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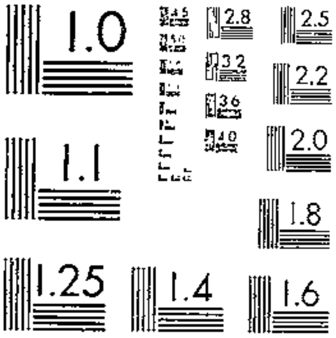

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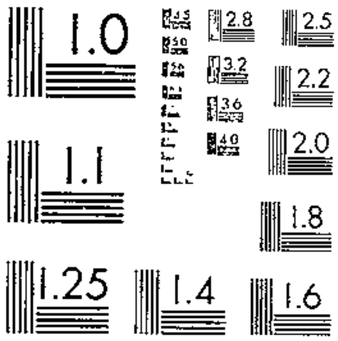

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Technical Bulletin No. 472 May 1935

UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C.

THE DESERT MILKWEED (ASCLEPIAS SUBULATA) AS A POSSIBLE SOURCE OF RUBBER

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INTRODUCTION

The possibility of obtaining rubber from native North American plants has attracted the attention of individuals, rubber companies, and State, Federal, and other agricultural institutions. Many species of native plants are known to contain rubber, though generally in such small quantities as to offer little encouragement to commercial utilization. A few of these species have received detailed study (*1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13*).[2]

Of 64 species of southwestern plants examined by Hall and Long (*6*), *Asclepias subulata*, one of the desert milkweeds, appeared the most promising. Further investigations of this plant were undertaken in 1922 by the United States Department of Agriculture at the United States Acclimatization Garden on the Yuma Reclamation project, near Bard, Calif. Strains of this milkweed were established in cultivation with seed collected from wild plants growing in the vicinity. This afforded material for cultural and other experiments and for comparisons with wild plants. The nature of these experiments and the results obtained are reported in the following pages, with notes on the description and distribution of the species.

DESCRIPTION

The plants of *Asclepias subulata* Decaisne grow as perennial herbs with numerous rushlike stems rising from a central crown near the surface of the ground (fig. 1). The young stems are dark green, later

[1] On Feb. 9, 1934, the Rubber Investigations project was transferred to the Division of Plant Exploration and Introduction.

[2] Italic numbers in parentheses refer to Literature Cited, p. 19.

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becoming woody at the base, and acquiring a grayish-white bloom at maturity. The mature stems are from a quarter to a half inch in diameter and from 2 to 5 feet in height, tapering only slightly from the base to the apex. The leaves, which are short and slender, are produced

FIGURE 1.—*A*, Group of *Asclepias subulata* plants as they appear in their natural habitat, near Yuma, Ariz ; *B*, an individual plant growing wild near Bard, Calif.

only on young stems and shoots and are retained for a comparatively short period. The flowers are greenish yellow and are arranged in umbels at the apex of the stems. The slender tapering seed pods are 4 to 6 inches long and when ripe split along one side, allowing the seeds, each of which bears a pappus of stiff silky hairs, to be scattered by the wind. Floral buds, seed pods, and seeds are shown in figure 2.

FIGURE 2.—Floral buds, flowers, seed pods, and seeds of *Asclepias subulata*. (Natural size.)

A more detailed description of this plant may be found in the report by Hall and Long (*6*).

DISTRIBUTION

The geographic distribution of *Asclepias subulata* extends over a wide area, from southern Nevada on the north to the south end of Baja California and Sonora, Mexico, and from southeastern Arizona westward to the Coast Range of southern California.

Asclepias subulata usually is confined to the dry stony stream beds, where the water runs after the infrequent rains, and in the depressions on the mesas, where the water accumulates and remains for a short period after the rains. Occasionally plants are found on the barren hill slopes. In the depressions where the soil is fairly fertile the plants are considerably larger than those on the hill slopes. In some localities there may be several groups of plants scattered about the washes, mesas, and hill slopes, but often only a few plants are found in isolated groups. The largest continuous area known to the writers begins about 13 miles south of San Luis, Sonora, Mexico, and continues practically to the Gulf of California, a distance of about 55 miles. The plants in this area are found in scattered groups, which are separated by salty flats and sandy mesas. Other large groups of plants have been found in the vicinity of Mesa, Superior, and Yuma, Ariz., and Holtville, Calif.

The areas in which this plant grows most abundantly are subject to wide ranges of climatic conditions, such as frequent high temperatures in the summer and occasional freezing temperatures in the winter, while rains may occur at any time of the year and be followed by long periods of drought. During the past 9 years (1924–32) the temperatures at the United States Acclimatization Garden ranged from 24° to 120° F., with a mean yearly rainfall of 3.91 inches. At Yuma, Ariz.,[3] during the past 54 years (1878–1931) the temperature ranged from 22° to 120° F., and the mean yearly rainfall was 3.47 inches. Records at Mesa, Ariz.,[4] for the past 33 years (1898–1930) show that the temperatures there ranged from 15° to 119° and that the mean yearly rainfall was 8.65 inches.

COLLECTION AND PREPARATION OF MATERIAL

Material for rubber determinations was collected from plants growing near Dome, Mesa, Parker, Sentinel, Superior, and Yuma, Ariz.; Bard, Campo, Holtville, Kane Springs, and Oasis, Calif.; and in the States of Sonora and Baja California, Mexico.

In order to obtain samples for rubber determinations, 2 average stems were selected from the center of the plant and 4 stems from different parts of the outer section, thus making a sample of 6 stems and minimizing the possibility of securing all old or all young stems.

The samples selected for analysis were labeled, wrapped in paper, and stored in a dry room. After sufficient drying, the stems were cut into small sections, about one-fourth of an inch long, and then ground in a hand mill until all of the material would pass through a 20-mesh sieve. This ground material was thoroughly mixed, and a 4-g sample was taken for analysis.

[3] Data furnished by the U. S. Weather Bureau, Yuma, Ariz.
[4] Data furnished by the U. S. Weather Bureau, Phoenix, Ariz.

EXTRACTION OF RUBBER

The method used for extracting rubber was the same as that employed by Hall and Long (*6*), and may be described briefly as follows: Four g of the ground plant material is placed in an extraction thimble and extracted 3 hours in the Bailey-Walker apparatus with 20 cc of acetone. The acetone-soluble material, containing chlorophyll, fats, and resins, is evaporated to dryness and weighed, and the sample is then placed in a clean flask and extracted for 3 hours with 20 cc of benzol. The benzol-soluble material is allowed to stand overnight in the extraction flask, and then is decanted into a 100 cc beaker to eliminate any sediment that may have worked its way through the siphon tube of the extraction thimble. The solvent is evaporated in a water-jacketed oven, and, after cooling in a desiccator, the residual rubber is weighed and reported as a percentage of the original sample. Duplicate analyses were made of each sample of plant material and the results given are the mean of the two determinations.

EFFECT OF STORAGE AND EXPOSURE ON RUBBER CONTENT OF PLANT MATERIAL

An experiment was begun in 1926 to determine the length of time harvested plant material could be left in the field or be stored without affecting the rubber content. The stems from each of two plants that were harvested in January 1926 were divided into 12 samples. Six samples from each plant were left exposed to the weather, and the other samples were cut into short sections, merely for convenience, and stored in paper bags in a dry and partially darkened room. The rubber content was determined at the time of harvesting and for the exposed and stored material at monthly intervals from March to August 1926. At that time all of the exposed material had been used, but samples of the remaining stored material were analyzed at various intervals until October 1930. The results are shown in table 1.

The mean rubber content of the exposed samples decreased from 2 percent in January to 0.20 percent in August, whereas that of the stored material remained practically constant until April 1928, after which it decreased gradually to 1.47 percent in October 1930. This represents a loss of approximately one-fourth of the original rubber content of the plant material during the 4½ years of storage.

TABLE 1.—*Mean percentage of rubber from stored and from exposed material of two Asclepias subulata plants harvested at Bard, Calif., in January 1926 and sampled and analyzed monthly until August 1926 and at indicated intervals until October 1930*

Date of analysis	Rubber content of—		Date of analysis	Rubber content of stored material
	Exposed material	Stored material		
	Percent	*Percent*		*Percent*
January 1926	2.00	2.00	July 1927	1.88
March 1926	1.38	1.98	October 1927	1.91
April 1926	.34	1.90	January 1928	1.84
May 1926	.30	1.93	April 1928	2.01
June 1926	.29	2.00	August 1928	1.82
July 1926	.24	2.05	November 1928	1.72
August 1926	.20	1.98	April 1929	1.49
September 1926		1.92	September 1929	1.50
October 1926		2.05	April 1930	1.53
March 1927		2.11	October 1930	1.47

An experiment with stored material was begun in January 1927 and continued until November 1932. Ten plants were harvested January 15, 1927, and the material was stored in the same manner as in the previous experiment. Samples were analyzed at 3-month intervals during 1927, at 4-month intervals during 1928, and at 6-month intervals during 1929, 1930, 1931, and 1932. The results are as follows:

The rubber content in this case decreased about one-fourth during the first 2 years. The results show clearly that if the plant material is left exposed to the weather its rubber content decreases within a few months after harvesting, but if stored in a dry and partially darkened room it retains practically all of its rubber for at least 2 years.

Date of analysis and percentage of rubber content

	Percent		*Percent*
January 1927	2.29	September 1929	1.84
May 1927	2.22	June 1930	1.78
August 1927	2.56	October 1930	1.77
November 1927	2.16	April 1931	1.90
April 1928	2.06	November 1931	1.48
August 1928	1.91	May 1932	1.44
November 1928	1.86	November 1932	1.42
April 1929	1.82		

RUBBER CONTENT OF WILD PLANTS

Analyses made on wild plants collected in Arizona, California, Sonora, and Baja California showed a range in rubber content from 0.5 to 6.0 percent. Although the plants with 3.0 to 3.5 percent rubber formed the largest group, the groups with lower proportions of rubber were much larger than groups with higher proportions, as shown below.

Range in rubber percentage	*Number of plants*	Range in rubber percentage—Con.	*Number of plants*
0.50–1.00	13	3.51–4.00	44
1.01–1.50	15	4.01–4.50	25
1.51–2.00	41	4.51–5.00	3
2.01–2.50	73	5.01–5.50	2
2.51–3.00	73	5.51–6.00	1
3.01–3.50	102	Mean=2.86.	

The rubber content of individual plants growing in the same locality was found to differ considerably (table 2). Where series of analyses were comparable, as of plants from Bard and Oasis, Calif., in January 1925, and from Dome and Mesa, Ariz., in February 1925, it appeared that some of the groups might have a higher rubber content than others. Many other determinations of rubber content were made on individual plants from these and other localities from 1924 to 1932, and with a few exceptions the majority of the analyses fell within the ranges shown in table 2.

To obtain further information regarding the nature of these differences, two series of samples were taken from two large plants, and duplicate analyses were made of each sample (table 3). The rubber content of the samples ranged from 3.05 to 3.94 percent. The greatest difference between the duplicate analyses was that between 3.35 and 3.42 percent, so that the error in sampling appears to be several times as great as the error in analysis. As each plant usually consists of

150 to 200 stems, each of the 6-stem samples would represent approximately only 3 or 4 percent of the plant, so that variation in such samples would be expected, but the method of taking samples would not explain the wide range of differences among the wild plants shown in table 2.

TABLE 2.—*Rubber in wild plants from different localities*

State and locality	Date collected	Plants	Range in rubber content
		Number	*Percent*
Arizona:			
Dome	February 1925	10	0.62–2.48
Mesa	do	12	1.33–3.45
Parker	April 1927	8	1.98–3.80
Superior	September 1924	6	1.75–4.29
Sentinel	September 1925	10	2.24–4.50
Tempe	May 1928	10	1.61–2.35
Yuma	January 1927	10	1.98–3.85
California:			
Bard	January 1925	10	1.59–4.49
Oasis	do	8	1.57–3.67
Holtville	January 1931	10	2.63–4.29
Sonora, Mexico:			
El Doctor	April 1931	10	2.05–3.85
San Luis	March 1925	34	1.61–5.09
Do.	January 1926	20	1.75–4.14

TABLE 3.—*Duplicate rubber determinations of samples from 2 Asclepias subulata plants, and mean rubber percentage and range for each plant*

Sample number	Rubber content: Plant 1, Individual determination	Plant 1, Mean	Plant 2, Individual determination	Plant 2, Mean
	Percent	*Percent*	*Percent*	*Percent*
1	3.50	3.50	3.67	3.63
1	3.50		3.60	
2	3.65	3.62	3.57	3.57
2	3.60		3.57	
3	3.73	3.73	3.80	3.79
3	3.73		3.78	
4	3.72	3.70	3.08	3.05
4	3.68		3.03	
5	3.80	3.80	3.77	3.73
5	3.80		3.70	
6	3.45	3.45	3.35	3.38
6	3.45		3.42	
7	3.95	3.94	3.77	3.70
7	3.93		3.75	
8	3.58	3.56	3.83	3.84
8	3.55		3.85	
Mean		3.66± [1] 0.057		3.59± [1] 0.093
Range	3.45–3.94		3.05–3.84	

[1] Standard error.

PROPAGATION AND CULTURAL METHODS

Numerous unsuccessful attempts were made to propagate the plants vegetatively by cuttings and root-crown divisions and by budding. However, no difficulty was encountered in germinating the seed or in transplanting seedlings, and several large plants were successfully transplanted. All of the experimental plantings were made from selected seed.

The wild plants were marked when sampled and later seed from high rubber-yielding individual plants were collected separately and planted as selections. Also general plantings were made of seeds from groups of plants all of which had a high percentage of rubber.

The individual selections were started in small tar-paper pots and transplanted to the field when 6 to 8 inches tall. The general plantings were made with a small hand planter, at the rate of about 2 pounds of seed to the acre, in rows spaced 3 feet apart in preirrigated seed beds. When the seedlings reached a height of approximately 6 inches they were thinned to a distance of about 3 feet in the rows. Other spacings are being tried in order to determine the optimum condition of growth.

The seed beds were irrigated as soon as necessary after planting, and during the first 2 years the plantings were cultivated and irrigated in the spring and again in the summer. After that time the plants usually were large enough to overlap in the rows and further cultivation was not feasible or necessary, but irrigation was applied as needed.

Under favorable conditions the seed germinated within 7 or 8 days and the seedlings made rapid growth, developing from a single stem to a many-stalked plant during the first year. Seedlings when 1 month old averaged 2½ inches in height and had 5 pairs of true leaves. Year-old plants under field conditions averaged 33.9 inches in height and 5 inches in circumference at the base and had 65 stems; 2-year-old plants averaged 39.7 inches in height and 10.7 inches in circumference at the base and had 121 stems; 3-year-old plants averaged 46.2 inches in height and 11.8 inches in circumference at the base and had 149 stems.

Flowers and pods are developed during the first year, and thereafter, especially with plants irrigated in the spring, there are two definite flowering periods, the first during May and June and the second in September. Most of the pods from the first flowering period are mature when the second period starts. During the second period only a few flowers are produced and the pods seldom reach maturity on account of cold weather.

RUBBER CONTENT IN RELATION TO GROWTH, FRUITING, AND DORMANCY

Plants of *Asclepias subulata* under normal conditions produce vegetative growth and fruit during the spring and summer and are dormant during the fall and winter. Data collected from a few individual plants indicated that there was a tendency for the percentage of rubber to fluctuate with such changes in the plant activity, and several experiments were conducted from 1924 to 1932, to provide information on this point.

In one of these experiments 15 plants growing on the station were sampled and analyzed every 3 months from January 1927 to October 1930. At the time of the first analysis the plants were about 2½ years old, having been planted July 7, 1924, and the spacing was approximately 3 by 3 feet. The plat was irrigated and cultivated at about 4-month intervals during the first 2 years, and once each spring thereafter. The results of these analyses are given in table 4.

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TABLE 4.—*Individual percentages and range of rubber of 15 Asclepias subulata plants sampled and analyzed at 3-month intervals from January 1927 to October 1930*

Plant no.	Percentage of rubber																Range
	1927				1928				1929				1930				
	January	April	July	October	January	April	July	October	January	April	July	October	January	April	July	October	
1	2.29	[1] 1.81	[1] 1.82	2.62	2.31	2.30	[1] 2.06	2.23	2.78	[1] 1.72	[1] 1.04	1.45	[1] 1.19	[1] 1.15	[1] 1.34	2.39	1.04–2.78
2	2.35	[1] 1.70	2.65	2.86	2.85	3.04	[1] 2.60	3.11	1.85	[1] 1.51	1.80	1.76	1.80	[1] 1.94	2.20	2.47	1.51–3.14
3	1.74	[1] 1.75	2.16	1.94	2.22	[1] 1.84	[1] 1.82	2.45	2.11	2.14	[1] 1.34	[1] 1.55	1.41	[1] 1.20	[1] 1.60	2.11	1.20–2.45
4	1.89	[1] 1.70	[1] 1.83	2.25	2.14	[1] 2.19	2.36	2.67	2.70	[1] 1.83	2.22	1.98	[1] 1.41	[1] 1.50	2.42	2.31	1.41–2.70
5	1.82	[1] 1.44	[1] 2.01	2.32	2.39	[1] 1.92	2.36	2.74	3.09	[1] 1.65	[1] 1.05	1.74	1.67	[1] 1.13	[1] 1.69	1.95	1.05–3.09
6	2.54	[1] 2.16	2.70	3.35	2.97	[1] 2.56	[1] 2.66	3.05	2.82	[1] 2.31	3.00	2.35	[1] 1.74	[1] 2.42	2.50	3.76	1.74–3.76
7	3.40	[1] 2.17	3.28	4.58	4.25	[1] 3.61	4.21	5.01	3.36	[1] 2.09	3.04	[1] 2.30	[1] 1.78	2.50	2.50	3.69	1.78–5.01
8	2.59	[1] 1.59	[1] 1.65	2.17	2.24	[1] 1.85	[1] 2.01	2.50	2.25	[1] 1.90	[1] 1.36	1.76	[1] 1.28	[1] 1.39	2.05	2.80	1.28–2.80
9	2.56	[1] 1.59	2.25	2.31	2.35	[1] 1.74	2.58	2.54	2.47	----	[1] 1.58	2.30	[1] 1.57	[1] 1.51	2.55	2.83	1.51–2.83
10	2.96	[1] 2.50	[1] 2.41	3.55	3.90	[1] 2.95	[1] 2.90	4.75	2.34	2.30	[1] 2.00	[1] 1.96	[1] 1.35	[1] 1.89	2.29	2.51	1.35–4.75
11	1.70	[1] 1.70	2.69	2.83	2.96	[1] 1.56	[1] 1.87	2.57	2.11	3.50	[1] 1.46	2.05	[1] 1.18	[1] 1.12	2.27	2.42	1.12–3.50
12	1.88	[1] 1.69	[1] 1.67	2.40	2.17	[1] 2.30	3.37	3.59	2.46	2.15	[1] 1.32	1.99	[1] 1.28	[1] 1.69	2.00	3.31	1.28–3.59
13	2.10	[1] 1.74	2.85	2.48	2.83	[1] 2.21	2.55	3.82	1.93	2.46	[1] 1.42	2.31	[1] 1.22	[1] 1.75	2.00	3.10	1.22–3.82
14	3.19	[1] 2.56	[1] 2.42	3.46	3.52	[1] 3.38	[1] 3.07	3.75	2.86	2.42	[1] 1.81	2.02	[1] 1.55	2.00	2.01	2.77	1.55–3.75
15	2.32	[1] 2.25	[1] 2.17	2.41	3.24	[1] 2.15	[1] 2.03	2.70	1.65	[1] 1.53	[1] 1.19	1.93	[1] 1.18	[1] 1.64	1.86	2.85	1.18–3.24

[1] Plant producing vegetative growth or flowers and pods when sampled.

It will be noted that the percentage of rubber in each plant fluctuated widely during the 4 years and also that the periods of plant activity were not the same for all plants. With such variation in the time of plant activity, differences in the rubber content are not equally significant at each date of analysis. However, when the rubber content of the individual plants during the periods of plant activity is compared with analyses representing dormant periods, differences in favor of the dormant periods are shown by all the plants (table 5). Also, it will be seen that the minimum rubber content of each plant was recorded during a period of plant activity and that the maximum was recorded during a dormant period. The fact that all 15 plants had a higher rubber content during the dormant period definitely indicates that the rubber content is affected by the physical condition of the plant.

TABLE 5.—*Mean rubber percentage of samples of 15 Asclepias subulata plants during periods of plant activity and dormancy from January 1927 to October 1930*

Plant no.	Mean rubber percentage during periods of—		Mean difference in rubber percentage	Plant no.	Mean rubber percentage during periods of—		Mean difference in rubber percentage
	Activity	Dormancy			Activity	Dormancy	
1	1.52	2.29	0.77	9	1.60	2.47	0.87
2	1.94	2.40	.46	10	2.25	3.07	.82
3	1.59	2.03	.44	11	1.48	2.51	1.03
4	1.74	2.29	.55	12	1.66	2.53	.87
5	1.56	2.23	.67	13	1.67	2.58	.91
6	2.31	2.90	.59	14	2.46	2.80	.34
7	2.30	3.02	1.23	15	1.77	2.37	.60
8	1.63	2.29	.66				
				Mean	1.84	2.56	.72

The responsiveness of *Asclepias subulata* plants to favorable climatic conditions was clearly shown during the winter of 1929–30. During August and September of 1929 the rainfall amounted to 3.38 inches, which was three times the normal rainfall for these months. This additional moisture and the mild winter that followed brought about an active vegetative condition of the plants, and new growth was produced by 3 plants in October 1929 and by 12 plants in January 1930. This period of plant activity was, no doubt, responsible for the comparatively low percentage of rubber recorded during these months.

Another series of comparisons for learning effects of plant activity on the rubber content was conducted with five wild plants in the vicinity of Mesa, Ariz. This was made possible through the cooperation of Evens Blewett, of Mesa, and of Harvey M. Hall and Frances Long, of the Carnegie Institution. The plants selected were sampled by Mr. Blewett about the first of each month, from February to August 1927 and again in December 1927. The samples were divided into two sections, representing, respectively, the apical and the basal portions of the stems. Dr. Long made the rubber determinations for February and March, but was unable to continue, and thereafter the analyses were made at Bard. The range and mean percentage of rubber for the apical and basal portions of the five plants analyzed each month is given in table 6.

TABLE 6.—*Range and mean percentage of rubber, during periods of plant activity and dormancy from February to December 1927, for the apical and basal portions of 5 wild Asclepias subulata plants growing near Mesa, Ariz.*

Month	Condition of plants	Percentage of rubber for—			
		Apical portion		Basal portion	
		Range	Mean	Range	Mean
February	Dormant	2.64–4.51	3.31	1.01–3.24	2.03
March	do	1.07–5.90	3.89	1.28–3.00	2.18
May	Active	1.42–3.36	2.10	.62–1.50	.99
June	do	.90–3.18	2.13	.52–1.49	.87
July	do	1.50–3.46	2.34	.70–1.32	1.01
August	Dormant	1.60–3.92	2.61	.50–1.62	1.05
December	do	2.30–4.21	3.41	1.12–2.61	1.72

While no definite records were made regarding the condition of the plants when sampled, the stems received from Mr. Blewett indicated that they followed the usual growth cycle. The stems collected in May and June bore a few flowers and pods, and the July samples had a few mature pods on the stems, indicating that the plants were active during the spring and were practically dormant when sampled in July.

The plants had a higher percentage of rubber during the dormant period than during the active period, and this difference appeared in both apical and basal samples. In the case of the apical portion, the mean rubber content for May, June, and July was 2.22 percent, and for February, March, August, and December the mean percentage of rubber was 3.31, a difference of 1.09 percent in favor of the dormant period. During the active period the basal portion had a mean percentage of 0.96 as contrasted with 1.75 percent for the dormant period, a difference of 0.79 percent in favor of the dormant period.

The consistently higher percentage of rubber in the apical portion of the stems is due to the fact that this portion of the plant has less woody fiber, which contains very little rubber, while a much greater percentage of rubber is found in the bark. Samples analyzed in 1929 showed that the bark represented 52.8 percent of the dry weight of the apical portion of the stems and 37.4 percent of the basal portion. For the entire sample the rubber content of the bark was 5.99 percent and that of the woody center was 0.10 percent.

The results of plant activity on the rubber content of the plants in this experiment are similar to those recorded in the previous experiment, although the plants were grown under different climatic and environmental conditions. Other data, collected from both wild and cultivated plants, showed the same tendency.

DATA ON SUCCESSIVE CROPS

The ability of *Asclepias subulata* plants to produce new stems from the root crown after the tops have been cut or destroyed suggests the possibility of obtaining successive crops from the same root stocks. The intervals between cuttings would depend on the amount of new growth and the time required for such growth to develop a sufficient amount of rubber. To obtain some information of this nature, several experiments were undertaken, and while the results are not conclusive, some information was obtained on the rate of growth and production of new stems and on the rate of increase in the rubber content of such growth.

Under cultivation on the Bard station, *Asclepias subulata* plants reach their full size in 3 years and attain their maximum rubber content in about 4 years. The rubber content showed a constant increase during the first 4 years, after which it appeared to fluctuate within a narrow margin. The low rubber content of the 5-year-old plants probably was due to the production of new growth when the majority of these plants were sampled. The frequency distribution and mean percentage of rubber of plants from 1 to 7 years old are recorded in table 7.

TABLE 7.—*Frequency distribution and mean percentage of rubber of cultivated Asclepias subulata plants, 1 to 7 years old*

Age of plants (years)	Number of plants showing indicated percentage of rubber										Mean percentage of rubber
	0.00 to 0.50	0.51 to 1.00	1.01 to 1.50	1.51 to 2.00	2.01 to 2.50	2.51 to 3.00	3.01 to 3.50	3.51 to 4.00	4.01 to 4.50	4.51 to 5.00	
1	73	93	32	19	5	0	0	0	0	0	0.78
2	3	39	78	93	74	21	4	0	0	0	1.72
3	0	0	21	84	75	52	18	5	2	0	2.22
4	0	2	0	43	52	30	17	11	2	3	2.49
5	0	0	24	34	22	5	4	0	0	0	1.80
6	0	0	1	6	13	6	2	2	0	0	2.42
7	0	1	6	16	17	26	13	6	1	1	2.52

In 1926 and 1927 a number of 2-, 3-, and 4-year-old plants and a few wild plants were harvested during the spring, summer, fall, and winter, and data were recorded on the rate of growth and the increase in rubber content of the new growth. The experiment begun in 1926 consisted of 12 plants planted in July 1924 and referred to as 2-year-old plants, and 12 plants planted in April 1923 and referred to as 3-year-old plants. Three plants from each planting were cut off within a few inches of the ground during January, April, July, and October (fig. 3).

The subsequent growth of the plants that were harvested in October was killed by cold weather in December. The height, number of stems, rubber content, and data for the subsequent growth of the other plants when 1 and 2 years old are shown in table 8.

TABLE 8.—*Mean height, number of stems, and rubber percentage of plants of Asclepias subulata 2 and 3 years old when harvested, and of the new growth 1 and 2 years later*

Month and year harvested and age of stems	2-year-old plants			3-year-old plants		
	Height	Stems	Rubber content	Height	Stems	Rubber content
	Inches	*Number*	*Percent*	*Inches*	*Number*	*Percent*
January 1926 (2 years)	35.0	68	2.08	48.6	288	1.98
January 1927 (new growth at age of 1 year)	40.7	189	1.15	39.7	592	1.48
January 1928 (new growth at age of 2 years)	[1] 38.1	173	2.58	[1] 33.3	580	2.31
April 1926 (2 years)	33.6	71	2.06	42.0	162	2.85
April 1927 (new growth at age of 1 year)	41.0	155	1.49	34.6	252	1.22
April 1928 (new growth at age of 2 years)	41.6	158	1.93	34.6	250	2.07
July 1926 (2 years)	40.0	117	2.09	61.3	252	2.24
July 1927 (new growth at age of 1 year)	17.5	123	1.64	24.0	271	1.11
July 1928 (new growth at age of 2 years)	23.5	133	1.70	24.0	270	1.39

[1] Tips of st[illegible] killed by frost.

FIGURE 3.—*A*, 3-year-old *Asclepias subulata* plant; *B*, root crown with stems cut off; *C*, new growth 1 month after being cut back.

Ratooning resulted, in the case of plants harvested in January and April, in a marked increase in the number of stems, which in a year's time were as tall as the original plants (fig. 4). Although the 3-year-old plants had many more stems, the increase due to ratooning is in nearly the same ratio as for the 2-year-old plants. No increase in size or number of stems was recorded during the second year. The rubber content of plants harvested in January was higher 2 years after ratooning. While the rubber content of the April-harvested plants increased steadily, it did not attain the percentage of the original stems.

The plants that were harvested in July did not grow as rapidly as those harvested in January and April. Two years after harvesting

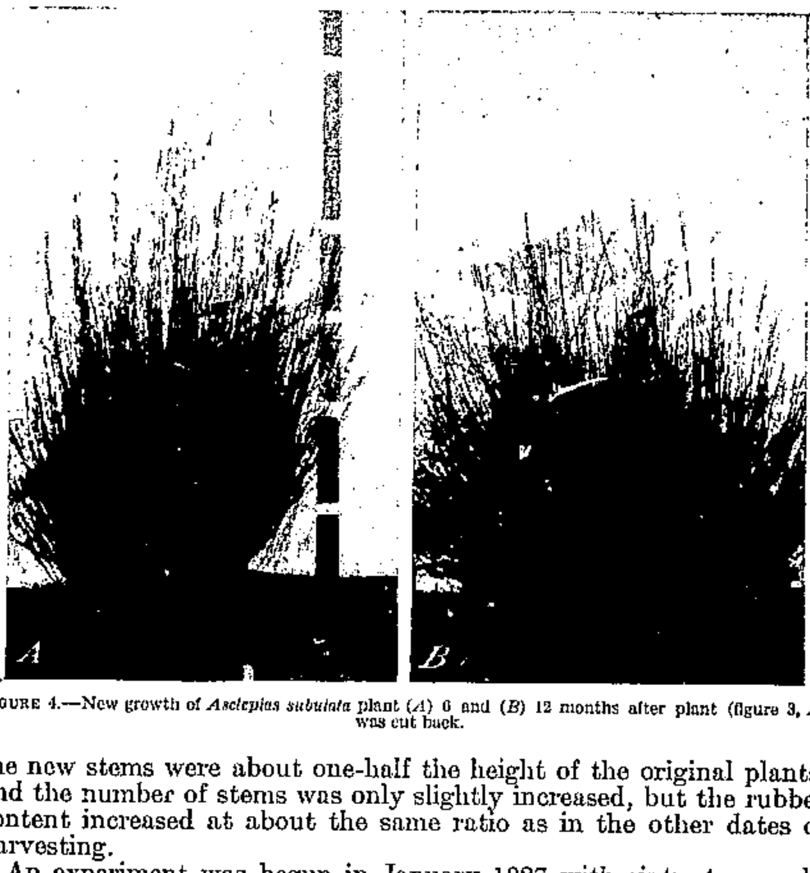

FIGURE 4.—New growth of *Asclepias subulata* plant (*A*) 6 and (*B*) 12 months after plant (figure 3, *A*) was cut back.

the new stems were about one-half the height of the original plants, and the number of stems was only slightly increased, but the rubber content increased at about the same ratio as in the other dates of harvesting.

An experiment was begun in January 1927 with sixty 4-year-old station plants and 20 wild plants from the Yuma mesa. These plants were divided into four groups, each group consisting of 15 station plants and 5 wild plants, harvested during January, April, July, and October. For 4 consecutive years the mean height, number of stems, and percentage of rubber were determined for each group of plants when harvested and for the new growth. These data are given in table 9.

TABLE 9—*Mean height, number of stems, and rubber content of 15 cultivated plants of Asclepias subulata, harvested when 4 years old, and of 5 wild plants from the Yuma mesa, harvested on the same dates, and of samples of the new growth collected each year*

Month and year harvested and age of stems	Station plants			Wild plants		
	Height	Stems	Rubber content	Height	Stems	Rubber content
	Inches	*Number*	*Percent*	*Inches*	*Number*	*Percent*
January 1927 (4 years)	41.7	139	2.18	46.0	121	2.87
January 1928 (new growth at age of 1 year)	27.3	261	1.83	35.5	310	2.95
January 1929 (new growth at age of 2 years)	28.1	267	2.52	37.0	206	4.01
January 1930 (new growth at age of 3 years)	51.3	234	[1] 1.51	37.0	310	[1] 3.06
January 1931 (new growth at age of 4 years)	52.8	230	1.90	43.0	315	3.66
April 1927 (4 years)	37.0	70	[1] 1.97	40.0	73	[1] 2.52
April 1928 (new growth at age of 1 year)	28.2	90	1.58	34.2	165	1.30
April 1929 (new growth at age of 2 years)	28.0	90	2.40	40.0	173	[1] 1.75
April 1930 (new growth at age of 3 years)	46.7	107	[1] 1.55	51.0	140	[1] 2.77
April 1931 (new growth at age of 4 years)	46.4	99	2.57	51.0	137	[1] 2.55
July 1927 (4 years)	42.0	74	[1] 2.49	48.4	91	[1] 2.68
July 1928 (new growth at age of 1 year)	25.3	130	1.37	26.6	227	1.63
July 1929 (new growth at age of 2 years)	39.0	166	[1] 1.77	32.0	179	[1] 2.17
July 1930 (new growth at age of 3 years)	48.3	140	[1] 1.87	44.0	190	[1] 2.44
July 1931 (new growth at age of 4 years)	50.0	135	[1] 2.99			
October 1927 (4 years)	36.7	118	[1] 2.92	34.2	74	3.62
October 1928 (new growth at age of 1 year)	21.7	73	2.39	27.7	55	3.84
October 1929 (new growth at age of 2 years)	41.0	101	[1] 2.72	28.0	60	3.45
October 1930 (new growth at age of 3 years)	40.0	101	[1] 2.80	30.0	85	[1] 2.53
October 1931 (new growth at age of 4 years)	39.2	135	3.59			

[1] Plants flowering and producing pods.

These plants, with the exception of the October harvest, also showed an average increase in the number of stems, due to ratooning, although the rate of growth was somewhat slower than that of the plants ratooned in 1926. The new growth for each period of harvesting had practically reached its maximum size and number of stems at the end of the third year, and in most cases the plants were larger than when harvested. October is apparently too late in the season to harvest. In 1926 all October-harvested plants died, and in the 1927 experiment the ratooning process reduced the number of stems for a 3-year period. The rubber content in the new growth fluctuated considerably during the 4 years, due no doubt to the error of sampling and to the climatic conditions encountered during the different years.

The results of these two experiments indicate that the cultivated plants reach their maximum size and rubber content about 3 or 4 years after planting and that the new growth produced by wild and cultivated plants after ratooning reaches its maximum size and rubber content in about the same period. Therefore, the maximum yield of rubber could be expected from plants about 3 years old and harvested during a dormant period, with successive crops at approximately 3-year intervals.

EFFECT OF SPACING ON PLANT DEVELOPMENT AND RUBBER CONTENT

Plant measurements and rubber determinations were made for several different spacings between plants in the rows as well as for a small broadcast area. The small broadcast planting was made in April 1923, and 70 plants were harvested and weighed in January 1926 from an area of 143 square feet. The mean dry weight per plant was 0.72 pound and the mean rubber content 1.99 percent. At this rate, an acre yield of 18,327 pounds of dry plant material, or

365 pounds of rubber, might be calculated. Though comparisons with yields of plants in wider spacings were not made at this time, the results obtained from this small area would afford a slight indication of yields of rubber that might be obtained on a scale of commercial production.

A bulk planting in April 1927 consisted of 10 rows 3½ feet apart and 165 feet long. The seed was planted at the rate of 2 pounds to the acre in beds previously irrigated and harrowed, and a good stand was obtained. Five of the rows were thinned to 1 plant every 2 feet and the other 5 left unthinned. A section of the unthinned and 2-foot spaced plants, approximately 1 year after planting, is shown in figure 5.

In May 1928, when the plants were about 1 year old, a section 12 feet long was harvested across the 10 rows, and the height, number of stems, dry weight, and rubber content of the plants recorded. The individual 2-foot spaced plants were larger in all respects and had a slightly higher rubber content than the unthinned plants, but the total yield of dry plant material from the harvested area of unthinned plants was more than twice as great as that from the 2-foot spacing, and the yield of rubber was 1.82 times as great. These data indicated an acre rubber yield of 70.63 pounds for the unthinned rows and 37.75 pounds for the plants spaced 2 feet apart in the rows.

On April 3, 1928, another planting was made with rows spaced 1, 2, 3, and 4 feet apart. A good stand was obtained and on June 25 the plot was divided into two sections; the plants in one section were thinned to 1 plant every 3 feet in the rows, with the exception of the 1-foot rows, which were left unthinned in both sections.

A 20-foot section was harvested across the rows of both sections in November 1929, and the mean size and rubber content of the plants was determined for each row spacing of the unthinned and thinned sections. The individual plants of the thinned rows of all of the row spacings were larger in all respects than those of the unthinned rows. However, the larger number of plants in unthinned rows more than balanced this increase in plant size, as the unthinned rows produced more plant material in each comparison with the thinned rows (table 10).

TABLE 10.—*Percentage of rubber in dry plant material, and the computed acre yields of dry plant material and rubber for plants and rows of different spacing*

Space between rows	Space between plants	Rubber content of dry plant material	Computed acre yield of dry plant material	Computed acre yield of rubber
Feet	*Feet*	*Percent*	*Pounds*	*Pounds*
1	(1)	2.25	9,431	212
2	(1)	2.13	6,067	130
2	3	2.23	4,096	91
3	(1)	2.41	6,890	166
3	3	2.37	3,663	87
4	(1)	1.97	7,972	157
4	3	2.01	3,453	71

1 Plants unthinned.

The results of these experiments indicate that although the individual plants are reduced in size and weight, larger yields of rubber could be expected from closely spaced plants and that the cost of cultivation would be reduced, as very few weeds grow in the closely spaced rows.

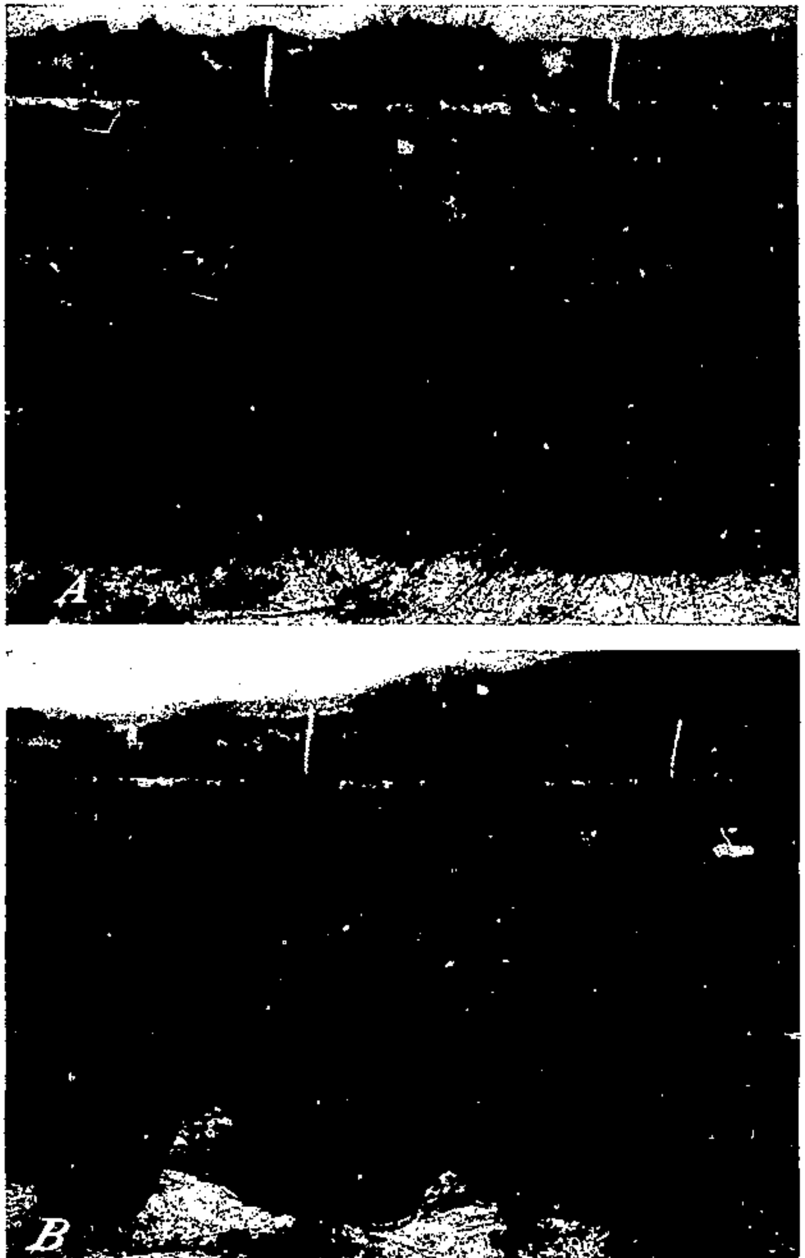

FIGURE 5.—*A*, Section of unthinned rows of *Asclepias subulata* plants; *B*, section of rows with plants spaced 2 feet apart.

BREEDING WORK

The pollination of *Asclepias subulata* is rather complex, and for that reason the breeding and maintaining of desirable strains is very difficult. It is reported that the flowers of *Asclepias* are infertile not only to their own pollen but also to that derived from plants raised vegetatively from the same stock (7). Several unsuccessful attempts were made to secure self-pollinated seed from high rubber-yielding plants and to propagate such plants by cuttings, by divisions of the root crown, and by budding.

The flowers of this species are especially adapted to cross-pollination by insects, as the pollen is found on special organs, the pollinia, five in each flower, which are located in stigmatic chambers that alternate with fleshy petaloid appendages. Each of these chambers has a narrow slit into which the claw of a visiting insect may slip, so that pollinia are lifted out on the claws of the insects and carried to the stigmatic chambers of other flowers, thus effecting pollination.

Several hybrid pods were obtained by hand- and insect-controlled pollination. These operations, however, are very uncertain and tedious, and the viability of the seed was very low. Only a few seedlings were obtained and these, unfortunately, did not survive when transplanted to the field.

In cross-pollinating by hand, a long slender needle with a small hook on the point was used. The needle was slipped into the slit, as in the case of the insect claw, and gently drawn upward, pulling the hook and pollinium out, and a foreign pollinium was introduced. The controlled crosses by insects were obtained by placing a 16-mesh screen cage over two plants of different strains. When these plants began to flower, several large wasps, *Pepsis formosa* (Say), commonly called tarantula hawk, which apparently do most of the pollinating of the native milkweeds, were placed in the cage. These wasps were carefully examined to make sure that no pollinia were attached to their claws when introduced.

INSECT PESTS

Asclepias subulata appears to be comparatively free from insect pests. Only three have been observed to injure the wild or cultivated plants.

A species of aphid (*Aphis nerii* Fonscolombe or *A. lutescens* Monell) has been found to cause considerable damage to the tender seedlings and young growth, in some instances killing the seedlings. These insects usually appear in the spring and remain until midsummer, and are as abundant on the wild plants as on the cultivated. They can be satisfactorily controlled with 40 percent nicotine sulphate spray.

A sucking insect, the hemipteron *Oncopeltus fasciatus* (Dall.), feeds on the pods in the fall. These insects, which collect in colonies on the pods, cause considerable damage to the seeds. In order to ascertain the amount of the damage, a number of small pods that had not been attacked were covered by glazed bags, and another series of pods, on which the insects were feeding, were tagged. As the pods matured they were collected and a germination test made. The percentage of viable seeds from the protected pods was 82.6, while only 6 percent of the unprotected seeds germinated. However, as these insects appear in the late summer, after the majority of the pods have matured, the damage is not considered of great importance.

The larva of the monarch or milkweed butterfly, *Danaus menippe* (Hbn.), causes some damage to the small plants for a brief period during the summer months. These insects are not very abundant and can be controlled by dusting the plants with lead arsenate.

SUMMARY

The investigations conducted at the United States Acclimatization Garden near Bard, Calif., with *Asclepias subulata* (one of the desert milkweeds) show that harvested plant material when stored for a period of 2 years showed no appreciable loss in the rubber content, but plant material when left exposed to the weather after being harvested lost practically all of its rubber within 90 days.

In Arizona and California and in Sonora and Baja California, Mexico, the rubber percentage of the wild plants examined ranged from 0.5 to 6.0 percent, with a mean of 2.86 percent. Seeds selected from high-yielding wild plants and grown under cultivation at Bard had a maximum rubber content of 5 percent in 3-year and 4-year plants, the age at which the plants reached their maximum size.

The results of the experiments herein reported indicate that the rubber content of the wild and cultivated plants is highest during the dormant period, which usually occurs in the fall and winter.

Plants harvested in January and April ratooned rapidly and produced a greater number of stems, while those harvested in July ratooned slowly. Plants harvested in October died or recovered very slowly. New growth and rubber produced by plants 2½ to 3 years after ratooning often exceeded that of the original plants.

Closely spaced plants produced larger yields of rubber than did wide-spaced plants. Unthinned 2-year-old plants in rows 1 foot apart produced rubber at the rate of 212 pounds to the acre, as compared with a rate of 71 pounds to the acre for plants spaced 3 feet apart in rows 4 feet apart.

The development of high-yielding strains through selection is likely to prove difficult, as the flowers are self-sterile, artificial pollination is a very slow and tedious process, and vegetative propagation by buds, cuttings, or divisions of the root crown has not proved feasible.

Only three species of insects have been observed to injure the plants and pods. The damage caused by these pests is comparatively slight and control methods have been fairly successful.

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U. S. GOVERNMENT PRINTING OFFICE: 1935

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price 5 cents

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