similar to guayule, and many species of the Southwest and of Mexico were investigated in this connection. The one reported most frequently, presumably because of its superficial resemblance to guayule, together with its gummy and resinous nature, was the brittlebrush or incienso (*Encelia farinosa*). Repeated analyses of this plant prove conclusively that rubber is not present. A closer relative of guayule, namely, the mariola (*Parthenium incanum*), of Mexico, carries but a very meager amount of rubber, according to Lloyd (1911).

III. ACKNOWLEDGMENTS.

It is a pleasure to make grateful acknowledgment for assistance received from a number of people who have been sufficiently interested to gather and forward samples for analysis, and in some cases to supply information of considerable value. The list of those who have contributed in this manner includes the following: Professor E. B. Babcock, University of California; Mr. W. W. Eggleston, United States Department of Agriculture; Mr. C. L. Forsling, Jornada Reserve, Las Cruces, New Mexico; Mr. M. French Gilman, Banning, California; Mr. C. Hildreth, Lincoln, Nebraska; Mr. Ivan M. Johnston, University of California; Professor W. L. Jepson, University of California; Mr. C. F. Korstian, United States Forest Service; Mr. J. V. G. Loftfield, Tucson, Arizona; Dr. E. B. Payson, Missouri Botanical Garden; Mr. Albert J. Perkins, Santa Ana, California; Mrs. C. P. Powell, Berkeley, California; Mr. Carl Purdy, Ukiah, California; Miss Inez Sandusky, Wichita Falls, Kansas; Mr. E. E. Schellenger, Riverside, California; Dr. Forrest Shreve, Carnegie Institution of Washington; Miss Laurene Stevens, Lawrence, Kansas; Professor J. J. Thornber, University of Arizona; Miss H. A. Walker, University of California; Professor J. E. Weaver, University of Nebraska. Professor E. C. McCarty, of the Colorado Agricultural College, has generously made a number of chemical examinations and assisted in other ways, and Mr. H. R. Reed, of the United States Department of Agriculture, not only collected numerous samples of *Asclepias subulata*, but also carried on experiments with this plant while he was stationed at the experiment farm at Bard, California. The studies have been carried out under the authority of Dr. F. E. Clements, who has not only given his wholehearted support, but has also collected many of the plants here considered.

IV. METHODS EMPLOYED.

Collection and Preparation of Samples.

Most of the plants examined are perennial herbs. Samples of these were gathered by severing the stems near the base, or at about the level where a low-set mowing machine would cut them. The cut ends were immediately plunged into fine dust to aid in the coagulation of the latex and thus check the loss of rubber through bleeding of the stems. Pulling was commonly resorted to in the case of annuals, but the roots were discarded except in the few cases where the analysis of the root is specifically indicated. This rejection of the roots was practiced because of the almost total absence of rubber below the soil-line in latex plants and also because the roots would not be utilized in the preparation of rubber for commercial purposes.

A wooden drying-oven provided with screen-bottom trays was found convenient for purposes of desiccation, the heat being supplied from below. From 12 to 24 hours of such drying at 40° to 50° C. was found to be sufficient for most samples. High temperatures were avoided, because of their tendency to convert the caoutchouc into resins or other products of oxidation. The moisture still remaining, although slight, was determined in most cases by the usual methods, and the final analyses were computed upon the basis of absolutely dry material. The few exceptions are indicated in the tables.

The leaves and stems of most samples were separated after drying, since it was early found that they were not equally rich in rubber, and that separate analyses were therefore desirable. The removal of the leaves before drying would have resulted in the loss of latex through bleeding. Leaves and stems were then ground separately in coffee mills, until nearly all of the material would pass through a 30-mesh brass sieve, i. e., one with apertures 0.0195 inch in diameter. It was found desirable to include with the finely ground sample a very small amount ground to pass only a 20-mesh or 10-mesh sieve (i. e., with apertures of 0.0335 or of 0.0799 inch), since otherwise the sample would pack too tightly in the extractors and clog the entrance to the siphons.

Chemical Analysis.

The acetone-benzene method of extraction was used, the practice being essentially that described by Hall and Goodspeed (1919, p. 216) in their work on chrysil. The Bailey-Walker extraction apparatus was used, because of its simple construction, efficiency as an extractor, and the ease with which the parts could be cleaned. The usual method was modified through the introduction into the bottom of the extraction thimble of a thin layer of cotton, with two disks of filter paper above it. About 5 grams of the thoroughly mixed and ground plant material, taken from a weighing bottle with aid of a spatula, were then added. This filled the thimble for about two-thirds of the way to the top. A second thin layer of cotton was placed on top of the sample to prevent danger of an overflow of the material into the extraction flask. The extraction itself consists of two parts, as follows:

(*a*) Extraction with 10 c. c. of boiling acetone for 3 hours on a water-bath. This period was determined upon after it had been found by experiment that all of the acetone-extractable substances came over within the three-hour limit. The first portion of the extract siphoned over is usually bright green in color. This is due to the chlorophyll, which is very readily soluble in acetone. If the siphon is working properly the chlorophyll will soon be completely dissolved from the ground material and the acetone extract, as it passes through the siphon, will be perfectly clear. At the close of the three-hour period the thimble was removed from the flask with blunt forceps and the acetone evaporated in a water-jacketed drying-oven. The excess acetone in the flask was distilled and the residue dried for 4 hours in the oven, after which it was cooled in a desiccator and weighed. This residue is assumed to contain all of the chlorophyll, fats, resins, and similar substances. It is reported in the following tables, under the heading of "acetone extract." Since rubber itself is partially soluble in boiling acetone when fats are present, it is possible that small amounts are included in this extract, but since the parts of the plants examined presumably contain but small amounts of fats, it is believed that the error due to this is negligible.

(*b*) Extraction with 10 c. c. of boiling benzene for 3 hours, preferably on an electric plate. The material remaining in the thimble after the extraction with acetone as just described was thoroughly dried, the thimble with its contents was placed in a clean flask, and subjected to boiling benzene. At the close of the extraction the benzene was distilled off and the residue dried in a water-jacketed oven, cooled in a desiccator, and weighed. This residue was taken to be rubber and is so reported in the following tables, since all other compounds soluble in benzene had been previously removed by the acetone. In some cases, especially those in which the percentage of the benzene extract ran very low, the residue would have the consistency of thick sirup and lacked elasticity. It seems not unlikely that in some species which carry less than 1 per cent, as given in the tables, the material is not really rubber, but other substances that escaped extraction by acetone, perhaps mixed with more or less fat. On the other hand, when larger amounts of benzene extract were obtained, the material would possess elasticity, resilience, and other properties of crude commercial rubber. Whether or not the substance is in reality pure rubber depends somewhat upon the definition of that word, but since the methods of analysis used are those generally employed by rubber chemists, and in consideration of the physical properties of the product, there is every reason to believe that the percentage obtained in each case represents approximately the amount of crude rubber present, and it is so reported in the tables of analyses.

In regard to the accuracy of the results, it may be stated that, in view of the partial solubility of rubber in acetone when fats are present, and because of the difficulty in attaining perfection in the extraction from plant tissues, the reported percentages of rubber may be too low. It is to be noted, in comparing the results with those given by rubber chemists, that the latter often report the percentage of crude rubber extracted by some process that carries out with it a larger or smaller amount of impurities, these sometimes constituting as high as 30 per cent of the yield. Even by the method used in the present investigation, a varying amount of impurity doubtless finds its way through to the benzene extract, so that the result is not a pure hydrocarbon. However, the percentages reported are believed to approximate those obtained by commercial processes, and in any event they may be used for purposes of comparison between the species and forms.

Duplicate analyses were run of most samples, and when unusually high results were obtained they were checked by a larger series of examinations. The close agreement in the results obtained adds to the confidence in the method employed.

V. THE MOST IMPORTANT SPECIES.

Of the 64 species examined and found to contain rubber, there are 16 which seem sufficiently promising to warrant treatment in some detail. These have been selected because of their comparatively high rubber-content, this running from 1 to 8 per cent of the dry weight, at least for mature leaves. Whether or not this is sufficient to encourage experimental planting with a view to growing the rubber commercially is a matter concerning which the writers are not competent to judge. It is certain, however, that such percentages have not been approximated in any latex-bearing plant native to the United States that has been heretofore examined, and since this fact may render them of special interest to the rubber industry as well as to the botanist, the following descriptive accounts have been prepared.

The Genus Asclepias, or True Milkweeds.

Since most of the species here discussed belong to the genus *Asclepias*, a preliminary account of this group of plants will avoid repetition. 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, which spread, in most cases at least, by horizontal branches which give rise at intervals to vertical roots, these in turn dividing when they reach the surface of the soil 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 leafy stems. Vegetative propagation by portions of the horizontal roots is entirely feasible. The horizontal root-branches have been almost universally mistaken for rootstocks, but their true nature has been recently pointed out by Eggleston (in Marsh *et al.*, 1920). But in at least one species (*A. subulata*) there seems to be only a single taproot, without connection with other taproots, but this needs verification.

A few of the milkweeds have woody stems, but those here described die down to near the base each autumn or winter, new shoots appearing from the same root or stump at the beginning of the following growing-season, which usually follows the melting of the snows in the colder regions or the first rains in the warmer and arid southwestern districts. When the stems are injured new ones spring up to take their place. There can therefore be no doubt that if a crop is once taken off for any purpose it will be replaced by a new one, either in the same or in the following season. This has been experimentally demonstrated in the case of several of the species. Three "crops" of shoots of *Asclepias mexicana* have been harvested in one season. The stalks are erect in some species, spreading in others, and a few inches to 8 feet or more long, but they are always straight and with few or no branches. The bast fibers are long and stronger than in most native plants, for which reason they have been examined to some extent with a view to their utilization 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. In *A. subulata* this reduction is carried to so great an extent that for the greater part of the year the plant consists only of naked, rush-like stems. 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, technically called umbels, in the axils of the upper leaves and often at the apex of the stem. Their structure is exceedingly complicated as the result of adaptation to insect pollination. The principal pollinators are bees, wasps, ants, and flies of various species. It is quite certain that any species of milkweed would fail to set seed if grown where the particular insect necessary for its pollination is absent. The flowers, at least of some species, produce an abundance of nectar, and bee-keepers report an average production of 50 pounds of honey of good quality per colony of bees year after year from some species, especially *A. syriaca*.

The flowers are followed by pods, and each pod is filled with numerous seeds. The seeds bear tufts of soft, downy hairs at the apex, this down being especially noticeable as the pod opens, when the hairs may be from 1 to nearly 2 inches long. Natural propagation is chiefly by seeding. Germination tests of two collections of seed of *Asclepias mexicana* showed that 60 per cent were viable; one collection of *A. verticillata* gave 64 per cent, one of *A. sullivanti* gave 16 per cent, and in one collection of *A. syriaca* no germination was effected. The seeds are slow to germinate, and some difficulty has been experienced in getting field-sown seeds to grow at all. More favorable results are to be expected from seed gathered at time of full maturity. 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, as has been demonstrated by Hall and Yates (1915) and by Marsh *et al.* (1920). On the other hand, the young shoots and young pods, at least of *A. syriaca*, are cooked and eaten with impunity.

The genus is characterized by the presence of a milky sap or latex, which is carried in special vessels of the laticiferous tissue. As in the case of *Hevea, Ficus,* etc., the rubber is borne in the latex, but the plants are so small that extraction by a process of tapping, such as is practiced on those trees, is here out of the question. A more rational method of preparation would consist in cutting the plants near the ground, after which they would be passed between rollers and the rubber extracted by chemical or mechanical means with the aid of water. It is possible that, by using properly constructed machinery, the fiber as it comes from the mill could be processed and utilized in manufacturing low-grade fabrics, or if this is not feasible, the crushed residue would furnish material for the manufacture of paper-pulp.

Asclepias subulata (Desert Milkweed).

Description.—Plant a rounded perennial herb, woody at base in some types, 3 to 8 feet high, 2 to 6 or even 10 feet broad when growing in low places where water accumulates after rains, narrow and few-stemmed when on dry upland slopes (this upland form is more woody and may be a distinct race); roots deep, ending above in a much-branched crown; stems usually 12 to 30 in poor plants, but up to 500 or more in robust forms, straight, either simple or with a few straight branches, glabrous but with a gray bloom; leaves usually reduced to linear, very acute scales 3 inches or less long, but more developed in good seasons, and then often quite copious; flowers appearing after the rains regardless of season, dull greenish white, in rounded clusters which terminate erect or ascending branches of the inflorescence; pods from erect to pendent on curved stalks, fusiform, very slenderly tapering to the apex, 3.5 to 6 inches long, 0.5 to 0.75 inch thick, smooth and glabrous or only minutely puberulent.

References.—Torrey, Pacif. R. Rept., 5: 362, pl. 7, 1857. Gray, Syn. Fl., 2^1:96, 1878.

Distribution and ecology.—This is preeminently a desert species, although it ranges from southeastern California, western Arizona, and western Sonora across Lower California to the islands off the west coast. The northernmost known station is Searchlight, Nevada, while to the east it extends but slightly beyond Florence, in southwestern Arizona. To the south it grows at least as far as Cape San Lucas and Guaymas. At the latter place it is common and said to be known as yumete. The only known station in upper California, outside of the desert area, is Tecate Valley, near the Mexican border, southeast of San Diego. Even within the area as thus delimited, *A. subulata* 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 the infrequent rains. Occasionally the plants are found growing in better soil of depressions where the water remains for some time. Here they readily respond to the improved conditions and form large, bushy plants, with a greatly increased number of stems. For example, at Sentinel, Arizona, a few plants were found in such depressions which weighed from 12 to 16 pounds, and H. R. Reed has collected at Dome, Arizona, plants with over 500 stems and weighing 25 to 30 pounds. The largest plants thus far located were discovered by Dr. F. E. Clements at a point about 15 miles east of Mesa, Arizona. One of these measured 6 feet high, 7 feet broad, and had approximately 2,000 ultimate branches. It was estimated to weigh close to 100 pounds.

The difference just mentioned in regard to habit raises the question as to the possible presence of two distinct races or subspecies. There is some evidence to indicate that this is the case. The woody type, as one form may be called, grows mostly on the bench-lands and stony slopes, sometimes also in dry streamways. It is found as scattered individuals and withstands excessive drought, as shown, for example, by its presence near the very dry and well-drained summit of Picacho Peak, California, at an altitude of 1,945 feet. The plants of this form are almost shrubby, the lower portion of the stems being decidedly woody. The branches are comparatively few, commonly about 30 or 40 at midway from the ground, and are not widely spreading. Individuals as much as 8 feet high have been noted on Picacho Peak by Mr. Reed. Perhaps this form is to be identified as *A. albicans* Watson (Proc. Am. Acad. Sci. 24: 59, 1889).

The second form, which may be spoken of as the stooling type, has been found only in dry streamways, or in depressions, or on plains where apparently there is a little more moisture than at places where the woody type occurs. Yet even in these more favored spots the conditions are decidedly arid and the plants are fully exposed to desert conditions. These statements apply only to plants of Arizona and southern California, since the conditions under which they grow in Mexico are not well understood. The plants of this type are woody only at the very base, which branches or stools near the ground into a large number of erect or ascending reedy stems. A specimen is illustrated in plate 1. The number of stems varies from about 100 to 600 or more, and since they average fully as long as in the other type, the total weight of the plant is usually much greater. Small plants will weigh from 5 to 15 pounds; exceptionally large ones are estimated to weigh 50 to 100 pounds.

In comparing the two forms of *Asclepias subulata* as to their relative value for agricultural purposes, it is first noted that the stooling type will yield much the greater tonnage, that its growth is more rapid, and that it could be more easily harvested by mowing machines. On the other hand, the woody type is more drought-resistant and carries a lower percentage of moisture. The moisture-content of two woody plants, as determined by Mr. Reed, was 43 and 49 per cent, respectively, while one plant of the stooling type contained 60 per cent. The samples were taken 8 days apart and from different localities, which may account for the difference, but this ratio is about what one would expect from a casual examination of average stems and may be accepted for purposes of general comparison. Only two samples of the woody type have been analyzed. These carried less rubber than the average for the stooling type, but the results might be quite different if a large series could be examined. If the differences in size and habit as above noted are purely ecological, it may be assumed that only the stooling type would be obtained under cultivation, regardless of the source of the seeds. If, however, these types represent hereditary races, then the selection of seed becomes a matter of importance. In this latter case attempts should be made to hybridize the forms in order to obtain a progeny combining the best characters and with as high a rubber-content as possible. Judging from experience with other plant species, it is quite probable that the percentage of rubber can be considerably increased through hybridization and selection, and if each of the types already distinguished is itself composed of minor strains, as is likely to be the case, these should first be segregated in order to furnish material as a basis for the work. An increase in the rubber-content is one of the requirements necessary to bring such plants into the list of agricultural possibilities.

The desert habitat of *Asclepias subulata* indicates that it may be brought under cultivation more cheaply than other species. It certainly could be grown on land that is now considered worthless because of the lack of water and which could therefore be had at a minimum price. The low water requirement is evidenced by the growth made under desert conditions. The normal rainfall at Sentinel, Arizona, whence came many of the samples, is 4.2 inches; that at Yuma is 3.1 inches. The maximum temperature for 1919 at Sentinel was 120° F. and the minimum 22° F.

The better type of the desert milkweed grows in dry streamways and in slight depressions on the desert mesas, indicating the desirability of increasing the soil-moisture, either by slight irrigation or through cultivation and other practices of dry farming. A system of cross-furrowing or checking that would retard the run-off after rains, together with surface tillage, would doubtless increase the tonnage. Under such methods, and especially under irrigation, the plants would probably develop normal foliage, but what effect this, or, for that matter, the methods themselves, would have upon the total yield of rubber can be determined only by experiment.

It is highly desirable that cheap and effective methods of vegetative reproduction be found for perennial plants to be grown for their rubber. Since *Asclepias subulata* grows from a taproot and is apparently lacking in the horizontal, connecting root branches of most milkweeds, it seems to propagate itself in nature only by seeds. However, some recent and incomplete experiments made by Mr. H. R. Reed, while connected with the Experimental Farm of the United States Department of Agriculture at Bard, California, tend to show that vegetative reproduction can be practiced without great difficulty. This investigator worked entirely with the stooling type, and, in addition to making a number of successful transplants, also grew plants from portions of the crown removed for this purpose. The division was made in such a manner as to leave a few coarse, fibrous roots attached to the propagules, which were grown first in a pot and then in the open ground. The divisions were made January 19, 1921. By March 26 the young shoots were 4 inches high. During the same period the parent plant, which had been pruned back and transferred to the experiment station at Bard, California, along with the propagules, had sent up new shoots 6 inches long. Other portions of the same crown were started without irrigation by covering with 2 feet of sandy soil, but were lost when shallowly planted in the field. This was probably due to the extreme exposure to the hot sun before the new roots had become established.

In order to determine whether plants would send up new shoots if the tops were removed, Mr. Reed cut back some bushes on January 30, 1921. These were growing near Dome, Arizona. One of the plants, which had 96 stems when cut back, had sent up 260 new shoots by May 25 of the same year. At this time the new growth was 30 inches high and "absolutely full" of latex.

The above experiments indicate (1) that *Asclepias subulata* can be successfully transplanted; (2) that when plants are cut back a new "crop" of stems will be produced; and (3) the possibility of vegetative reproduction by division of the crowns.

Rubber-content.—It will be noted from table 1 that all of the analyses are of the 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 results show that the laticiferous tissue of the stem takes over the rubber-holding properties of the leaves of other species, just as it also assumes their photosynthetic activities. The green and glabrous nature of the stem is doubtless correlated with this modified rôle.

The tabulated analyses give evidence of a considerable fluctuation in the percentage of rubber present. The possible explanations of this include seasonal variation, the effect of different environments, the presence of genetic strains, and a lack of uniformity in the selection of the material to be analyzed. Only by detailed experiments can the actual causes be determined. It is noted, however, that almost uniformly low yields were obtained from the samples gathered at Dome, Arizona, on January 30, 1921. It is possible that the plants at this station are of a poor type, but the two collected on October 18, 1920 (Nos. 1121 and 1122), at the same place ran fairly high. The explanation is suggested that all plants are higher in rubber-content during the autumn than in the early spring. This seems not unlikely, since the stems dry up and become brittle during the winter months, thus rendering probable the decomposition of rubber at this time.

These dry stems are not unlike the woody base, which always carries less rubber than the green middle portions.

TABLE 1.—*Chemical analyses of Asclepias subulata.*[1]

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	p. ct.
892	Near Yuma, Ariz	Oct. ..	Stems	14.0	5.2
954	Sentinel, Ariz.[2]	Sept. 29	Stems	5.8	2.1
			Base	4.8	0.5
955	....do	...do....	Stems	7.3	2.6
956	....do	...do....	Stems	9.3	4.4
957	....do	...do....	Stems without bark	6.7	1.7
			Stem-bark	16.5	5.6
958	....do	...do....	Stems	8.8	3.5
971	....do	May ..	Young stems	9.9	0.8
			Old stems	10.1	2.5
997	Imperial Valley, Calif	May 5	Stems	14.1	3.3
1011	Sentinel, Ariz	Apr. 3	Young stems	9.8	1.8
			Old stems	10.2	2.5
1015	....do	Sept. 29	Young stems	14.6	6.5
			Woody base	4.7	1.3
1120	Tinajas Altas, Ariz.[3]	Mar. 19	Upper half	16.6	5.4
			Lower half	15.2	2.1
1121	Near Dome, Ariz.[4]	Oct. 18	8-inch tips	14.4	5.4
			Next 12 inches	14.8	2.5
			Lower part	9.4	1.9
			Base	8.6	0.8
1122	....do	Oct. 18	Entire stem	11.9	3.9
1123	Near Picacho, Calif	Dec. 5	Tops	....	2.5
			Middle	....	2.2
			Base	....	2.0
1125	Sentinel, Ariz	Sept. 29	Tips	18.5	3.9
			Next below	16.5	5.7
			Lower part	12.3	3.8
			Base	11.1	3.0
1126	....do	Sept. 29	Top	16.0	4.5
			Middle	....	2.8
			Base	10.4	1.3
1127	Yuma Mesa, Ariz	Jan. 19	Top	14.6	4.5
			Middle	16.9	6.4
			Base	14.1	4.3
B7	Near Dome, Ariz	Jan. 30	Top	16.4	3.9
			Middle	16.0	3.4
			Base	11.5	2.4
B8	....do	...do....	Upper half	16.7	2.3
			Lower half	13.5	1.2
B9	....do	...do....	Top	18.4	3.1
			Middle	16.2	2.5
			Base	15.4	1.9
B10	....do	...do....	Upper half	17.5	1.8
			Lower half	17.4	2.2
B11	....do	...do....	Top	18.6	2.5
			Middle	15.2	1.6
			Base	10.9	1.0

[1] In this and in all following tables the acetone extract includes the resins and other acetone-soluble substances, whereas the benzene extract is taken to represent the amount of crude rubber, although a negligible amount may have been extracted with the acetone (see p. 14). With few exceptions the percentages are based on absolutely dry weight of the plant parts analyzed.

[2] Growing in depression. [3] From granite slope. [4] Estimated weight, 27 pounds, green.

The several series of analyses of different parts of the same plant indicate conclusively that the percentage increases up the stem until the young tips are reached, when it again falls off in some cases. The continued increase, even to the uppermost sections, as reported under a few numbers, may be due to a different selection of the height at which the cuts were made. For a comparison between different plants it would be better to take equal portions of all parts above the woody base.

Asclepias sullivanti.

Description.—Plant a stout, strictly erect perennial herb, 2 to 5 feet high; roots connected by underground branches, which give rise to clumps of stems at irregular intervals, but 1 to 3 feet are common distances between the clumps; stems sometimes solitary, but usually 2 to 6 from the base, simple or with few branches, straight, very smooth and without hairs; leaves numerous to the top, 7 to 12 pairs on each stem, sometimes 3 or 4 in a whorl at some of the joints, oblong or somewhat ovate, 4 to 6 inches long, 1.5 to 3 inches wide, thick, smooth, not hairy; flowers purplish or flesh-colored, appearing from the middle of June to early September, many in a spherical stalked cluster (umbel) which terminates the stem, or the clusters sometimes also in the axils of the upper leaves; pods on curved stalks, erect, ovoid, 3 to 5 inches long, about 1 inch thick, not hairy, but usually with small blunt processes near the apex, maturing in late August and September.

References.—Gray, Syn. Fl., 2^1: 91, 1878. Britton and Brown, Ill. Fl., ed. 2: 27, fig 3390, 1913.

Distribution and ecology.—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 section where soil and moisture conditions are suitable, there are but few records of its occurrence in abundance. Professor T. J. Fitzpatrick, of the University of Nebraska, reports it as common on many of the bottom lands along streams in southern Iowa, and especially along the Chariton River opposite Centerville. Other localities where it may be obtained include Lincoln, Nebraska; Manhattan, Kansas; Baltimore and Ohio Railway near Kimball, Erie County, Ohio.

Asclepias sullivanti grows only on low land where the soil is moist. At the present time it seems to be most abundant along streams and lake-shores, where the land is overflowed at certain seasons, but this must not be taken as evidence that such conditions are essential to its growth. Possibly it was once much more common on better drained and drier soil, from which it has been crowded by agricultural practice. Its distribution indicates that it can endure very low temperatures in winter, at least as low as 30° F. below zero, and that a fairly high summer temperature and humidity are at least suitable and perhaps requisite to its best development.

Since this is a species of rich, moist bottom-lands, it is probably not suited to arid conditions. If this assumption is correct, *Asclepias sullivanti* would seem to hold but little promise of success as a cultivated plant, since, regardless of the amount of rubber it might yield, other crops could probably be grown at a greater profit. However, the adaptability of the species to other soils and the variation in rubber-content, which would undoubtedly accompany such a change of habitat, are matters which should be tested experimentally, for this is in other respects one of the most promising of all of the milkweeds thus far examined. The tall-growing erect habit of *A. sullivanti* is much in its

TABLE 2.—*Chemical analyses of Asclepias sullivanti.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
387	Lincoln, Nebr.	Aug. 9	Leaves	8.7	5.1
			Stems	6.2	0.4
817	Ellsworth, Kans.[1]	Sept. ..	Leaves	....	5.0
			Stems	....	8.2
886	Lincoln, Nebr.[2]	Aug. 2	Leaves	9.5	8.1
			Stems	6.0	0.2
1016	.....do	Aug. 28	Leaves	9.4	5.4
			Stems	6.3	0.5
1017	.....do.[3]	...do....	Leaves	8.5	3.0
			Stems	6.7	0.2
1018	.....do.[3]	do....	Leaves	8.5	1.2
			Stems	7.8	0.9
1019	.....do.[3]	...do....	Leaves	7.1	3.0
			Stems	7.0	0.9
1020	.....do.[4]	...do....	Leaves[4]	8.1	3.6
			Stems	4.7	0.4
1021	.....do.[4]	...do....	Leaves	7.7	4.0
			Stems	7.1	0.2
1022	.....do.[5]	Sept. 6	Leaves	7.3	4.1
			Stems	6.4	0.2
1023	.....do	...do....	Leaves[4]	10.6	2.7
			Stems	9.3	0.5
1024	.....do.[6]	...do....	Leaves	8.2	2.0
			Stems	1.2	0.3
1025	.....do.[5]	Sept. 14	Leaves	10.9	2.7
			Stems	6.4	0.4
1026	.....do.[7]	...do....	Leaves	9.9	3.6
			Stems	2.3	0.3
1027	.....do.[6]	...do....	Leaves	11.7	4.2
			Stems	6.1	0.2
1028	.....do.[5]	Sept. 22	Leaves	7.9	3.0
			Stems	4.3	0.2
1029	.....do.[7]	...do....	Leaves	10.0	4.2
			Stems	4.6	0.6
1030	.....do.[6]	...do....	Leaves	8.1	4.2
			Stems	1.9	0.1
1031	.....do	Sept. 12	Leaves[4]	7.9	2.3

[1] Plants injured by frost and leaves with more blackish patches.
[2] Verified by 6 duplicate analyses.
[3] Same locality as 1016.
[4] From 5 plants.
[5] Five plants from same spot as 1020.
[6] Five plants from same spot as 1021.
[7] Five plants from same spot as 1023.

favor, since this is conducive to ease of manipulation in harvesting. The robust stems, even of wild plants, are sometimes 0.75 inch thick, but they are not so firm as to render harvesting by machinery especially difficult. The height of the stems, well-clothed to the summit with leaves of fairly large size, indicate that the tonnage that could be grown per acre is probably greater than in any other species, but unless forms can be found in which the stems carry a larger percentage than the chemical analyses usually show, it will be necessary to use only the leaves, which constitute but 50 per cent of the total weight of the plant.

Rubber-content.—This milkweed has yielded the highest percentage of rubber of all the species thus far tested. The most remarkable records are those of plant No. 817, with 5.0 per cent in the leaves and 8.2 per cent in the stem; and No. 886, with 8.1 per cent in the leaves and only a trace in the stem. The high percentage in the stem of No. 817 is unique and needs verification through the examination of a larger series of plants. Yet the results seem trustworthy, since they were checked by a second analysis, and both analyses were carried out with the greatest care and in the same manner as the others. The average of the 19 lots of leaves analyzed is 3.7 per cent, and there is the unaccountable individual variation always encountered when a large series of plants is analyzed. The encouraging feature is the remarkably high percentage in a few cases, possibly indicating superior strains suitable as a beginning in breeding experiments.

Asclepias syriaca (Common Milkweed).

Synonym: *Asclepias cornuti.*

Description.—Plant a stout, erect perennial herb, 3 to 6 and sometimes 7 feet high; roots probably spreading by deep horizontal branches; stems usually several at a place, often very numerous and crowded so as to form thickets of large extent, simple up to the flower-clusters, straight, at first finely soft-hairy; leaves numerous to the top, usually 20 or more on each stem, opposite, lance-oblong or broadly elliptic, 5 to 8 inches long, 2 to 4 or rarely 6 inches wide, thick, pale, soon smooth and glabrous above, but minutely downy beneath; flowers dull purple to white, appearing from late June to September, many in stalked umbels from the upper leaf-axils; pods on deflexed stalks, erect, ovoid and acuminate, 3 to 5 inches long, 1 to 1.25 inches thick, gray with a dense wool-like tomentum, with small soft spine-like projections, maturing in late August and September.

References.—Gray, Syn. Fl., 2^1: 91, 1878 (as *A. cornuti*). Britton and Brown, Ill. Fl., ed. 2: 30, fig. 3398, 1913.

Distribution and ecology.—This is the most abundant milkweed in the eastern United States and Canada, where it grows from New Brunswick to North Carolina and west as far as Kansas and Saskatchewan. It is a species especially of fields and waste places, commonly coming in where the soil has been disturbed. Railroad rights-of-way are therefore often lined with it. The climate of southern Michigan is apparently well suited to the growth of the plants, since they are reported as very abundant in that region. Specific localities whence samples may be obtained include London, Ontario; Stevensville, Michigan; and Lincoln and Madison, Nebraska. The plant has been successfully grown near Akron, Ohio, where it was used experimentally in the preparation of rubber by Fox (1910).

Although *Asclepias syriaca* is usually reported as growing in waste places, there is no direct evidence available that it will grow on soils unsuited to any other crop. It will make a better growth than most agricultural plants on shallow soil and in worn-out pastures and will flourish in places so stony that cultivation is impossible. But since such conditions seldom prevail over large areas, the competition with other crops, such as beans and corn, will need to be taken into account. This species belongs to the more humid eastern climate and is probably quite unsuited to the arid districts of the West and Southwest. Its ability to grow and form large plants in the climate of New Brunswick and Saskatchewan indicates that it is the most hardy of the American milkweeds and one of the few to be considered for Canada or the States along the Canadian border. Other characteristics favorable to this species include its large size, robust habit, abundance of foliage, and especially its ability to spread rapidly by underground parts, thus coming to cover large areas with a solid stand of erect, leafy stems.

Rubber-content.—The first American milkweed to be tested for its rubber was *Asclepias syriaca*, and up to the time of the present study this was the species to receive the most attention (William Saunders, 1875; Fox, 1911). These earlier examinations demonstrated the presence of rubber, but in small amounts, this being due either to the chance gathering of poor strains or to harvesting at the wrong season or from plants grown under conditions unfavorable to the formation of rubber. The percentage content was not determined and expressed in a sufficiently definite manner to render comparison with the tables possible. The analyses here reported give further evidence of great variability in rubber-content between different plants. Whether this is due to hereditary qualities or to environmental causes is still a subject for experimentation. As a beginning on this problem an analysis was made of green leaves for comparison with fully matured and yellow leaves of plants growing in the same locality and under conditions that seemed to be identical. In each case leaves were taken from 5 plants, both lower and upper leaves being selected; these were dried, pulverized, and thoroughly mixed. In this manner it was hoped to reduce the error due to individual variation, although it is admitted that a much larger number would give more convincing data. The results as shown in table 3 under Nos. 1034 and 1035 indicate that mature leaves contain the highest percentage. This is in accordance with the analyses reported under Nos. 826 and 827, where younger and older leaves from individual plants are compared, and with what has been suggested from other species. No. 1036 seems, however, to be an exception, perhaps accounted for by the pathologic conditions of the foliage.

Another item of interest brought out in table 3 is the fact that large, robust plants, like No. 1032, may carry as high or higher percentages of rubber in their leaves as average or small ones. The practical application of this is self-evident. In common with the other species examined, excepting only *A. subulata,* the amount of rubber in the stems is almost negligible.

TABLE 3.—*Chemical analyses of Asclepias syriaca.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
826	Madison, Nebr.	Aug. 27	Leaves[1]	....	1.4
			Leaves[2]	....	2.4
			Stems[3]	....	0.3
			Stems[4]	....	0.21
827	.....do	...do....	Leaves[1]	....	0.53
			Leaves[2]	....	1.10
			Stems[4]	....	0.27
895	Near Humphrey, Nebr.[5]	Sept. 25	Leaves	8.8	4.2
			Stems	11.6	0.2
898	Enola, Nebr.	Sept. 24	Stems	6.5	0.4
			Leaves	9.8	2.1
1032	Lincoln, Nebr.[6]	Oct. 20	Leaves	10.6	4.1
			Stems	5.5	0.3
1034	.....do	...do....	Leaves[7]	10.2	3.6
			Stems	6.4	0.3
1035	.....do	...do....	Leaves[8]	11.8	4.4
			Stems	4.4	0.4
1036	.....do	...do....	Leaves[9]	8.6	3.3
			Stems	5.7	0.5

[1] Young.
[2] Old leaves from lower down.
[3] Upper portion.
[4] Lower portion.
[5] Between Humphrey and Madison.
[6] Very large plant; leaves just turning yellow.
[7] Dried while green; mixture from 5 plants.
[8] Dried when yellow; mixture from 5 plants.
[9] Dried when yellowing; mixture from 5 plants, partly mildewed.

ASCLEPIAS CALIFORNICA.

Synonym: *Gomphocarpus tomentosus.*

Description.—Plant a rounded perennial herb, 2 to 3 feet high and about as broad; roots exceptionally large, branching near the surface of the soil to form a broad crown; stems usually 4 to 10, unbranched, straight, not erect, but spreading or ascending, closely covered with matted hairs like wool; leaves 4 to 8 pairs on each stem, ovate or oblong, acuminate, 2.5 to 5 inches long, 1.5 to 3 inches wide, covered like the stems with matted white hairs which are somewhat deciduous as the leaves mature; flowers appearing from March to early July, greenish or dull purplish, in rounded clusters (umbels), the clusters pendent from the axils of the upper leaves and ends of the stems, differing from all of the other milkweeds here described in having neither horn nor crest to the hoods; pods on bent stalks, pendent or erect, elongated ovoid, about 4 inches long, white with a dense wool-like tomentum, maturing from late July into the autumn.

References.—Torrey, Bot. Mex. Bound., 160, pl. 44, 1859 (as *Acerates tomentosa*). Gray, Syn. Fl., 2^1: 100, 1878 (as *Gomphocarpus tomentosus*). Hall, Bot. Gaz., 31: 389, 1901.

Distribution and ecology.—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. It grows scatteringly on the inner Coast Ranges, where it reaches its northern limit on Mount Diablo, and is common only in southern California. The largest quantities have been found on the foothill slopes along Lytle Creek and Cajon Pass; on sandy washes and slopes from Corona to Elsinore and Temecula; and again on the foothills of San Gorgonio Pass north of Banning. It grows also on the desert area, as, for example, near Victorville, but it does not range far from the surrounding mountains. Although an abundance of material for experimental purposes may be obtained from these localities, the species is nowhere truly abundant; that is, it does not form pure stands over large areas.

The ecologic requirements of *Asclepias californica* include a rather 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 total annual precipitation at some of the stations mentioned above does not exceed 16 inches, most of this coming from January to April. The temperature falls to about 20° F. in winter and rises to about 110° F. in summer. The plants are usually surrounded by a sparse growth of grasses and other herbs; but these are not sufficiently high to yield shade. Sometimes the milkweeds are partially shaded by shrubs, but the species grows only along the edges of the chaparral formation and does not creep up under the shrubs for protection.

Judging from conditions under which the plants grow wild, it would seem that *Asclepias californica* could be brought under cultivation on exceedingly poor land. A light, well-drained soil should be selected and a location where winter temperatures do not fall much below 20°. High summer temperatures are quite certainly desirable, since the best development both of the species and of individuals is found on the hot foothill slopes of southern California, whereas in the Coast Ranges farther north the plants are more scattered and less well developed. Irrigation would not be essential, although in some districts it might be practiced during the winter or spring in order to stimulate growth. On the other hand, an excess of moisture and low heavy soil, as well as alkali, should probably be avoided.

A feature of this species which might militate against its use is its lack of an erect growing-habit. Since the stems spread more or less from the base, each plant requires considerable space and perhaps would be somewhat difficult to catch with ordinary mowing machinery. However, the stems never lodge or lie directly on the ground, and it is probable that they would approach a vertical position if grown closely together. The abundant woolly hairiness of the stems and leaves should also be taken into account, since this might interfere with the use of certain types of machinery used in preparing the plants for extraction.

TABLE 4.—*Chemical analyses of Asclepias californica.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
350	Banning, Calif.	Aug. 25	Leaves[1]	6.9	4.1
			Leaves[1]	8.0	3.99
			Leaves[2]	8.0	3.77
			Stems	9.7	0.75
			Water-free latex	58.0	10.0
360	Mount Diablo, Calif.	Oct. 13	Leaves[3]	....	2.6
919	San Benito Co., Calif.	June 1	Leaves[4]	7.0	0.9
			Stems	7.1	0.7
992	Banning, Calif.	May ..	Leaves[5]	6.8	1.2

[1] Good condition. [2] Partly molded. [3] Old and drying. [4] Very old.
[5] Young; product granular, not rubber-like.

Rubber-content.—The results of the chemical examination of three collections of this milkweed exhibit a wide range of variation. This may be due to the inclusion of several strains in this one species, but it may also be explained on other grounds. It is noted, e. g., that the leaves of No. 919 were very old and dry, that those of No. 360 were also past maturity, although not yet hardened, while those of No. 350, which gave the highest yield, were about at the stage of full maturity.

The analysis of the dried latex is interesting, since it is one of the few analyses made of this substance as it occurs in *Asclepias*. The results are considerably higher than those given by Fox (1911) for *Asclepias syriaca*, and also higher than those found in tropical latex plants, such as *Hevea brasiliensis*.

Asclepias latifolia (Broad-leaf Milkweed).

Synonym: *Asclepias jamesi.*

Description.—Plant a stout, very leafy perennial herb, usually 1 to 2 but sometimes 3 feet high; roots coarse and woody; stems several, sometimes much crowded and forming bush-like plants, unbranched, either erect or spreading, not hairy; leaves ample, commonly 12 to 20 but often 30 on each stem, oval to orbicular, somewhat heart-shaped at base, 4 to 6 inches long and nearly as wide, very thick, minutely hairy when young but soon becoming smooth and green; flowers greenish, appearing from June to August, borne in dense, short-stalked clusters from the axils of the upper leaves; pods erect on curved stalks, ovoid, 2 to 3 inches long, about 1 inch thick, maturing in September and October.

References.—Gray, Syn. Fl., 2[1]: 92, 1878 (as *A. jamesi*). Britton and Brown, Ill. Fl.' ed. 2, 27: fig. 3391, 1913.

Distribution and ecology.—The broad-leaf milkweed is an inhabitant of the plains and lower foothills from Nebraska and Colorado south and west to Kansas, Texas, and northwestern Arizona. It belongs to the piñon-juniper association and always grows, so far as we have been able to observe, in small, widely separated clumps, these occupying several square feet and with stems probably all from one root. Along the eastern base 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. Specific localities include hills south of Hays, Kansas; Ashfork and near Williams, Arizona; and the following, all in Colorado: Canyon City, low hills north of Walsenberg, and south slopes above the Purgatoire River just west of Trinidad. Records of rainfall and temperature at all of these stations are not at hand, but at Trinidad, which may be taken as representing the slopes along the easterly base of the Colorado Rockies, where the species is abundant, the normal annual precipitation is 17 inches, the lowest recorded temperature is −26° F., and the highest recorded temperature 101° F. At Pueblo, in the same general district, the temperatures are about the same, but the normal precipitation is slightly under 12 inches.

In this species we have a form which is not exacting in its requirements. To all appearances it has been driven to the habitats just described because of competition with other plants where the soil and moisture conditions are more favorable. If this has been the case, then if brought under cultivation on good soils and competition removed through proper tillage the plants would doubtless respond with a greatly increased vigor and growth. While this would increase the tonnage, the percentage of rubber in the plant might also be affected and perhaps disastrously. Only by experiment can this point be positively determined. Aside from experimenting with this species on good soils, it should be tried also on sandy or stony slopes, since such lands would be less expensive and the natural habitat indicates that growth can be made under such conditions. As in the case of *Asclepias californica*, the tendency of the plants to spread out close to the ground may interfere somewhat with mowing, although close planting might correct this tendency. Field observations indicate that there is considerable variation in the habit, the stems in some localities tending to spread, in others to assume a strictly upright position. The best-formed plants seen during the present study were found south of Pueblo, Colorado. Here each individual formed a dense leafy clump 3 feet high and about 4 feet across. The exceptionally large size of the roots of this species augurs well for its ability to send up new shoots after a crop has been gathered.

Rubber-content.—In considering table 5, Nos. 342 and 914 may be ignored, since the former includes very old leaves and the latter only stems. This leaves 2 to 3.8 per cent for the rubber-content as far as known. A study of the weight of the foliage and of probable yield of rubber per acre has been made on the basis of material gathered at Ashfork, Arizona, under Nos. 928 and 953, as follows: average number of leaves per stem, 24; average dry weight of single leaves, 0.037 ounce; average number of stems per square foot, 4; computed weight of dry leaves per acre, 9,392 pounds. On the basis of a 3 per cent analysis this would yield 281 pounds of rubber per acre. It is evident that a yield so low as this would not justify one in growing this plant for rubber even on cheap land, and that other species, notably *Asclepias subulata*, are much more promising as rubber producers, based upon our present knowledge. The figures indicate, however, only the yield from the unimproved form. Attempts to increase the yield should aim at the development of a more erect and taller grower, as well as of a strain with increased rubber-content.

TABLE 5.—*Chemical analyses of Asclepias latifolia.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
824	Hays, Kans	Sept. ..	Stems	....	0.64
928	Ashfork, Ariz	Aug. 22	Leaves	7.1	2.5
			Stems	8.3	0.63
342	Near Walsenberg, Colo	Aug. 16	Leaves[1]	8.0	3.7
			Leaves[2]	9.0	1.0
800	Near Dodge City, Kans	Sept. ..	Leaves	7.0	3.8
			Stems	7.0	0.7
880	Royal Gorge, Colo	Aug. 30	Leaves	8.0	2.0
			Stems	10.1	0.7
913	Magdalena, N. Mex	Oct. 13	Leaves	7.4	3.3
914	.....do	...do....	Stems	11.0	0.5
953	Ashfork, Ariz	Sept. 28	Leaves	8.1	2.1
			Stems	8.5	0.7

[1] Medium material. Leaves of this number from several plants. [2] Very old.

Asclepias mexicana.

Description.—A perennial erect herb, woody at the base, 2 to 4 feet or in moist situations to over 6 feet high, usually narrow and slender-stemmed, but up to 8 feet in diameter in vigorous forms, especially in alkaline soil, sometimes spreading by the growth of the roots to form beds 15 feet or more across; roots connected by deep-seated underground horizontal branches; stems usually few at a place, but under favorable conditions as many as 80 to 100 are crowded into a single clump, straight, erect, mostly unbranched, green and glabrous; leaves 40 to 80 on each stem, arranged in whorls of 3 or 6 each, linear, tapering to the apex, 2.5 to 6 inches long, 0.25 to 0.5 inch wide, green and glabrous like the stems; flowers appearing in summer, dull white, smaller than in most other species, in small rounded clusters on erect peduncles from axils of upper leaves; pods on curved or straight stalks, narrowly ovoid, tapering to apex, 2.5 to 3.5 inches long, about 0.5 inch thick, minutely pubescent, the seeds ripening from late July to October.

References.—Cavanilles, Icon., 1: 42, pl. 58, 1791. Gray, Syn. Fl., 2^1: 96, 1878. Hall and Yates, Calif. Agr. Exp. Sta. Bull. 249, fig. 5, 1915.

Distribution and ecology.—The range of this species extends 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 plenty of vigorous plants are also to be found in the more elevated valleys of western Nevada, such as those of the Carson and Truckee Rivers. The largest plants are always found in moderately alkaline soil and are often associated with such halophytes as *Sporobolus airoides* and *Distichlis spicata.* These facts suggest that the proper place for the cultivation of the plant on a large scale would be the vast expanses of territory in the San Joaquin Valley of California and the valleys of western Nevada which are now uncultivated either because of alkaline conditions or the lack of water for irrigation.

An ecologic 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 percentage content of rubber (see p. 52). Even a third crop seems not impossible if the roots receive a reasonable amount of moisture. In the single instance where this was attempted the locality and the season were so unfavorable that only a sparse growth resulted. The experiment should be repeated in one of the moist, alkaline valleys where the plants exhibit their maximum vigor. It must be remembered, however, that excessive cropping might so weaken the roots as to diminish the growth of the year following.

Rubber-content.—The chemical analyses of *Asclepias mexicana* indicate that there is a wide range of variation in rubber-content between the different samples tested, with the highest one yielding 4.8 per cent from the leaves. It seems impossible to correlate this variation either with geographic distribution or ecologic conditions. The inference, therefore, is that the species comprises a considerable number of genetic strains, that further exploration may discover better ones than any thus far found, and that breeding experiments with so large a number to select from might yield surprising results. On the other hand, the foliage is more sparse than in most other milkweeds and constitutes only a minor portion of the total weight of the plant. A form in which the stems as well as the leaves would carry a high rubber-content is therefore desirable. The possibility of producing such a strain is indicated by sample No. 918, from alkaline soil of the San Joaquin Valley, in which the stems yielded 2.3 per cent at the same time that the leaves carried 4.4 per cent. If it is found that these figures can be increased by scientific breeding and the plants grown on alkaline soil to the size and density of that shown on plate 3, *Asclepias mexicana* will take its place as one of the most promising species.

TABLE 6.—*Chemical analyses of Asclepias mexicana.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
356	Carson Valley, Nev.	Sept. 23	Leaves	....	2.6
			Stems	....	0.75
358	Antioch, Calif.	Oct. 12	Leaves	....	2.7
359	Walnut Creek, Calif.	Oct. 13	Leaves	....	4.8
			Stems	....	0.68
905	The Dalles, Ore.	Sept. 25	Leaves	8.9	1.4
			Stems	6.6	0.5
909	Woodland, Calif.	Oct. 5	Leaves	10.0	1.8
			Stems	8.7	0.6
910	Mount Diablo, Calif.[1]	Oct. 11	Leaves	10.3	3.2
			Stems	6.6	0.6
911	do.[1]	do.	Leaves	11.0	4.1
			Stems	7.1	0.84
912	do.[1]	do.	Leaves	12.3	2.8
			Stems	8.3	0.63
916	Tehachepi, Calif.[1]	Oct. 22	Leaves	12.5	4.0
			Stems	6.4	0.5
918	Bakersfield, Calif.[2]	Oct. 23	Leaves	11.0	4.4
			Stems	12.9	2.3
923	Solano Co., Calif.[3]	Nov. 13	Leaves	8.9	4.1
924	Mount Diablo, Calif.[4]	Nov. 14	Leaves	11.1	3.5
941	do.[5]	July 9	Leaves	8.2	3.7
			Stems	10.9	1.0
			Whole[6]	....	2.1
942	do.	do.	Leaves[7]	14.0	2.2
			Stems	11.5	0.7
1037	do.[8]	Oct. 12	Leaves	11.1	4.6
			Stems	5.5	0.8
			Whole[6]	....	2.4
1038	do.[9]	do.	Whole	9.0	1.5

[1] Single plant.
[2] Soils trongly alkaline.
[3] Second growth; mixture of leaves from 80 plants.
[4] Mixture of leaves of 40 plants.
[5] Second growth.
[6] Computed.
[7] Second growth; mixture from 40 plants.
[8] Second growth from areas adjacent to 941 and 1038.
[9] Third growth from same roots as 941.

Asclepias galioides (Whorled Milkweed).

Description.—An erect perennial herb, sometimes slightly woody at the base, 1 to 3 feet high; roots erect and much branched just below the surface, but these crowns connected below by horizontal root-branches; stems few to numerous at a place, straight, unbranched, green, and glabrous; leaves 20 to 60 on each stem, in whorls of 3 or 6 each or some of the lower only in pairs, linear, tapering to the apex, 2 to 4 inches long, about 0.8 inch wide, green and smooth on both sides; flowers appearing from June to August, dull white, small, in small stalked umbels from the axils of the upper leaves; pods strictly erect, on straight stalks, fusiform, much narrowed above, 3 to 4 inches long, scarcely 0.5 inch thick, glabrous and smooth, the seeds ripening in August and September.

References.—Britton and Brown, Ill., Fl., ed. 2: 32, fig. 3405, 1913. Marsh *et al.*, U. S Dept. Agr. Bull. 800, pls. 1 to 3, 1920.

Distribution and ecology.—This is a species of the southern Rocky Mountain region, from middle Utah and middle Colorado (Glenwood Springs and valley of the Arkansas), south into Mexico and Central America. It seems to be most abundant in Arizona and New Mexico. Specific localities where it may be obtained in abundance include El Paso in Texas and Flagstaff and Holbrook in Arizona. The natural habitat of this plant is on the dry plains and foothills, often in sandy soil. It is abundant on 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, and then makes a rank growth, spreading rapidly over large areas. The downy seeds are carried both by wind and by irrigation-water, while in cultivated fields the horizontal roots are broken up and distributed, each piece giving rise to a new plant. When this milkweed gets a start in neglected orchards it sometimes forms a solid growth between the trees. Its poisonous nature has been described by Marsh *et al.* (1920).

Asclepias galioides has been much confused with a more easterly species, namely, *A. verticillata*, a species which is sharply set off by the whorls of numerous fibrous adventitious roots from the lower nodes of the stem and by other characters, as recently emphasized by Eggleston (in Marsh *et al.*, 1920). It is, in reality, much more closely related to *A. mexicana*, from which it is scarcely distinguishable, except by its usually narrower leaves. Also in the matter of its rubber-content and in its ecologic requirements, *A. galioides* closely resembles *A. mexicana*, and it is not unlikely that it should be treated as a geographic variety of this more westerly species.

Rubber-content.—The small number of analyses made of this species does not warrant the drawing of definite conclusions as to the amount of rubber present. The somewhat high yield of 5.2 per cent in the leaves of one collection seems to justify the hope, however, that further examinations would show that it would average at least as high as in *A. mexicana*. These two species are so closely similar in their botanical characters that the extent of variation found in *mexicana* may be reasonably predicted for *galioides*. A cross between the two, using the individuals with the highest rubber-content in each case, might bring results of interest.

TABLE 7.—*Chemical analyses of Asclepias galioides.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
338	Purgatoire River, N. M. .	Aug. 15	Leaves................	10.7	0.62
842	Las Cruces, N. M........	Sept. ..	Leaves................	....	5.2
			Stems.................	....	0.85
879	Canyon City, Colo.......	Aug. 30	Whole.................	6.0	1.5

ASCLEPIAS BRACHYSTEPHANA.

Description.—Plant a comparatively slender leafy herb, 1 to 2 feet high; roots thick and woody, producing clusters of stems, the clusters perhaps connected by deep horizontal cross-roots; stems usually branched near the base, but otherwise mostly simple and straight, erect, very smooth, and without hairs; leaves numerous to the top, commonly 15 to 30 on each shoot, all opposite, narrowly lanceolate, 2 to 5 inches long, 0.25 to 0.5 inch wide, rather thin, smooth, veiny, not hairy; flowers pink or dull purple, small, appearing from April to August, or even September after summer rains, in small, short-stalked clusters among the upper leaves; pods on sharply deflected stalks, erect, narrowly ovoid, long-pointed, 1.5 to 3 inches long, about 0.75 inch thick when mature, covered when young with a fine gray scurfy tomentum, but smooth and nearly glabrous in age, maturing from middle July to October.

References.—Gray, Syn. Fl., 2^1: 94, 1878. Britton and Brown, Ill. Fl., ed. 2: 31, fig. 3402, 1913.

Distribution and ecology.—This species is most abundant in New Mexico, but ranges west almost throughout Arizona, where it is much less common, and southeast into western Texas. It occurs also in northern Mexico. Specific localities include the forestry experiment station and the Turney pasture, both near Las Cruces, New Mexico. The plants have rather well developed xerophytic characters and grow on dry mesas and foothill slopes. They are especially common on 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. Seemingly the only possibility of this species taking important rank will depend upon the development of larger plants under cultivation and the maintenance of the unique quality of carrying as much rubber in the stems as in the leaves, as will be indicated below.

Rubber-content.—It will be noted from table 8 that all of the plants analyzed came from one general locality. Little can be said, therefore, regarding the rubber-content of the species as a whole. The most remarkable feature of the results here tabulated is the almost equivalent percentages of rubber in stems and leaves in 3 out of the 4 samples. Even in the fourth the difference is not so great as is found in other species. It must be added, however, that the analyses given under "whole" are not of the same individual plants as those reported under "leaves" for the same number. In the first two numbers the leaves and stems are from the same plants in each case. The word "whole" as used in the table is somewhat misleading, since the roots were not included in any case. It should therefore be taken to mean stems and leaves as ground up and analyzed together. The results of Nos. 884 and 885 indicate that mature plants contain a higher percentage of rubber than immature ones. This is in accordance with the findings for other species.

TABLE 8.—*Chemical analyses of Asclepias brachystephana.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
801	Las Cruces, N. Mex.[1]	Sept.	Leaves	9.0	2.7
			Stems[2]	7.0	2.9
823	.....do.[3]	...do.	Leaves	...	2.4
			Stems[2]	...	1.7
884	.....do.[4]	Aug. 31	Leaves	8.0	2.1
			Whole[5]	7.8	2.1
885	.....do.[6]	...do.	Leaves	8.0	2.9
			Whole[5]	8.0	3.0

[1] Growing in pastures. [2] Same plant. [3] Growing in yards. [4] Plants in blossom.
[5] Other plants. [6] Plants in fruit.

ASCLEPIAS SPECIOSA (SHOWY MILKWEED).

Description.—Plant a robust, erect perennial herb, 4 to 6 feet high; roots connected by deep horizontal branches, the vertical roots branched near the surface to form a crown; stems several to numerous from the crown, sometimes forming clumps 5 feet or more in diameter, simple, straight, covered with a fine down which is deciduous, leaving the old bark smooth; leaves numerous to the top, 10 to 20 or perhaps more to each stem, either all in pairs or some of the upper ones in whorls of 3, broadly lanceolate or oblong-ovate, 4 to 6 inches long, 2 to 3 inches wide, thick, finely gray-tomentose on both sides, or greener and nearly smooth above; flowers flesh-color, large, and showy, appearing from June to August, in stout-stalked umbels from the upper leaf-axils and terminal; pods on deflexed stalks, either erect or pendent, with an ovoid base but prolonged into a stout beak, 3.5 to 4 inches long, 1 to 1.25 inches thick, covered with a gray felt-like tomentum, through which project numerous short, soft processes, maturing in August and September.

References.—Curtis, Bot. Mag., pl. 4413, 1848. Gray, Syn. Fl., 2[1]: 91, 1878. Britton and Brown, Ill. Fl., ed. 2: 30, fig. 3399, 1913.

Distribution and ecology.—This is the most widely distributed of all of the milkweeds of western North America. It ranges from Alberta and Minnesota to Iowa, Texas, Arizona, California, and British Columbia. The vertical distribution is also remarkable, since it grows from the hot, low, interior valleys, as at St. George, Utah, and Caliente, southern Nevada, to the moderately cool mountain meadows in the lower part of the pine belt (Transition Zone), 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.

It is readily seen from the facts of distribution and habitat that the showy milkweed is a species which could be grown under a wider range of temperature conditions than any other. It is also to be noted, on the other hand, that it is very exacting in its moisture requirements and that probably it could not be grown to perfection, except in moist and fairly good soil. Sandy soil would doubtless be satisfactory if kept moist and free from excessive alkali. These conditions, together with the usually small percentage of rubber carried by the plant, do not indicate this as a promising species for further trial.

Rubber-content.—The earlier analyses by Widtsoe and Hirst have been already referred to (p. 10). The discouragingly low yields obtained by these workers are practically duplicated by most of the analyses reported upon in table 9. The amount of rubber in the leaves reached as high as 3 per cent in only 2 samples out of the 7 examined. It is possible that the analysis of a large series from widely separated localities will disclose some high-percentage plants, but *Asclepias speciosa* does not hold out as much promise in this respect as some other species of similar habit.

TABLE 9.—*Chemical analyses of Asclepias speciosa.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
304	Manitou, Colo.	July 18	Leaves	13.9	0.99
			Stems	8.4	0.14
			Roots	9.9	0.41
365	Vaca Valley, Calif.	Oct. 27	Leaves	....	3.0
370	Near Manitou, Colo.[1]	July 14	Leaves	7.8	1.6
			Stems	6.6	2.6
371	Colorado Springs, Colo.[2]	...do....	Leaves	5.9	1.4
			Stems	7.1	0.19
388	Fort Scott, Kans.	Aug. 9	Leaves	7.5	2.1
399	Ute Pass, Colo.	Aug. 20	Leaves	8.7	2.6
			Stems	7.1	0.7
889	Wichita, Kans.	Sept. 2	Leaves	7.0	3.0
			Stems	6.0	0.47
991	Colorado Springs, Colo.	....	Latex	67.5	2.1

[1] A broad-leaf form. [2] A narrow-leaf form.

APOCYNUM CANNABINUM (INDIAN HEMP) AND A. ANDROSÆMIFOLIUM (SPREADING DOGBANE).

Description (of *A. cannabinum*).—Plant an erect perennial herb, 3 to 6 feet high; roots connected by horizontal creeping rootstocks, a single plant thus coming to occupy areas several feet across under favorable conditions; stems several at a place or solitary, straight, smooth, and usually without hairs, the bast yielding a fiber of fair quality (p. 57); leaves numerous, except on the lower part of old stems, opposite, short-petioled, elliptic, acute, 1.5 to 4 inches long, 0.5 to 1.5 inches wide, smooth, glabrous or puberulent in some varieties, veiny; flowers pinkish, appearing in June, July, and August, small, in terminal and lateral stalked cymose clusters, yielding a moderate amount of nectar to honeybees; pods pendent, 2 on each recurved stalk, terete, 5 to 7 inches long, about 0.12 inch thick, smooth and without hairs, maturing from July to September, the earlier ones often well formed before the last flowers have fallen. (Family Apocynaceæ.)

References.—Gray, Syn. Fl., 2^1: 83, 1878. Dodge, U. S. Dept. Agr. Fiber Investig. Rept. 6: 46, pl. 5, 1894. Dodge, *ibid.*, 9: 62, fig. 20, 1897. Britton and Brown, Ill. Fl., ed. 2: 22, figs. 3378–3381, 1913.

Distribution and ecology.—The Indian hemp is a common plant throughout the United States and southern Canada. In altitudinal range it extends from the warm plains of Florida and the valleys of southern California to at least 6,000 feet in the western mountains, but it is not known with certainty above the lower part of the yellow-pine belt. It grows best in gravelly or sandy soil, sometimes where but few other plants can grow, but it requires a fair amount of soil-moisture.

The cultivation of Indian hemp would not be a difficult matter, since it propagates abundantly, both by seeds, which are provided with tufts of long, silky down and are therefore carried considerable distances by wind and water, and also by creeping rootstocks. When these rootstocks are divided, as in plowing, each piece gives rise to a new plant. The proper place for experimental plantings would be in moist sandy soil unsuited to agricultural crops. The other species of *Apocynum* here considered, that is, *A. androsæmifolium*, is a usually smaller plant with more spreading branches and grows in drier soils. Nothing has been thus far discovered that brings it into the list of promising plants for rubber culture.

Rubber-content.—The Indian hemp is considered as one of the most promising plants for further investigation. It is true that most of the analyses indicate only small percentages of rubber, but the high yield of No. 1039, together with the ease of vegetative propagation in poor, sandy soils and the high quality of the product greatly modifies our opinion of its possibilities. It is not unlikely that further search will discover still better plants, and any strain which may be developed through breeding can be perpetuated through the use of rootstocks. The foliage is too sparse and thin to yield much tonnage, but this is somewhat compensated by the large size to which the plants grow and the density of the stand under favorable conditions.

The first studies of the latex of *Apocynum* were by Fox (1912). He worked especially with *A. androsæmifolium*, but this and the larger *A. cannabinum*, or true Indian hemp, are so much alike in other respects that the latex and rubber of the two are doubtless quite similar. According to this investigator, the latex is coagulated neither by acids nor by alkalies, but it coagulates slowly and slightly on boiling, and immediately and completely by the addition of acetone in the proportion of 1 : 10 by volume. He reports further that formaldehyde coagulates it readily but much more slowly than acetone, and that the latex is coagulated by phenol, this giving a soft product. Fox also tried a salt solution and found that this coagulated the latex slowly, giving a finely divided precipitate hard to coalesce. Boiling the salt solution gave a soft product. Of all the methods tried, the use of acetone, perhaps with formaldehyde, was the one especially recommended as giving the best results. The condition of the soil in which the plants are grown exerts an influence upon the amount and quality of the rubber in the latex, according to Fox. He found that plants grown upon dry, sandy soil at West Akron, Ohio, gave a latex containing 2.27 per cent of rubber and 20.69 per cent of resin, whereas plants grown in the swamps of South Akron contained 1.12 per cent of rubber and 15.04 per cent of resin; also that rubber from dry-grown plants is of better quality than that of wet-grown plants. Because of more recent discoveries as to the great extent of individual variation in these and similar plants, such conclusions need verification by a long series of examinations before they can be accepted as final.

The quality of the rubber from *Apocynum* is said by Fox to be much superior to milkweed rubber, as will be noted on p. 54.

TABLE 10.—*Chemical analyses of Apocynum cannabinum and A. androsæmifolium.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
328	Minnehaha, Colo.[1]	Aug. 1	Leaves	20.7	1.2
				23.7	0.62
			Stems	12.4	0.68
384	Fort Scott, Kans.[2]	...do....	Leaves	6.5	0.79
			Stems	6.5	1.0
888	Wichita, Kans.[2]	Sept. 2	Leaves	11.0	1.6
			Whole	11.0	1.3
943	Mount Diablo, Calif.[2]	July 9	Leaves	9.1	2.2
			Stems	7.2	1.1
1984	Salt Lake City, Utah[1]	Sept. 1	Leaves	9.8	0.70
			Stems	6.6	0.22
1039	Lincoln, Nebr.[2]	Oct. 15	Leaves	....	5.1
				....	4.5
				....	4.6
				....	4.6
			Stems	6.4	0.8
				6.0	1.0

[1] A. androsæmifolium. [2] A. cannabinum.

VI. MISCELLANEOUS SPECIES.

In addition to the 10 species reported upon in the preceding pages there are 6 which, while not of such promise as these, yet will need to be considered in connection with any study of the native rubber plants of North America. In all cases the number of samples analyzed is so small that further examinations should be made. Quite possibly some of the species placed in this second list will be found on further study to excel those of the preceding group. All but the last two are members of the Asclepiadaceæ, or milkweed family.

Acerates auriculata.—This is a green and nearly glabrous plant with the aspect of an *Asclepias*. The stems are 3 feet or less high and the leaves are narrowly linear or filiform, so that the amount of rubber-carrying herbage that could be produced on a given area of land would not be so great as that from the true milkweeds. The species ranges from Nebraska and Colorado to western Texas and New Mexico, and grows in dry, stony, or sandy soil. A single collection (389) from Denver, Colorado, yielded on analysis 2.9 per cent of rubber from the leaves and 0.5 per cent from the stems. Another species, the green milkweed (*A. viridiflora*), with much more copious foliage, is reported upon in table 12.

Asclepias eriocarpa.—The robust habit, leafiness, and ecologic requirements of this species are such as to render it especially suited to rubber culture. The few samples thus far analyzed furnish a very insufficient basis for a judgment as to the amount of rubber that it may be expected to yield. The stems grow in clumps to a height of 2 to 3 feet and are densely clothed with broadly oblong, hoary-tomentose leaves in whorls of 3 or 4 at each node. The species is an inhabitant of poor soils, often growing in places too stony or dry for other than a low growth of herbaceous plants, and is limited in its distribution to California, from the upper end of the Sacramento Valley south to San Diego County, growing in the hottest valleys and on exposed foothill slopes, but not upon the desert. Although often crowded out into poor soils, it responds readily to better treatment, as is evident by the exceptionally vigorous growth made when it is occasionally permitted to develop in young orchards or cultivated fields. A plant of this sort (915), gathered at Atascadero, in the south Coast Ranges, October 15, 1919, was found to contain 2.2 per cent of rubber in the leaves and 0.7 per cent in the stems. The parts analyzed were from second growth, the original spring growth having been cut earlier in the season. The leaves of a plant (939) gathered at Auburn, in the Sierra Nevada foothills, on June 19, 1920, yielded 1.3 per cent of rubber. Another sample (944) from Corning, in the northern part of the Sacramento Valley, gathered July 12, 1920, carried 2.4 per cent in its leaves and 0.5 per cent in the stems.

TABLE 11.—*Chemical analyses of Asclepiodora decumbens.*

No.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
				p. ct.	*p. ct.*
339	Trinidad, Colo.	Aug. 15	Leaves	9.5	1.2
372	Near Manitou, Colo.	July 14	Whole	9.2	1.3
882	Pike's Peak, Colo.	Aug. 31	Whole	8.0	0.8
983	Near Salt Lake City, Utah	Sept. 1	Leaves	7.7	1.7
			Stems	9.1	0.4
985	do.	do.	Leaves	8.5	1.0
			Stems	10.0	0.5

Asclepiodora decumbens.—The stems of this milkweed are 1 to 2 feet long and spreading or decumbent. They grow in clumps from deep, perennial roots. The leaves are alternate, lanceolate, 0.25 to nearly 1 inch wide, and nearly glabrous. The plants resemble some of the species of *Asclepias* in general appearance and could probably be handled much like *A. latifolia* or *A. californica*, but they differ from all of the true milkweeds in the entirely alternate leaves and in the flowers, the corona-hoods of which are prominently crested within instead of being provided with horns. In the bast fibers and the down on the seeds they are quite similar to *Asclepias*. The distribution is from Kansas west to Utah and south to Texas, Arizona, and Mexico, on dry slopes and mesas. The analyses are not encouraging, but are of interest in that they demonstrate positively the presence of rubber in this genus of plants and show that the leaves carry a higher percentage than the stems. Perhaps the most significant result is the finding of 1.3 per cent in a mixture consisting of a stem with all of its leaves (372).

Cryptostegia grandiflora.—This is a native of the Old World, probably of Indian origin, and as such scarcely falls within the scope of the present survey. A sample was sent by a correspondent of Los Angeles, California, with the statement that it came from Lower California. If this is correct, the sample was from a cultivated specimen. The plant has been used in India for its caoutchouc, but not to any considerable extent. It is a woody climber that is often grown in greenhouses for its showy blue flowers and endures the out-of-doors temperature of Florida. The sample mentioned (935) was found to carry 1 per cent of rubber in the stems and 5.1 per cent in the foliage. These determinations are for pure rubber and are computed on the basis of dry weight. The product so obtained is shiny, very elastic, and may be pulled out into threads an inch long.

Jatropha cardiophylla.—The jatrophas are shrubs and trees of the warmer parts of both hemispheres. The genus, which belongs to the Euphoriaceæ, or spurge family, is well represented in Central America and Mexico, a few species occurring also in the southwestern part of the United States. *J. cardiophylla* is a shrub 1 to 4 feet high which grows on the very dry hills of southern Arizona and northern Sonora. It seems to be especially common on the lower slopes of the Santa Catalina Mountains. The leaves, which appear only after the summer rains, are broadly ovate or rhombic, with a truncate or cordate base, and are 0.5 to 1.5 inches wide. The plants readily produce new stems when pollarded and are easily propagated by cuttings. A collection (993) made on Tumamoc Hill, Tucson, Arizona, February 21, 1920, was found on analysis to carry 3 per cent of rubber in the stems. Further examinations should be made of this species, as well as of all others of the Southwestern States.

Hymenoxys floribunda utilis (*Colorado rubber plant, or Pinguay*).—This composite herb has been already discussed (p. 9). Two collections have been analyzed during the course of the studies. One of these (931), from Las Vegas, New Mexico, was divided into two parts. That portion consisting of the root and the old stem-bases contained 3.6 per cent of rubber. The other portion, consisting of the main stems and leaves, contained 0.84 per cent. The other collection (947) was made at Buena Vista, Colorado, August 1, 1920. In this the whole plant was ground up and the mixture of root, stem, and leaf yielded 0.9 per cent of rubber. All of these analyses were by the acetone-benzene method as already described, so that the percentages are taken to represent the proportion of pure rubber in the samples. This perhaps accounts for the low percentages as compared with those reported by others.

VII. SPECIES WITH VERY LOW RUBBER-CONTENT.

In the course of the investigation it was found that, while perhaps all latex-bearing plants contained rubber, it occurs in most of the species in such small quantities as to be negligible. However, it is quite probable that further studies will demonstrate considerably higher percentages in the individual plants of some of the species here reported as containing but small amounts. This assumption is based on the fact that rubber-content varies with ecologic conditions and with the hereditary strain or race. It is also probable that the percentage content of these low-grade species could be increased by bringing them under cultivation, where they could be subjected to a considerable variety of cultural methods, such, for example, as changes in the water relation, and where they could be improved through selection and breeding. However this may be, it seems unnecessary to do more than to give the results of our analyses at the present time, and so in table 12, which refers for the most part to very poor species, will be found a few in which the rubber-content is sufficiently high to be of more than passing interest.

All of the species listed in table 12 are latex plants, with the exception of *Aster spinosus*, *Hymenoxys odorata*, *Pyrrhopappus multicaulis*, and *Silphium laciniatum*. The discovery of rubber in these species is especially noteworthy in that its presence has not been heretofore known in any of the genera to which they belong, with the exception of *Hymenoxys*. This is of some biologic although not of much commercial interest. There is, of course, a possibility that the benzene extract reported for these as "rubber" may, in some instances, be some other substance, something that comes out with the benzene extract through errors in methods or manipulation. In each case, however, the results have been checked by one or more duplicate analyses and the percentages are sufficiently high and sufficiently in agreement to justify a fair degree of confidence in the report.

Table 12 includes some latex plants in which the benzene extract is so low, 1 per cent or less, that it can not be said with certainty that rubber is present. Yet since every species with a latex is of interest as a possible carrier of rubber, all of these are here listed for comparison, regardless of the percentage found on analysis.

In cases where the part of the plant analyzed is reported as "whole" this is to be taken as exclusive of root and flowers; in other words, the stems and foliage were ground up and analyzed together. All percentages are computed upon the basis of absolutely dry weight of the material analyzed.

TABLE 12.—*Species with low rubber-content, including some latex plants with percentages so low that the presence of rubber is in doubt.*

No.	Name.	Family.	Place of collection.	Date of collection.	Part of plant analyzed.	Acetone extract.	Rubber (benzene extract).
						p. ct.	*p. ct.*
394	Acerates angustifolia	Asclepiadaceæ	Manitou, Colo	Aug. 18	Whole	4.5	0.70
950	Acerates viridiflora	do	Wellington, Kans	May 31	Whole	5.0	1.0
327	Agoseris aurantiaca	Compositæ	Cascade, Colo	July 30	Whole	7.5	0.22
331	do	do	Minnehaha, Colo	Aug. 9	Whole	8.2	0.16
381	Agoseris glauca	do	Cascade, Colo	July 28	Whole	7.2	0.6
322	Asclepias arenaria	Asclepiadaceæ	Colorado Springs, Colo	July ..	Leaves	11.6	0.70
					Stems	16.6	0.53
937	Asclepias cordifolia	do	Newcastle, Calif	June 18	Whole	8.3	0.7
940	do	do	Grass Valley, Calif	June 24	Leaves	7.2	1.5
366	Asclepias erosa	do	Colorado Desert, Calif	Nov. 7	Leaves	....	1.9
					Stems	....	0.48
891	do	do	Yuma, Ariz	Oct. ..	Leaves	7.8	1.54
					Young stems	9.7	1.39
					Old stems	6.3	0.93
917	do	do	Tehachepi, Calif	Oct. 22	Leaves	9.1	2.5
					Stems	5.7	0.50
373	Asclepias halli	do	Ute Pass, Colo	July 10	Leaves	6.8	0.8
					Stems	7.4	0.6
869	do	do	do	Sept. 1	Leaves	8.5	1.0
					Stems	8.0	1.0
871	do	do	Florissant, Colo	do	Leaves	9.0	1.4
					Stems	7.0	0.9
899	do	do	Ute Pass, Colo	July 28	Water-free latex	59.9	21.0
900	do	do	do	July 17	Water-free latex	54.5	4.7
302	Asclepias pumila	do	Manitou, Colo	July 10	Whole	17.6	0.86
					Root and base	8.3	0.16
376	do	do	Southern Colo	Aug. ..	Whole	8.7	1.6
1043	Asclepias verticillata	do	Lincoln, Nebr	Oct. 15	Whole	11.5	2.4
927	do	do	do	Oct. 15	Latex	54.0	12.0
385	Asclepiodora viridis	do	Fort Scott, Kans	Aug. 1	Leaves	5.9	1.4
					Stems	5.1	0.3
930	Aster spinosus	Compositæ	El Paso, Texas	June ..	Whole	6.5	0.90
934	do	do	Berkeley, Calif. (cult.)	Dec. 8	Leaves	5.9	1.4
					Whole	3.4	0.2
921	Campanula pyramidalis	Campanulaceæ	San Mateo, Calif. (cult.)	Dec. ..	Leaves	8.0	1.0
					Stems	2.6	0.1

TABLE 12.—*Species with low rubber-content, including some latex plants with percentages so low that the presence of rubber is in doubt*—Continued.

No.	Name.	Family.	Place of collection.	Date of collection.	Part of plant analysed.	Acetone extract.	Rubber (benzene extract).
						p. ct.	*p. ct.*
335	Campanula rotundifolia	do	Minnehaha, Colo.	Aug. 10	Whole	....	1.2
391	Campanula (garden escape)	do	Manitou, Colo.	Aug. 18	Whole	7.2	1.4
959	Crepis taraxicifolia	Compositæ	Berkeley, Calif. (cult.)	May 30	Whole	7.5	0.6
807	Euphorbia albomarginata	Euphorbiaceæ	Tucson, Ariz.	Oct. ..	Whole	....	0.21
949	Euphorbia arkansana	do	Wellington, Kans.	May 31	Whole	12.0	2.0
313	do	do	Manitou, Colo.	July 29	Whole	9.9	0.19
815	Euphorbia glyptosperma	do	Las Cruces, N. Mex.	Sept. ..	Whole	....	0.86
920	Euphorbia lathyris	do	Berkeley, Calif. (cult)	Dec. ..	Leaves	12.9	0.1
					Stems	5.6	0.1
329	Euphorbia marginata	do	Denver, Colo.	Aug ...	Leaves	14.3	0.75
					Stems	6.5	0.3
802	do	do	Hays, Kans.	Sept. ..	Leaves	7.0	0.57
					Stems	4.0	0.21
821	do	do	Guymon, Oklahoma	do	Leaves	....	0.85
					Stems	....	0.32
887	do	do	Wichita, Kans.	Sept. 2	Leaves	8.5	0.4
					Stems	3.0	0.3
300	Euphorbia montana	do	Colorado Springs, Colo.	July 10	Leaves	3.7	0.4
					Roots	15.8	0.46
380	do	do	Cascade, Colo.	July 28	Whole	13.2	0.2
844	Euphorbia nutans	do	Tucson, Ariz.	Oct. ..	Whole	....	0.43
893	do	do	Madison, Nebr.	Sept. 24	Whole	9.6	0.3
1101	do	do	Tucson, Ariz.	Mar. ..	Old growth	4.6	0.1
1102	do	do	do	do	New growth	13.9	0.3
945	Euphorbia ocellata	do	Wadsworth, Nev.	July 24	Whole	12.5	0.6
990	Euphorbia pulcherrima	do	Santa Ana, Calif. (cult.)	Dec. 17	Whole	6.6	0.9
1105	Ficus carica	Moraceæ	Tucson, Ariz.	May ..	Leaves	6.2	0.4
818	Grindelia nuda	Compositæ	Northern Texas	Sept. ..	Whole	....	1.1
925	Grindelia robusta	do	Solano County, Calif.	Nov. 13	Whole	8.5	0.77
311	Grindelia squarrosa	do	Palmer Lake, Colo.	July 29	Whole	13.1	[1]0.5
1041	do	do	Canyon City, Colo.	Sept. 9	Whole	8.3	0.8
808	Hymenoxys odorata	do	Las Cruces, N. Mex.	Sept. ..	Whole	....	2.0
332	Lactuca ludoviciana	do	Pikes Peak, Colo.	July ..	Whole	7.1	0.3
377	Lactuca pulchella	do	Near Denver, Colo.	July 27	Whole	9.9	0.43
309	Lactuca scariola	do	Manitou, Colo.	July 19	Leaves	10.4	0.86

398	do	do	do	Aug. 18	Whole	5.4	0.20
872	do	do	Lawrence, Kans.	Aug. 28	Whole	13.0	0.64
897	do	do	Madison, Nebr.	Sept. 24	Whole	10.8	0.71
397	Lactuca virosa	do	Manitou, Colo.	Aug. 18	Leaves	12.3	0.7
					Stems	7.3	0.5
353	Lygodesmia spinosa[2]	do	Mono Lake, Calif.	Sept. 21	Stems	....	0.21
					Roots and base	....	0.43
355	do	do	Gardnerville, Nev.	Sept. 23	Whole	....	0.54
					Roots and base	....	0.32
963	Malacothrix californica	do	Tehachepi Pass, Calif.		Whole	7.6	0.5
1112	do	do	Vaughn, Calif.	Apr. ..	Whole	5.4	0.5
1106	Papaver rhœas	Papaveraceæ	Tucson, Ariz.	May ..	Leaves	9.3	0.3
364	Philibertia linearis	Asclepiadaceæ	Hemet, Calif.	Oct. 4	Whole	....	1.9
					Stems	4.6	0.1
972	do	do		May ..	Whole	10.0	1.8
1115	do	do	Southern Ariz.	Apr. ..	Whole	9.0	1.7
354	Ptiloria exigua	Compositæ	Mono Lake, Calif.	Sept. 21	Whole	....	0.40
352	Ptiloria runcinata	do	Inyo Mountains, Calif.	Sept. 12	Stems	....	0.42
357	do	do	Pyramid Lake, Nev.	Sept. 24	Whole	....	0.56
					Roots and base	....	0.21
321	Ptiloria tenuifolia	do	Colorado Springs, Colo.	July 30	Whole	13.0	1.4
382	do	do	Cascade, Colo.	July 28	Whole	8.7	0.3
361	Ptiloria virgata	do	Mount Diablo, Calif.	Oct. 13	Whole	....	0.48
952	Pyrrhopappus multicaulis	do	McLean, Texas	May 29	Root	5.2	1.5
922	Schinus molle	Terebinthaceæ	Santa Ana, Calif. (cult.)	Nov. 26	Leaves	15.5	0.22
					Stems	5.3	0.10
926	Schinus molle (staminate)	do	Oakley, Calif. (cult.)	Nov. 14	Leaves	21.0	0.63
					Stems	13.0	0.16
927	Schinus molle (pistillate)	do	Oakley Calif. (cult.)	do	Leaves	15.0	0.63
896	Silphium laciniatum	Compositæ	Madison, Nebr.	Sept. 25	Leaves	8.3	1.8
1042	do	do	do	Sept. 15	Leaves	4.4	1.6
					Stems	5.1	0.2
933	Sonchus congestus	do	Berkeley, Calif. (cult.)	Dec. 8	Leaves	8.0	0.54
					Stems	6.0	0.18
932	Sonchus pinnatus	do	do	do	Stems	7.0	0.63
330	Taraxacum officinale	do	Minnehaha, Colo	Aug. 9	Whole	6.4	0.4
310	Tragopogon porrifolius	do	Manitou, Colo.	July ..	Leaves	17.6	0.7
					Stems	7.2	0.8
860	Tragopogon pratensis	do	do	Aug. ..	Whole	8.0	0.4

[1] Product of a yellowish-green color, with the consistency of thick, waxy sirup; pulls out into threads 1 inch long.
[2] Used by the Paiute Indians under the name of *du-wannup* as a source of chewing "gum."

VIII. SPECIES EXAMINED WITH NEGATIVE RESULTS.

In the attempt to discover as many rubber-bearing species as possible many sorts were examined on the mere chance that rubber might be present. In a few cases it was unexpectedly found in non-latex plants, as indicated in the preceding table. The remaining species, those in which no rubber could be detected with certainty, are enumerated below. All were subjected to a chemical analysis, but in no case was more than a fraction of 1 per cent of benzene extract obtained. Such small amounts are almost certainly some other substance than rubber when they occur in non-latex plants. The locality mentioned for each species is the place of collection of the sample.

A. Compositæ.

876. Achillæa millefolium, Pike's Peak, Colorado.
393. Ambrosia artemisiifolia, Manitou, Colorado.
395. Ambrosia trifida, Manitou, Colorado.
873. Anaphalis margaritacea, Mount Manitou, Colorado.
396. Artemisia campestris, Manitou, Colorado.
877. Aster bigelowi, Pike's Peak, Colorado.
865. Bahia dissecta, Manitou, Colorado.
1107. Baileya multiradiata, Santa Rita Reserve, Arizona.
906. Balsamorhiza deltoidea, near La Grande, Oregon.
1040. Balsamorhiza deltoidea, Ogden, Utah.
904. Bidens frondosa, Twin Falls, Idaho.
878. Brickellia wrighti, Canyon City, Colorado.
908. Chrysanthemum balsamita, Grant's Pass, Oregon.
868. Chrysopsis villosa, Manitou, Colorado.
946. Chrysothamnus howardi, Buena Vista, Colorado.
809. Dysodia papposa, Northern Texas.
1104. Encelia farinosa, Tucson, Arizona.
326. Eriophyllum lanatum integrifolium, Eastern Colorado.
875. Gaillardia aristata, Royal Gorge, Colorado.
819. Gutierrezia texana, Texas.
867. Gymnolomia multiflora, Manitou, Colorado.
883. Haplopappus parryi, Pike's Peak, Colorado.
864. Haplopappus spinulosus, Colorado Springs, Colorado.
929. Helianthus ciliarus, near El Paso, Texas.
948. Hymenopappus filifolius, Buena Vista, Colorado.
392. Iva xanthifolia, Manitou, Colorado.
866. Kuhnia eupatorioides, Manitou, Colorado.
862. Liatris punctata, Colorado Springs, Colorado.
852. Parthenium incanum, San Andreas Mountains, New Mexico.
850. Pectis angustifolia, Sonora, Texas.
810. Pectis papposa, Western Texas.
901. Pericome caudata, Pike's Peak, Colorado.
1108. Psilostrophe cooperi, Tucson, Arizona.[1]
830. Senecio filifolius, Western Texas.
903. Solidago occidentalis, Twin Falls, Idaho.
861. Thelesperma trifida, Colorado Springs, Colorado.
874. Verbesina dissecta, Manitou, Colorado.
820. Vernonia marginata, Northern Texas.
851. Zinnia grandiflora, Las Cruces, New Mexico.

[1] A sample of *Psilostrophe cooperi* from Las Cruces, New Mexico (No. 805, September, 1919) yielded 1.4 per cent of benzene extract, indicating that rubber is possibly present in this species.

B. Miscellaneous Families.

305. Argemone platyceras (Papaveraceæ), Manitou, Colorado.
938. Aristolochia californica (Aristolochiaceæ), Newcastle, California.
375. Comandra umbellata (Santalaceæ), Colorado Springs, Colorado.
1117. Convolvulus occidentalis (Convolvulaceæ), La Jolla, California.
1111. Convolvulus soldanella (Convolvulaceæ), La Jolla, California.[2]
362. Croton californica (Euphorbiaceæ), Brentwood, California.
806. Croton corymbulosus (Euphorbiaceæ), Las Cruces, New Mexico.
828. Croton corymbulosus (Euphorbiaceæ), Sonora, Texas.
847. Croton texensis (Euphorbiaceæ), Sonora, Texas.
363. Eremocarpus setigerus (Euphrobiaceæ), Antioch, California.
1109. Fouquieria splendens (Fouquieriaceæ), Tucson, Arizona.
390. Gaura parviflora (Onagraceæ), Manitou, Colorado.
907. Hypericum perforatum (Hypericaceæ), Grant's Pass, Oregon.
812. Maclura pomifera (Moraceæ), Manhattan, Kansas.
825. Microrhamnus ericoides (Rhamnaceæ), Western Texas.
378. Oenothera serrulata (Onagraceæ), near Colorado Springs, Colorado.
989. Olea europaea (Oleaceæ), Tucson, Arizona (cult.).
811. Othake sphacelatum (Compositæ), near Guymon, Oklahoma.
863. Psoralea tenuiflora (Leguminosæ), Colorado Springs, Colorado.
379. Smilax herbacea (Smilacaceæ), Eastern Colorado.
1130. Stillingia annua (Euphorbiaceæ), Glamis, California.
803. Stillingia silvatica (Euphorbiaceæ), Northern Texas.
848. Stillingia torreyana (Euphorbiaceæ), Northern Texas.
881. Tragia ramosa (Euphorbiaceæ), Royal Gorge, Colorado.

IX. VARIATION IN THE RUBBER-CONTENT OF ASCLEPIAS AND APOCYNUM.

Distribution of rubber in the plant.—Since the rubber both in *Asclepias* and in *Apocynum* is carried by the latex, it is not surprising to find that the highest percentages are obtained from those plant parts in which the laticiferous tissue is well developed. As will be seen from an examination of the tables of analyses, the foliage nearly always carries a much higher percentage than any other part. In all but one species the amount carried by the stems is so slight, usually less than 1 per cent of their dry weight, that its recovery in commercial rubber manufacture is perhaps not to be considered. However, the occasional appearance of a plant in which the stem carries a fair amount of rubber gives rise to the suggestion that improved strains might be developed in which stems as well as leaves could be utilized. Such a plant is one of *Asclepias mexicana* (No. 917) which yielded on analysis

[2] A second sample of *Convolvulus soldanella*, from the sand-dunes at La Jolla (No. 1114, April 3, 1920) yielded 1.5 per cent of benzene extract from the stems, indicating that rubber may possibly be present in small amount.

4.4 per cent from the leaves and 2.3 per cent from the stems. This plant was growing in alkaline soil, which fact may have influenced the formation of rubber in its stems or perhaps have caused its translocation from the leaves. It is to be noted that in *A. mexicana* the stems are green and doubtless share with the foliage in the photosynthetic activities of the plant. It is probable that a species of this sort would respond more readily to experiments designed to increase the rubber-content of the stalks than would one in which the stems played little or no part in photosynthesis.

The exceptional species referred to above, in which the stems carry more than a negligible percentage of rubber, is *Asclepias subulata*, a milkweed of the southwestern deserts and Lower California. In this plant the leaves are so few and small that it has not been possible thus far to assemble a sample for analysis, but the stems themselves take over the rôle of leaves to a considerable extent and in consequence are found to carry considerable amounts of rubber, in some specimens as high as 6 per cent. It is thus again suggested that the formation of rubber is closely connected with the photosynthetic activity of the plant. This in turn lends support to the view that the formation of caoutchouc is closely associated with that of carbohydrates. In this connection it should be noted that the bark of the stem in *A. subulata* carries much more rubber than the stele itself (No. 957 of table 1). This suggests that there is a prompt transformation of the carbohydrates if the caoutchouc is a conversion-product of the sugars, as investigators of the chemistry of rubber formation are now inclined to believe (Harries, 1905, 1919).

The almost total absence of rubber in the old woody parts, and especially in the roots, is expected in latex plants. That this holds for *Asclepias* is shown by a number of analyses of these parts (for example, No. 1015 of table 1, and No. 304 of table 9).

Variation due to heredity and to environment.—During the three years' time devoted to the studies here described, much attention has been given to the extent and cause of the variation in rubber-content of the species of *Asclepias*. With all of the data now assembled, the only positive statement that can be made is that there is a wide fluctuation both between the 16 species examined and within each of the several species studied in detail. In *Asclepias sullivanti*, which has received more attention than the others, the content was found to range from 1.2 to 8.1 per cent in the leaves and 0.2 to 0.9 (in one anomalous case 8.2) per cent in the stems. In case an attempt is made to improve the plants for commercial purposes, it will be important to determine whether such variations are due to differences in the heritable properties or to environmental causes. A start has been made on this problem, but it is so baffling that no positive conclusion has been reached. Some of the results will be indicated a little farther on, but it may now be said that probably both heredity and environment are concerned; that is, that each species is composed of many strains, each with a different rubber-producing capacity, and that at the same time the amount of rubber present in plants of each strain is modified by the local environment. If this assumption is correct, the chances of improvement through selection and breeding, and also through the manipulation of the environment, are greatly enhanced.

There is a wide individual variation in plants growing under uniform conditions, as is indicated, although not finally proven, by detailed studies made on several species. For example, 4 plants of *Asclepias sullivanti* growing near Lincoln, Nebraska, in what appeared to be uniform soil and only a few feet from one another, were all gathered at the same time (August 28, 1920) and analyzed separately, with the following results:

TABLE 13.—*Variation in rubber-content of plants of Asclepias sullivanti growing under apparently uniform conditions.*

No.	Stems.		Leaves.	
	Acetone extract.	Rubber (benzene extract).	Acetone extract.	Rubber (benzene extract).
	p. ct.	*p. ct.*	*p. ct.*	*p. ct.*
1016	6.6	0.5	9.5	5.4
	6.0	0.4	9.3	5.3
1017	6.8	0.2	8.1	3.1
	6.5	0.2	8.9	2.9
1018	8.0	1.0	8.5	1.2
	7.5	0.8	8.5	1.1
1019	7.0	0.9	7.0	2.9
	7.0	0.8	7.2	3.0

The extreme variation from 1.1 to 5.4 per cent in the leaves, as indicated in this table, can scarcely be attributed to what slight difference there might have been between the environments of the two plants. Similar evidence is deduced from the analyses of 3 plants of *Asclepias subulata* gathered at Sentinel, Arizona. The rubber-content of the stems of these plants, the foliage being so sparse as to be negligible, was found to be 2.6, 3.5, and 4.4 per cent respectively. In this case the differences are conceivably due to slight inequalities in the soil surface and hence in the water relation.

A third series of samples was taken to test this point, this time of *Asclepias mexicana.* Three plants (910, 911, and 912) were selected near Mount Diablo, California, all apparently alike and all from within a foot from one another in a field where the herbaceous vegetation exhibited great uniformity in its growth. The leaves of these plants were analyzed and found to contain in one case 2.8 per cent, in another 3.2 per cent, and in the third 4.1 per cent of rubber. In no species have approximately equal amounts been found in more than 2 plants from a single small area.

The evidence thus far available seems, therefore, to point to the presence of innumerable strains within at least some species of *Asclepias*, the rubber-content varying with these strains, as well as with changes in the environment.

The influence of soil, moisture, and other external conditions has not been studied in detail, but there is some indication that the presence of alkali in the soil increases the rubber-content of *Asclepias mexicana*. On the other hand, there is no evidence that poor or dry soil or deficiency in rainfall increases the amount. In fact, some of the best rubber-producing species, such as *Asclepias sullivanti*, grow only on rich and moist bottom-lands. Within single species the plants from poor soil average about the same as those from good soil, but with some indication that especially robust plants are likely to carry rather high percentages of rubber, this being associated, perhaps, with their increased photosynthetic activity.

Seasonal variation.—Detailed studies were carried out on several species in order to determine the presence or absence of a correlation between the age of the plant and its rubber-content. It was thought that such correlation, if it existed, would throw some light upon the perplexing question of the rôle that rubber plays in the economy of the plant. The effect of other factors, however, is too great to permit the drawing of any definite conclusions. Aside from such obvious modifying influences as changes in temperature and moisture, the translocation of rubber within the plant must be allowed for, and more important than all, the wide extent of individual variation. It is obvious that analyses made from leaves of a single plant but taken on different dates would yield data of very doubtful value, since there is no evidence that leaves in different positions carry equal percentages even at the same time. Moreover, the removal of a sufficient number of leaves to permit of analysis would almost certainly modify the process of rubber formation in the rest of the plant. With these difficulties in view, seasonal studies on several species were inaugurated. There is a lack of concordance in the results, but the indications are that both the total amount and the percentage increases as the herbage matures, but that they again fall off as the parts approach senility, or, in the case of stems, as lignification sets in.

An experiment, the results of which seem to controvert the theory that the percentage increases with maturity, will be first described. Several plots of *Asclepias sullivanti* were selected near Lincoln, Nebraska, and samples from them were taken at intervals of approximately 8 days each. Each lot was chosen because of the apparent uniformity of the plants, and 5 specimens were taken from each lot at the close of each period. It was thought that by thoroughly mixing the dried and ground material of 5 plants a reliable average for the whole lot would be obtained. The results are shown in table 14.

TABLE 14.—*Seasonal variation in the rubber-content of Asclepias sullivanti at Lincoln, Nebraska.*

No.	Date.	Stems.		Leaves.		Precipitation for preceding period.	Mean temperature for preceding period.
		Acetone extract.	Rubber (benzene extract).	Acetone extract.	Rubber (benzene extract).		
		p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*inches.*	*° F.*
Lot 1:							
1020	Aug. 28	4.9	0.4	7.8	3.6	0.99	66
		4.3	0.4	8.5	3.6		
1022	Sept. 6	6.0	0.2	6.8	4.1	1.31	66
		6.8	0.2	7.8	4.0		
1025	Sept. 14	6.3	0.4	10.7	2.6	0.34	70
		6.4	0.4	11.0	2.7		
1028	Sept. 22	4.0	0.2	8.0	3.0	0.00	76
		4.5	0.2	7.8	2.9		
Lot 2:							
....	Aug. 28	....	0.6	....	3.1	0.99	66
1023	Sept. 6	10.0	0.4	10.0	2.6	1.31	66
		8.5	0.5	11.1	2.7		
1026	Sept. 14	2.1	0.3	10.0	3.7	0.39	70
		2.5	0.3	9.7	3.5		
1029	Sept. 22	4.3	0.5	9.0	4.3	0.00	76
		4.8	0.6	11.0	4.0		
Lot 3:							
1021	Aug. 28	6.1	0.2	7.8	4.0	0.99	66
		8.2	0.1	7.6	4.0		
1024	Sept. 6	1.3	0.3	8.2	2.0	1.31	66
		1.0	0.2	8.2	2.0		
1027	Sept. 14	6.2	0.2	11.8	4.2	0.34	70
		6.0	0.2	11.6	4.1		
1030	Sept. 22	1.7	0.1	8.1	4.2	0.00	76
		2.0	0.1	8.4	4.2		

In considering the results set down in table 14, only the rubber-content of the leaves need be taken into account, since the amount in the stems is so slight that the differences are not significant. For lot 2 it will be noticed that, with the exception of the first period, the rubber-content gradually increased as the season advanced. This is in agreement with results often but not always obtained in other species. The analyses of lots 1 and 3, however, entirely negative this conclusion and indicate an irregular fluctuation difficult to account for, except on the basis of some unknown factor or on that of individual variation, which, as shown in table 13, is so great that it is not wise to draw conclusions unless a very large number of plants are included in each analysis. Therefore the principal value of table 14 is to indicate the lack of concomitance in the various lots and thus to warn against the danger of explaining seasonal variation on the basis of a limited number of analyses and without taking all possible factors into account.

With due regard to the warning just given, the results of an experiment on *Asclepias mexicana* may now be considered. A uniform growth of this plant on an area a few meters square was located near Mount Diablo, California. A swath was cut across the middle of this plot on July 9, 1920. The leaves at that time carried 3.7 per cent. The growth along both sides of this strip was cut on October 12 of the same year, when it was found that the percentage had increased to 4.6. The content of the stems had dropped during this interval from 1 to 0.8 per cent, but in view of the small amount of rubber in the stems this slight difference is not considered significant.

Further evidence may be deduced from certain of the tables of analyses. For example, in table 3 several instances may be noted where the analysis of young leaves yielded lower percentages than older leaves taken from farther down on the same stem. But most convincing of all are comparisons between Nos. 1034, 1032, and 1035, made in this order from table 3. Here the increase with age is perfectly regular. Also, in the case of *A. subulata* (table 1), the green stems are found to carry smaller percentages in the young growth than in the more mature but not woody portions. On the other hand, the percentage of rubber in very old leaves and stems is always much reduced (see No. 919 of table 4, No. 342 of table 5, and various numbers of table 1). This lends support to the theory that caoutchouc may undergo considerable modification, or even entirely disappear, after it is once formed in the plant.

In case it is found that the amount of rubber increases as the season advances, as seems to be indicated by the above considerations, it will be interesting to know whether this is due to an increase in the volume of the latex or to an increase in the percentage carried by the latex itself. The only evidence at hand indicates that the latter may be the case. A number of plants of *Asclepias halli* growing in Ute Pass, Colorado, were "bled" on July 17, 1919, and 7 c. c. of latex obtained and analyzed. The results showed but 4.7 per cent of rubber in the water-free latex. A similar sample was obtained from another colony of plants on July 28, 1919. This was found to carry 21.0 per cent of rubber on the same basis. This seems to indicate a considerable increase in the richness of the latex for *A. halli* as the season advances, although the difference may be due to individual variation.

Variation in successive crops.—When the stems of some and perhaps all species of *Asclepias* are removed by mowing or cutting in any manner near the base, a new growth of shoots will spring up. Thus two or more "crops" may be obtained in a season, as in the case of the well-known alfalfa or lucerne. Since this practice would greatly increase the tonnage of herbage, its use in case the plants are brought under cultivation is at once suggested. The cutting in itself, however, might modify the percentage content of succeeding crops. While the data at hand are not conclusive, they seem to indicate that the second crop would carry as high or perhaps a higher percentage than the first, but that the third crop might show a considerable decline, at least in plants grown under unfavorable conditions.

The evidence for these conclusions is as follows: A grain field in Solano County, California, was infested with a scattered growth of *Asclepias mexicana.* This had been mowed off with the grain in the early summer of 1919, before a study of its rubber-content could be made. By November 13 of the same year the new shoots had reached maturity, and these were gathered from 80 different plants (sample No. 923). The dried and mixed leaves analyzed 4.1 per cent of rubber, which is much higher than the average for the first growth of this species and which is rarely exceeded even by single plants. Two other collections of second-growth material, probably from one root, were made near Mount Diablo, California, one on July 9, 1920 (No. 941), the other on October 12 of the same year (No. 1037). The leaves of these analyzed 3.7 and 4.5 per cent respectively, the higher percentage of the latter corresponding to its greater degree of maturity. Again the percentage of the first crop is not known, but these returns for the second crop are so high for *A. mexicana* that no considerable falling-off could have taken place.

The only evidence that the percentage may drop with the third crop is supplied by studies of the above-mentioned plot near Mount Diablo, and even here the result is evidently due to the poorly developed condition of the third crop when harvested. The stems of this plot are connected by horizontal roots, so that the percentage content may be assumed as the same for all at any one time. On July 9, 1920, a swath was cut through the middle of the second growth and the leaves and stems together were found to carry 2.1 per cent of rubber (No. 941; leaves 3.7 per cent, stems 1 per cent). By October 12 it was found that the shoots (stems and leaves) not cut in July had increased their rubber-content to 2.4 per cent (No. 1037; leaves 4.5 per cent, stems 0.8 per cent), whereas the third crop from the cut swath yielded only 1.5 per cent (No. 1038). The shoots of this third crop were so weak and slender that the leaves and stems were not analyzed separately. It is possible that by giving the plants the proper cultural conditions, and by so timing the harvests as not seriously to weaken the roots, a third crop may be obtained which would be as rich as either of the other two. The effect of cutting upon the vigor of successive crops has been noted only under the unfavorable conditions obtaining at the place just noted. The experiment should be repeated on some of the robust stands in the alkaline districts of the San Joaquin Valley and more time given the third crop to fully mature its stems and leaves.

X. PROPERTIES OF THE RUBBERS.

The product obtained from *Asclepias* and *Apocynum* by the methods used during these studies is true rubber, with only a small admixture of resins, fats, or other substances such as are sometimes obtained from plants and called by this name. The reasons for this conclusion have been given in connection with the discussion of the chemical methods employed (p. 14). Samples have not been prepared by mechanical processes, but the accumulations of the benzene extract resulting from the chemical analyses have been preserved for some of the species. The largest accumulation (4 grams) is from *Asclepias sullivanti.* This sample is nearly black in color and possesses elasticity and some resilience. It emits the characteristic odor of rubber when it is burned. During the 4 months since its preparation the surface has undergone slow oxidation, as indicated by the formation of resin-like granules. No attempt has been made to vulcanize the sample.

The properties of a rubber prepared from some unknown species of milkweed have been reported by A. T. Saunders (1910). The sample, which weighed about 2 grams, was permitted to stand for 10 years before examination, after which period it was found to contain but 20 per cent of hydrocarbon, the remainder being vegetable matter and resin-like products of oxidation. It yielded to the usual solvents of rubber, resisted the same reagents, as far as tested, possessed elasticity, and was susceptible of cure. When rolled into a slender thread and subjected to the acid cure it was extensible to five times its length and returned sharply upon release. Fox (1911) reported caoutchouc obtained from *Asclepias syriaca* as flabby, lacking in strength and firmness, and high in gravity. It responded to the sulphur, chloride, and bromine tests.

The few and rather desultory examinations made thus far of *Asclepias* rubber would indicate that it is of low grade, not to be compared with fine Para, with imported plantation rubber, nor with chrysil. It would doubtless find use for mixing with better grades and in those manufactures where great elasticity is not demanded. It is possible, however, that other species will yield a better product than that obtained by Fox from *A. syriaca.* The rubber from *A. sullivanti,* for example, seems to be better than the sample with which he worked.

Rubber prepared from *Apocynum* (Indian hemp and dogbane) is probably superior to that from *Asclepias.* Fox (1912) reports his experience in the preparation of rubber from *A. androsæmifolium* as follows:

"The latex of *Apocynum* differs from that of *Asclepias* in that it coagulates spontaneously, even if it is kept in closed containers. The spontaneously coagulated latex gives:

	Per cent.
Liquid portion	67.58
Cheese (wet)	32.42

"The liquid is white, slightly acid, and [of an] acrid odor. This liquid failed to coagulate after addition of more acid. Slight excess of alkali increased its viscosity, changed its color from white to brownish yellow, but did not coagulate or precipitate it. Boiling had no effect. Excess of acetone gave a finely divided precipitate, the particles of which were not cohesive. Evaporation of the mixture, after washing with water and treatment with boiling acetone, gave a small quantity of black, soft rubber, destitute of strength. The cheese was composed of:

	Per cent.
Water	33.46
Rubber	3.99
Resin	62.95

"Working up this cheese of the plant in the usual manner with solvents, straining through gauze to remove dirt, evaporation with low heat, the excess of solvent, adding an excess of precipitant, washing the precipitant and dissipating the precipitating agent, gave a good grade of rubber.

"The rubber obtained in this manner is black, firm, not tacky, odorless, and strong. In quality it is much better than the product obtained from its neighbor, milkweed."

In drawing conclusions from the above remarks it should be remembered that no thorough test has as yet been made of the rubber either of *Asclepias* or of *Apocynum*, and that considerable variation may be expected in the rubbers prepared from different species. The collection of material in quantity for the purpose of extracting enough of the rubber to permit of extensive tests is now being undertaken. Several of the more important species will be studied in this manner.

XI. BY-PRODUCTS FROM ASCLEPIAS AND APOCYNUM.

If financial success ever attends the growing of any native extra-tropical North American plant on a commercial scale for its rubber, this will doubtless be due in part to other products derived from the same crop. The most promising of these by-products, as far as the plants especially treated in this report are concerned, is fiber. It is a fortunate circumstance that the botanical groups which include the most important species from the point of view of rubber-content are also characterized by the presence of bast fibers suitable to the manufacture of at least the cheaper grades of cloth and cordage. If not so used, this fiber, which would be left after the extraction of the rubber, could be utilized as pulp for the manufacture of paper.

Fiber.—The cultivation of milkweeds, especially *Asclepias syriaca* and *A. incarnata*, for their fiber has been advocated from time to time by enthusiasts, some of whom have claimed that commercial success was assured. But the actual demonstration has never been carried through in this country, although the former species is reported as having been grown for its fiber in Syria and as far north as Upper Silesia (Dodge, 1897), it having been introduced from America. It is not impossible that, although the cultivation of the plants for their fiber alone might be unprofitable, the utilization of the fiber after these plants had been grown and extracted for their rubber might add very largely to the net income and thus would be established an industry based upon two important products. In this case two prime assumptions will be necessary, namely, that the proper time of harvesting for the two products will coincide, and that one of these can be extracted without so treating the material as to make the recovery of the other impossible.

Certain considerations seem to render these assumptions reasonably safe. For example, it is generally true of plants yielding bast fibers, such as hemp and flax, that the best quality and yield are obtained if they are harvested at about the time of maturity. Such plants are often gathered when the leaves begin to turn yellow or when the seeds begin to ripen. If this holds also for milkweeds and Indian hemp it is a fortunate circumstance, for while there is not a universal concordance in results, an examination of the tables of analyses presented in this paper will show that milkweeds gathered when fully mature usually carry more rubber than those of the same locality gathered earlier. Regarding the extraction of both fiber and rubber from the same plant, all that can be said is that experienced rubber manufacturers who have been consulted state that they see no insuperable difficulty in the proposal. In order to accomplish this, the mill should be so constructed that the wet plants could be passed between rollers that would crush the stems and separate the fibers without breaking them. If a chemical extraction method were used for the rubber it would be necessary to consider the effect of this upon the fiber. The solvents commonly employed would not injure it.

The quality of the fiber in the plants under consideration has not been thoroughly tested. It is quite likely that this will vary with the different botanical species. Perhaps the most concise published statement on the subject is one by Dodge (1897). Speaking of the common milkweed (*Asclepias syriaca*) Dodge says:

"The only portion of the plant of which practical use can be made is the *bast*, which furnishes quite a fine, long, glossy fiber that is strong and durable. Early authorities have given it a place between flax and hemp, and the yield has been claimed about equal to the latter. Dr. Schaeffer, as far back as the fifties, made comparisons of the two fibers in Kentucky, and his conclusions were most favorable to the *Asclepias* fiber. The native fiber was taken in winter from the decayed stalks as they stood in the ground where they grew without culture, while the hemp had not only been cultivated but treated afterwards with the usual care. The fiber of the milkweed was nearly, if not quite, as strong as that of the hemp, but apparently finer and more glossy, while the quantity from a single stalk of each was nearly the same."

Samples of milkweed fiber have been examined more recently by experts, who think that Dodge's statement is rather too optimistic. While these later opinions were not based upon actual tests for strength or in weaving, they seem fairly reliable and lead to the conclusion that milkweed fiber is not equal in quality to hemp. It seems to be a stiffer fiber that does not spin as smoothly or as evenly as the fibers now used, so that new methods and devices would need to be developed for handling it. The milkweeds referred to are *A. incarnata* and *A. syriaca*. It is probable that there is some variation in the properties of the fiber from different species.

The fiber of the Indian hemp (*Apocynum cannabinum*) is somewhat more promising than that of the milkweeds. Dodge (1897) says of it:

"Easily separated from the stalk, and when cleaned is quite fine, long, and tenacious. In color it is light cinnamon as usually seen, though finely prepared specimens are creamy white and remarkably fine and soft; will rank with *Asclepias* for strength, and is readily obtained, as the stems are long, straight, smooth, and slender. Although paper has not been made of it, it could doubtless be utilized for the purpose. It is principally employed by the North American Indians, who manufacture from it in rude fashion, bags, mats, small ornamental baskets, belts, twine, and other cordage, fishing lines, and nets. Among fine specimens received is a fish line, such as is used by the Pai Utes at the Walker River Reservation in Nevada."

Later opinions expressed by experts who have examined the fiber are that *Apocynum* fiber might have a commercial value if it could be produced at a cost that would permit it to compete with hemp or jute. The fiber of this plant has been confused by some authors with that of the Colorado River hemp (*Sesbania macrocarpa*), an entirely different plant of the Leguminosæ.

Aside from the bast fibers just discussed, both *Asclepias* and *Apocynum* yield a surface fiber that may be obtained from the seed. But it is unlikely that this could be gathered from plants grown primarily for their rubber, since harvesting would probably take place before the fiber would have time to develop, and aside from this it is of but low value.

Paper pulp.—In case the fiber is not of more value for the manufacture of cloth, it may be utilized as a source of paper. A pulp prepared from one of the eastern milkweeds, probably *Asclepias syriaca*, has been made up into a fair quality of paper at one of the leading factories. This was done many years ago and the matter dropped, since it was not profitable to grow the plants for this purpose alone. The only paper made from milkweed during the present investigation was manufactured from the desert species (*Asclepias subulata*) by the same firm and the product found to be much superior to that formerly examined. The plant from which this sample came was collected at Sentinel, Arizona, September 29, 1920, under No. 1054; it is illustrated in plate 1. The sample consisted of the very hard, dry stems, which were practically devoid of foliage, as is generally true of mature stems.

The material was worked up by the factory, following the usual procedure. The fiber expert for the company states that the report of the laboratory is very encouraging, that the milkweed has all the appearances of making a good pulp, and that the hand-made sheets show a long, soft fiber which under the microscope resembles linen. The processes used in the preparation of the paper were as follows:

Experiment 1.

1. 456 grams of material as received cooked with 10 per cent (45.6 grams) caustic soda for 3 hours in an open kettle.
2. This material run through wringer rolls to crush out.
3. Crushed material washed clean and dried out. Weight 196 grams.
4. Material thus washed next cooked in closed kettle with 10 per cent (19.6 grams) lime for 5 hours at 30 pounds pressure.
5. This cooked material washed and beaten in beater and run out on hand moulds. 151 grams of unbleached paper obtained.
6. This 151 grams unbleached paper next bleached with bleach solution made from an amount of bleach powder equal to 7 per cent by weight of the 151 gra ms of the unbleached fiber. This gave 130 grams of bleached paper.

Yields:

From material as received to washed, crushed, bone-dry fiber (end of operation 3), 43 per cent.

From material as received to unbleached paper (end of operation 5), 33 per cent.

From material as received to bleached paper (end of operation 6), 28.5 per cent.

Experiment 2.

A quantity of milkweed stalks, selected as described in Experiment 1, was boiled in an open kettle with water for 8 hours. Softened stalks were crushed in wringer as above described. Then furnished to autoclave, where they were cooked with 10 per cent caustic soda for 8 hours at 30 pounds pressure. The cooked material was washed, beaten, and run out into hand sheets. The yield from material as received to bone-dry paper, unbleached, is 40 per cent.

The paper resulting from this experiment was highly satisfactory; quite as satisfactory as that obtained from Experiment 1, and obtained in a much less expensive manner.

It was thought by cooking with lime a paper of equally soft, pliable quality might be obtained. The result of this attempt we report under Experiment 3.

Experiment 3.

A quantity of selected milkweed stalks was boiled in water for 8 hours, crushed in the wringer, and cooked in the autoclave with 10 per cent lime for 8 hours, at 30 pounds pressure. Cooked stock was washed clean and beaten, then run out in hand molds as sheets of paper.

Yield from material as received to bone-dry paper 42 per cent.

The resulting paper from Experiment 3 was much inferior in softness and pliability to that obtained in either Experiment 1 or 2, although the yield from material as received to unbleached paper was the highest reported. It is, however, relatively free from harsh, incrusted, shivey particles. Paper obtained from Experiments 1 and 2 was entirely free from harsh, shivey particles.

The lime used in these experiments was a good grade of hydrated lime, containing about 95 per cent calcium hydrate, 1.3 per cent impurities (silicon dioxide, iron, and alumina). The caustic soda was good grade 58 Solvay process caustic.

The resulting fibers, as obtained from sheets of paper made in Expermerments 1 and 2, have many of the characteristics of linen. They are long and silky, possessing remarkable strength for the type of material from which they are obtained.

It is of interest to note that this material does not yield readily to bleaching with calcium hypochlorite. It may, however, yield more readily to bleaching with hypochlorous acid or possibly sodium hypochlorite.

For material of this type, yields for material as received to unbleached paper in all cases are exceptionally high.

An interesting note is made by the laboratory expert that very likely in the process of extracting rubber the raw material may be put through a breaking-up process which would so separate the woody, fibrous, and pithy components as to render unnecessary the preliminary cook with caustic soda. The paper-maker therefore would start with the lime cook, thus saving the prohibitive cost of reduction by caustic and crushing.

This matter has been taken up also with a director of a scientific laboratory connected with one of the large rubber factories, and he is of the opinion that there will be no insurmountable difficulty in so constructing the rubber machinery as thoroughly to separate the fiber without injuring it. It seems reasonably certain, therefore, that not only could both rubber and fiber be extracted from the same material in a practical way, but that the extraction of the rubber would permit the paper manufacturer to proceed with considerably less expense than if he were to use the plant as it comes from the field.

In view of the above favorable reports, it is now proposed to collect a half-ton sample of the desert milkweed in order that the rubber may be extracted and the residue turned over to the paper manufacturers for further experimentation and report.

XII. AGRICULTURAL POSSIBILITIES OF ASCLEPIAS AND APOCYNUM.

If natural rubber is ever produced in commercial quantities in the United States, it will be from a plant which will give large yields on cheap land, and one which can be handled almost entirely by machinery. This is assuming that labor and other economic conditions will remain about as they now are. The reason for these requirements is the realization that North American rubbers, unless possessing unique qualities that would especially fit them for special uses, would need to compete in the market with the foreign product. The price of the best imported grades is now down to about 25 cents per pound, and even this will doubtless be lowered with the improvement of plantation methods and when the present voluntary restrictions on output are removed. Another quality which it may be necessary for the American-grown plant to possess is the ability to yield by-products. It seems quite possible, for example, that while the species of plants considered in this report might never be made to produce a suitable return from their rubber alone, yet their cultivation might become a profitable industry in view of the additional returns to be expected from the sale of the pulp after the rubber is extracted.

Of all the plants here considered, the desert milkweed (*Asclepias subulata*) apparently comes nearest to fulfilling the requirements above set forth. It is a perennial that grows rapidly on poor desert lands with a minimum of moisture, is of such a nature as to permit of harvesting by machinery, reproduces after cutting, and yields a paper-pulp of better quality than that from other milkweeds. The percentage of rubber present averages about as high as that of the others and is sufficiently fluctuating to indicate that superior high-yielding strains could be produced through breeding and selection. This building-up of the rubber-content will be an essential preliminary to the utilization of any of the plants here considered. It would be futile to attempt the profitable production of rubber on the basis of the percentage content thus far found in American species.

Before a fair idea can be formed as to the yields to be obtained, it will be necessary to carry out some experiments in growing the plants under field conditions. In the meantime, a study of the wild plants and of the tables of analyses may give some hint as to what may be expected. It is known, for example, that under favorable conditions individual plants of the desert milkweed (*Asclepias subulata*) weigh 15 to 80 pounds. Perhaps 30 pounds, green weight, is a fair average to expect when tillage and other methods to conserve moisture are practiced. Such plants have a spread of 3 to 6 feet and require perhaps 3 years to mature, after which annual crops presumably could be harvested. It is even possible that 2 or more crops could be gathered in one year, as is practiced with alfalfa, but the effect of frequent cropping on the vigor of the plant is not known. Irrigation, even in slight amount, would certainly increase the tonnage as well as permit closer planting and more frequent cropping. It might also modify, either one way or the other, the percentage of rubber produced.

In carrying out estimates an allowance should be made for about 60 per cent of water in the green stems. But the determining factor is the percentage of rubber present, and no definite prediction can be made as to what this will be. The average content of 9 unimproved plants growing at Sentinel, Arizona, exclusive of the woody base, was 3.1 per cent. With this and the above figures as to size and other factors as a basis, it would seem that between 300 and 500 pounds of rubber per acre might be expected from each crop in case a uniform stand of fair-sized plants can be secured. If it is assumed that the highest percentage found in an individual plant could be uniformly maintained under methods of seed selection, then these figures could be at least doubled. Notable success in the improvement of other agricultural crops through breeding combined with selection justifies the hope that the average of 3.1 per cent can be increased to several times this amount, with a corresponding increase in the total yield per acre. Such improvement would be necessary as a preliminary to the profitable cultivation of the desert milkweed for its rubber and fiber.

In actual practice the yield would be considerably modified through the inclusion of an undeterminable proportion of resins and other substances. The amount of such matter varies from about 6 per cent in the best Para to about 35 per cent in guayule, and even higher in some inferior Africas.

To the income of the rubber is to be added the value of the pulp for paper manufacture. As already demonstrated (p. 58) the air-dry stems yield about 43 per cent of bone-dry fiber, or 28.5 per cent of bleached paper. No figures have been obtained as to the value of the pulp, but it would be higher than that made from hemp and similar plants, since the separation of the fibers incident to rubber extraction would be such as to render unnecessary certain preliminary processes.

It may be found on further examination that other species than *Asclepias subulata* are suited to the purposes under consideration. *A. sullivanti*, for example, carries a higher percentage of rubber in the leaves alone than is found in the stems of the leafless *A. subulata*, and the plants are very tall, thus yielding a large tonnage. But usually its stems are very poor yielders and as far as known the plants grow only in fairly good soil. The fiber would be of value, but is probably of lower grade than that of the desert species. If *A. sullivanti* can be induced to grow on cheap land, or if the rubber-content can be very materially increased, particularly in the stems, it would have a chance as a possible rubber plant, occupying its own geographic area. Other species to be considered are the ones given special consideration in this report. Their qualifications, as far as known, are briefly discussed in each case under the subheadings of "Distribution and ecology" and "Rubber-content." It also should be remembered that only a few of the native latex plants have been studied. Possibly there are others which on examination would be found to hold out much more promise than any of these.

It is readily seen from the above statements that a much more extended and detailed investigation will be necessary before anything definite can be said regarding the possibilities of these plants as agricultural crops. The present study was undertaken chiefly to determine whether or not such investigations could be carried forward with some prospect of ultimate success. It seems to the authors that the facts thus far established amply demonstrate the desirability and wisdom of instituting further studies and experiments. In case these are carried out, they should be extended to include *Chrysothamnus* and other plants not treated in detail in this paper and should aim to cover the following points:

1. Further field studies of wild plants to discover better species and strains than those already found.
2. Experiments in breeding and selection.
3. Modifications in environment, especially the water and alkali relations, and their effect upon growth and yield.
4. Manipulation of the plant itself, with the object of increasing the amount of rubber-bearing tissue. This is already under way for chrysil.
5. Field experiments to determine the tonnage per acre to be expected, and the best methods of culture.
6. Studies in the seasonal formation of rubber in the plant. This includes a combination of the most refined chemical methods, with microscopic studies of cell-contents and their changes precedent to and during the deposition of rubber.
7. Quality and value of the product. Investigations along this line are already in progress. Chrysil and several species of *Asclepias* rubber will be studied.
8. By-products, including fiber, pulp for paper, acetone, alcohol, dyes, potash, essential oils, waxes, and resins.

XIII. SUMMARY AND CONCLUSIONS.

(1) The purpose of the investigation was to make a preliminary study of native North American plants in regard to their rubber-content. While this is a matter of general scientific interest, it was hoped that some species would be found that carried enough rubber to justify their further study with a view to establishing a rubber-growing industry within the United States. This is desirable in that it would utilize land now lying idle, and, furthermore, would render the nation to some extent independent of overseas importations.

(2) The species examined were mostly latex plants, especially species of *Asclepias* (milkweeds) and *Apocynum* (Indian hemp). The work is a continuation of earlier studies on native shrubs. A total of about 225 North American species have now been examined and a record made as to the presence or absence of rubber in their tissues. About 6 species of shrubs and 16 species of latex-bearing herbs are considered worthy of further study and experiment. Nothing is known concerning the rubber-content of about 80 other native species of *Asclepias,* all of which presumably contain at least a small amount of rubber.

(3) The researches of earlier workers on *Asclepias* and *Apocynum* revealed but very small amounts of rubber. By carrying the examinations to other species, and to other ecologic and genetic forms of the same species, much larger percentages in the plant have been found.

(4) The acetone-benzene method of analysis was employed. The percentages reported are therefore for rubber, practically free from resin or other admixtures. They are based upon the dry weight of the material analyzed.

(5) The species of *Asclepias* and *Apocynum* reported as of special interest are all perennials. Some make a good growth on land so poor or dry that it is not at present utilized. They grow rapidly from seed and from portions of the root. It is possible that several crops could be obtained in one year without replanting. The crop could be handled almost entirely by machinery.

(6) The amount of rubber in the plant appears to vary with the species, with small races, or strains within each species, and also with the ecologic conditions obtaining during the period of growth. High percentages are often associated with vigor of growth. Mature herbage often carries higher percentages than young herbage.

(7) The latex plants examined usually carry much higher percentages in the leaves than in the stems or roots. The one exception is a nearly leafless desert milkweed (*Asclepias subulata*), the stems of which contain from 2 to 6.4 per cent. This is a species of outstanding promise. Others considered as of special interest, with the rubber-content of their mature leaves, are:

	Per cent.
Asclepias sullivanti	1.2 to 8.1
syriaca	1.1 to 4.4
californica	2.6 to 4.3
latifolia	2 to 3.8
mexicana	1.4 to 4.8
Asclepias galioides	0.6 to 5.2
brachystephana	2.1 to 2.9
speciosa	1 to 3
Apocynum cannabinum	0.7 to 5.1

(8) The product has been examined for only a few species, and these examinations have not been thorough. They indicate, however, that the rubber is probably of low grade, not to be compared with fine imported Para, with plantation rubber, nor with chrysil. It would doubtless find use for mixing with other rubbers and in the manufactures where great elasticity is not demanded.

(9) A marked variability in the wild plants, and the number of species involved, indicate that strains with a higher rubber-content than any thus far discovered could be developed by breeding and then perpetuated either by using pedigreed seed or by vegetative reproduction. It is possible that improvement in the quality of the rubber can also be effected by such methods.

(10) By-products in the form of fiber and paper-pulp can be obtained from the residue after the extraction of the rubber. The pulp of *Asclepias subulata* has been worked up into paper of good quality, the yield of dry fiber being 43 per cent and of bleached paper 28.5 per cent of the air-dry weight of the stems. The previous extraction of rubber reduces the cost of paper-making. It seems not unlikely that for this species the profits from fiber would exceed those from rubber.

(11) No opinion is expressed regarding the financial results that might follow from an attempt to grow the plants on a commercial scale. It is certain, however, that considerable scientific experiment should precede any such attempt. Sufficient data have been accumulated to justify the recommendation that these experiments be now undertaken. In this connection there should be considered those native shrubs in which the rubber occurs as solid particles and also various exotic shrubs and herbs, as well as the native species of *Asclepias* and *Apocynum*.

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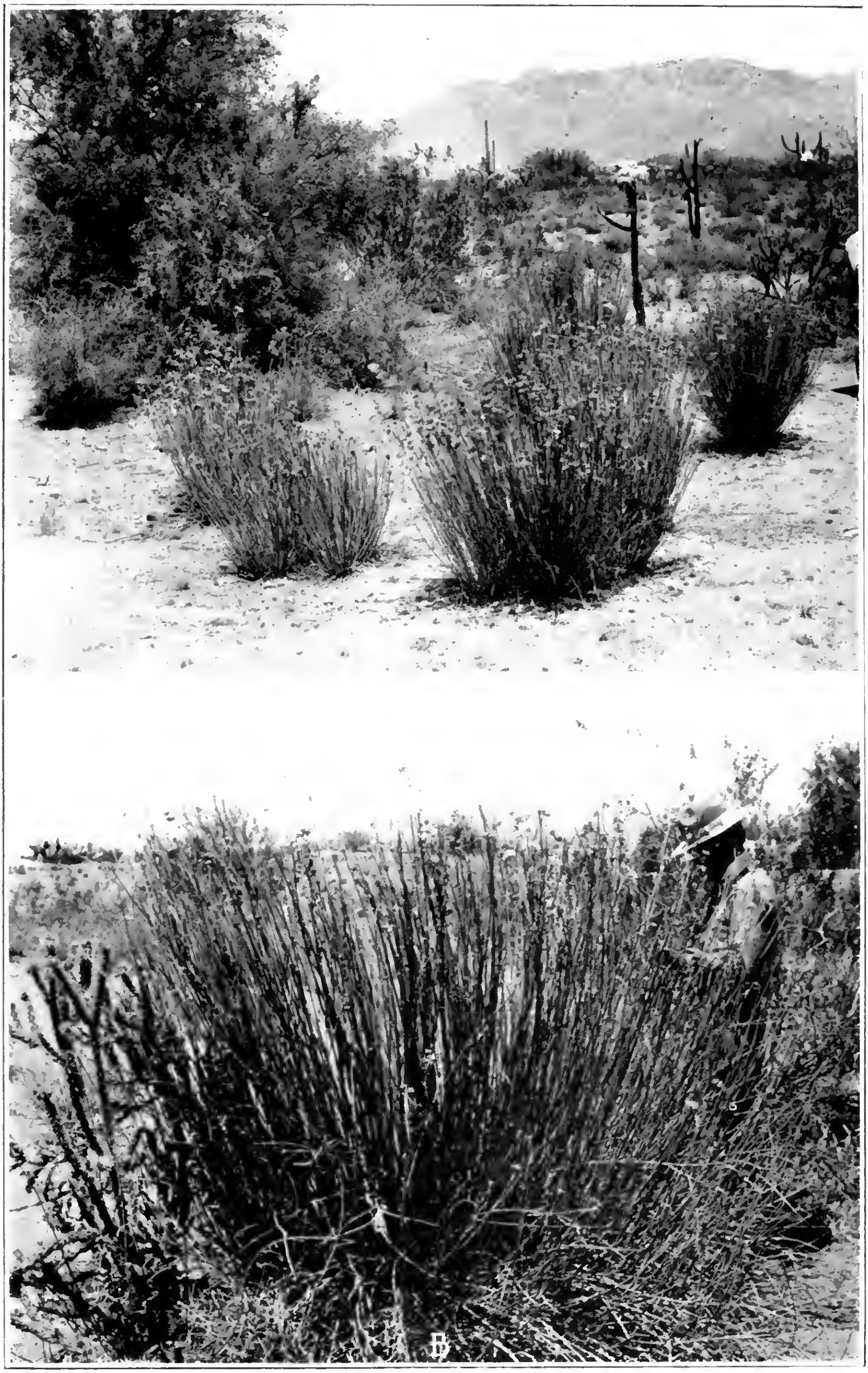
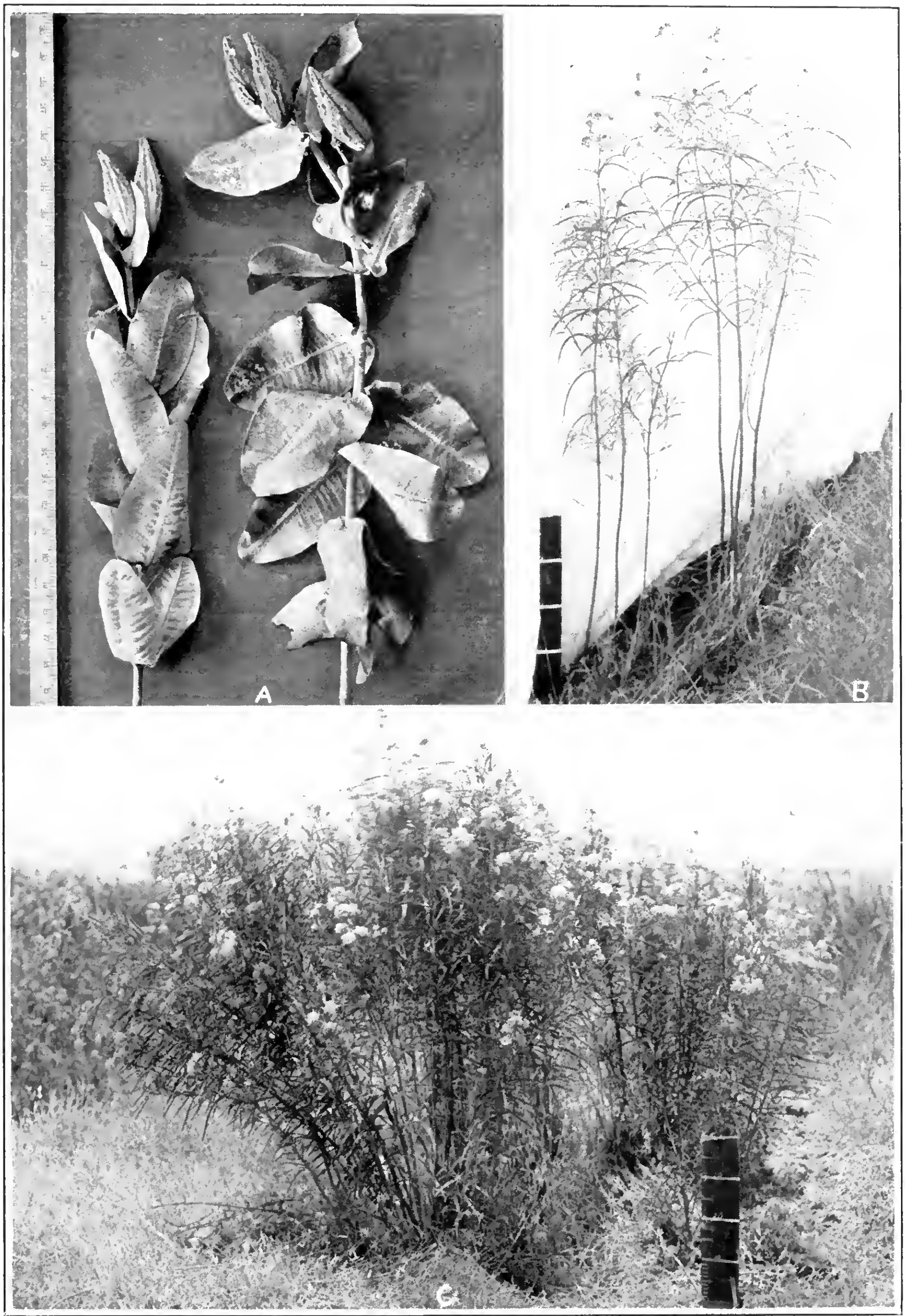
Asclepias subulata, collected at Sentinel, Arizona. Plant 5 feet high.



A. Community of *Asclepias subulata* in an arroyo near Mesa, Arizona.
B. Individual plant of *A. subulata*, showing maximum size in nature.



A. *Asclepias sullivanti*, collected at Lincoln, Nebraska.
B. *Asclepias mexicana*, growing near Dos Palos, California.
C. Community of *A. mexicana*, near Dos Palos. The plant in the foreground is 6 feet high.

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