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MASTER

FINAL REPORT

Assessment of Plant-Derived Hydrocarbons

September 30, 1981

Prepared for:

Department of Energy
Office of Program Analysis
Under Contract Number
DE-AC01-80ER30006

Prepared by:

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EXECUTIVE SUMMARY

We evaluated several hydrocarbon producing plants that have been suggested in the literature as possible crops for arid lands. These plants are potential sources of rubber, liquid fuel, and industrial lubricants.

Evaluating the commercial agricultural potential of these plants relative to that of traditional crop plants is not straightforward -- particularly in predicting the yields that can be expected. Some promoters of hydrocarbon producing plants have pointed to the tremendous gains in yields that have been achieved in breeding certain traditional crops: If even a fraction of such increases could be achieved in a hydrocarbon producing plant such as Euphorbia lathyris, this plant would currently be commercially viable, according to proponents. However, several factors must be considered in drawing these comparisons.

It should be remembered that much time and effort has been put into breeding current crops -- with some crops, such as corn and wheat, the genetic selection process has occurred over centuries. Modern genetic improvement techniques have drastically shortened the selection process, however, introducing new crops and improving them genetically is certain to be a time consuming and expensive process. Further, the genetic potential for improvement in these plants is unknown.

In order to increase yields, crop breeding has traditionally adapted plants to environmental conditions of high input agriculture: high nutrients, adequate water, and ample pesticides and herbicides to decrease competition with pests (Evans, 1980). If resources were unlimited, this strategy would be reasonable. However, in growing plants for energy production, it is necessary to determine whether or not high input levels make sense from an energy and economic standpoint.

Some researchers have claimed that hydrocarbon producing plants can be grown with minimal or no inputs. It is not known whether current yields can be maintained, let alone increased, without moderate to high levels of inputs, particularly without irrigation. Further, it has not been demonstrated that these plants can be cultivated on a commercial scale with minimal or no inputs on arid lands.

Other researchers have recommended growing hydrocarbon producing plants with minimal inputs and increasing the cultivation time (this applies only to perennial plants). The key assumptions in this recommendation are the following:

1. There is an abundance of inexpensive, arid land that is idle and could be put into production.

2. Hydrocarbon plants could be grown with only one irrigation at the time of planting to establish the plant.

3. Although the time period before a return is realized would be increased and the yields at harvest would be low, a reasonable return would still be realized at the end of the payback period.

This approach has not been demonstrated to date, but is being pursued by several researchers.

None of the hydrocarbon producing plants considered in this report are nitrogen fixing plants. It is likely that these species will require the addition of fertilizer for commercial cultivation. Alternatively, it may be preferable to cultivate hydrocarbon producing plants on a rotational crop basis or in mixed culture with legumes. According to Felker et al. (1980), plant productivity on semi-arid and arid lands may be more limited by nitrogen availability than by water availability.

Most of the economic feasibility and energy analysis studies (including our own) assume that a large percentage of the bagasse from these crops will be used as a source of combustible biomass or for conversion to alcohol. Commercially, this practice may be limited because of the potentially adverse effects on the soil of not returning this organic matter. Depletion of the organic matter in the soil can be a serious problem that requires years to correct.

Our evaluation of hydrocarbon producing plants relies on a thorough review of the literature as well as personal communications (both by telephone and by personal interviews) with researchers currently doing research relevant to this field. From these sources, we have gathered data that provides the basis for our technical and economic assessments. This approach was vital for obtaining state-of-the-art information.

Since the data in this field is preliminary, our analysis relies on many assumptions, which should be verified. We have identified these assumptions in the report. Further, we have identified the productivity and economic thresholds that must be achieved for the hydrocarbon products of these plants to be economically viable.

Sections 1.1 through 1.10 summarize our assessment of hydrocarbon producing plants. The documented assessment follows this summary. Plants are discussed according to the type of product that they produce: Those that are sources of chemical feedstocks and fuel are discussed first, followed by those that are sources of rubber, and finally, those that are sources of lubricants. The chief goal for all of these species is to increase the yield of the energy products.

1.1 Assessing Hydrocarbon Plants

Research in the field of hydrocarbon producing plants has been hindered by a problem that is not uncommon in fields where research breakthroughs could result in large economic gain -- the problem is that of not sharing research results with the scientific community. Many researchers of hydrocarbon producing plants do not publish their results, and others publish without providing the necessary details required to thoroughly assess their work. This is particularly a concern when private companies provide the funding for academic researchers.

Much of the available information is found in popular science magazines or from sources other than scientific journals. Frequently, these articles promote the development of hydrocarbon producing plants by claiming that large yields have already been obtained with minimal inputs. These claims are not supported by available data, nor have these articles passed the test of critical peer review.

Many of the researchers with whom we spoke would not disclose the number of accessions nor the number of plants that they analyzed in obtaining hydrocarbon yields. Some of the older literature cited in this report does include this information.

1.2 Euphorbia lathyris

Euphorbia lathyris (section 2.0) produces hydrocarbons that can be converted into liquid fuels. The hydrocarbons are located chiefly in the leaf tissues, and the entire plant is harvested to extract the oil. E. lathyris has been proposed as a plant that could be developed into a "gasoline tree."

The quality of the hydrocarbon product appears to be very high (section 2.4 Quality Parameters). Mobil Research and Development Corporation has cracked the crude rosin of E. lathyris on a zeolite-charged fluid bed at 500°C (other processes may prove to be as good or better for cracking this crude hydrocarbon into useful products, but to our knowledge, this is the only process that has been tried). The largest fractions obtained were fuel oil, toluenes, xylenes, and benzenes; the latter products are valuable for gasoline blending.

E. lathyris has been reported to be well adapted to arid lands. The plant is a native of the Mediterranean region. It has been naturalized in the Eastern United States and in coastal regions of California (section 2.12

Geographic Range). This plant was first grown experimentally for hydrocarbon production on small semi-arid plots in California. From these first experiments, many claims were made that this plant could be grown in the desert with little or no irrigation, and that it would produce anywhere from 8 to 60 barrels of oil per acre per year. These claims have not been supported by experimental data from either semi-arid or arid lands. Preliminary findings indicate that _E. lathyris_ is not well adapted to an arid environment: It is very susceptible to soil pathogens, and hydrocarbon and biomass yields have been very low for plants grown with and without irrigation on arid lands.

The hydrocarbon production of _E. lathyris_ has been disappointingly low (section 2.5 Yields): The average content has been 5 percent of the dry plant weight*. Yields on arid lands in Arizona have ranged from 0.2 to 0.8 barrels per acre per year and yields on semi-arid lands in California have ranged from 1 to 3 barrels per acre per year -- both yields are far below the early projections.

The data are very limited on the potential for increased hydrocarbon yields by selectively breeding _E. lathyris_. Ten percent is the maximum percent hydrocarbon found in an actively growing _E. lathyris_ plant. It is particularly questionable whether yields can be increased without greatly increasing inputs, particularly without irrigation.

Calvin (personal communication) has recently suggested that this plant be grown in temperate climates such as North Carolina, where a replacement crop is needed for labor intensive tobacco crops. However, according to Alder (personal communication), this plant is very susceptible to soil pathogens everywhere that it has been grown. If this plant is to become a commercial crop, disease resistant varieties will have to be developed.

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*Unless stated otherwise, all hydrocarbon and rubber percentages are based on dry plant weight.

We assessed the economic potential of E. lathyris by using the highest yields achieved to date (section 2.15 Economics). We found that it was uneconomic in California because of the high cost of land and irrigation. In fact, it is probably uneconomic in any region where irrigation is required, that is, in arid and semi-arid lands. However, if

1) petroleum prices increase as projected by DOE's base or high cases,

2) a disease resistant strain is found, and

3) it is found that E. lathyris can be grown in central or southern states where no irrigation would be required,

then E. lathyris hydrocarbon becomes economic between 1990 and 2005. Of course, dramatically higher or lower biomass and hydrocarbon yields will alter this conclusion.

There is a net energy gain from E. lathyris in the above scenario (see section 2.16 Energy Analysis). If it is assumed that energy must be expended to dry the plant, that alcohol is produced from the sugars, and that irrigation energy is required, the energy yield is two times the inputs. If irrigation is not required, that is, in central and southern states, the energy yield is three times the inputs.

In conclusion, we do not feel that there is enough data available to justify the development of E. lathyris as a source of hydrocarbon. Because there are so many unanswered questions concerning E. lathyris, we recommend that the following steps be taken before a decision is made to develop E. lathyris instead of other potential energy producing plants.

- Standardize the calculation and reporting of yields: Methods currently used define the hydrocarbon content according to different criteria; this practice makes it difficult to compare different researchers' data.

- Obtain yield data from different potential growing areas by using standardized agronomic techniques.
- Determine the potential for genetic improvement of hydrocarbon yields. This task would require further genetic screening of plants and some preliminary breeding and genetic manipulation.
- Determine the genetic potential for increasing disease resistance.
- Determine the amount of hydrocarbon produced in terms of the water required for that yield (that is, the water use efficiency of hydrocarbon production).

Once these data are obtained, the potential of _E. lathyris_ should be compared with other potential energy plants.

1.3 Milkweeds

We assessed three species of milkweed: _Asclepias subulata_ (section 4.0 Desert Milkweed), _A. syriaca_ (section 5.0 Common Milkweed), and _A. speciosa_ (section 6.0 Showy Milkweed).

There currently is not enough information available to assess these plants in detail. In general, the yield of hydrocarbon and/or rubber from the milkweeds will have to increased if these plants are to be economically successful. Given the complex pollination mechanisms in these plants (they require cross pollination, and they are pollinated almost exclusively by insects), breeding techniques will have to be developed. Tissue culture methods may prove to be very useful for genetic improvement.

Another important factor to consider is the tremendous potential genetic pool that is available in the genus _Asclepias_. According to Bailey (1949), there are over 150 species in this genus. Gray (1970) lists 25 species and states that they frequently hybridize. Some of these species may be a useful source of genetic variability in breeding *Asclepias* for hydrocarbon or rubber production.

The following briefly summarizes the research status of the three milkweed species.

1) *A. subulata* -- Little or no research has been done on *A. subulata* since Beckett and Stitt's study (1935). The rubber yield of this plant should be investigated in view of modern agricultural and processing techniques. In addition, its potential as a hydrocarbon producer should also be assessed.

2) *A. speciosa* -- Hydrocarbon yields of *A. speciosa* cultivated on irrigated, arid lands have not been very promising, to date (section 6.5 Yield). In fact, they have been even lower than the hydrocarbon yields of *E. lathyris* on arid lands. Since *A. speciosa* is not a native of ari lands and is not well adapted to an arid environment, this plant should also be cultivated on temperate, marginal lands, and its hydrocarbon yields assessed.

3) *A. syriaca* -- Little can be concluded from available data about the hydrocarbon yield of *A. syriaca*. Yields from this species should be determined for experimental plots on marginal soils in temperate lands.

We recommend that the commercial potential of the three species of milkweed be further investigated. The following are some suggestions:

1) Determine which of these plants are most suitable for commercial cultivation on arid lands.

2) Determine the genetic potential of increasing hydrocarbon and rubber yields.

3) Determine disease resistance of plant.

4) Determine quality of the products.

5) Determine whether other species of milkweed would be useful sources of germ plasm in breeding these species.

6) Determine water requirements, particularly, the water required per unit hydrocarbon produced.

1.4 Guayule

A tremendous amount of research has been devoted to investigating guayule's potential as a source of domestic natural rubber. Much of this research occurred during World War II under the Emergency Rubber Project, which was initiated in response to the Japanese cutting off of 90 percent of U.S. rubber supplies from Southeast Asia. The report of Foster et al. (1979) provides an excellent account of the background of the development of guayule rubber research in the United States.

Natural rubber is still vital to U.S. strategic interests. In fact, it has been identified as a critical and strategic material by the Federal Emergency Management Agency for the following reasons:

1) Synthetic rubber cannot be substituted for natural rubber in many products (for example, airplane tires are almost 100 percent natural rubber).

2) *Hevea brasiliensis*, the "rubber tree," is currently the source of all our natural rubber. This plant is extremely susceptible to a fungus called the South American Leaf Blight. If this fungus is ever introduced into Asia, which is the source of 94 percent of the world rubber exports (Grilli, 1979), the supply of natural rubber would be decimated.

3) The United States currently imports all of its natural rubber. The major source countries are Malaysia, Indonesia, and Thailand; the political stability of these countries is questionable.

In general, guayule appears to have great potential for development as a commercial domestic source of natural rubber. The following discussion summarizes some of the positive and negative aspects of developing guayule as a commercial crop.

The quality of guayule rubber varies, but strains can be selected that produce a high-quality rubber. Tests have shown that guayule rubber is almost equal to Hevea rubber. In addition, guayule is native to arid regions and to the southwest and therefore is well adapted to this desert environment. Most importantly, the breeding potential of guayule is very encouraging (section 7.14 Breeding Potential).

- Genetic variability is high in the natural population.

- Guayule has several close relatives with which it readily hybridizes. These species are a valuable source of germ plasm. It may be possible to obtain desirable traits such as disease resistance, increased vigor, cold tolerance, and direct germination of seed in the field from hybridization of guayule with these relatives.

- Guayule produces two kinds of flowers: apomictic and sexual. Apomictic flowers are asexual; they breed true for the maternal genotype. Since this characteristic can be induced in guayule plants that produce mainly sexual flowers, once a superior plant is developed, the genotype can be fixed by inducing apomixis.

Although the breeding potential of guayule is excellent, it will be a very challenging and time consuming process. One of the biggest problems faced by the guayule breeder is that apomictic flowers are extremely difficult to distinguish from sexual flowers.

Guayule produces rubber in the individual cells of the plant. It cannot be tapped to obtain the rubber; instead, the entire plant must be harvested, ground, and the rubber extracted with a solvent or with a water flotation process. The plant is a perennial and will probably be harvested after 3 to 5 years of growth.

The rubber content of the plant varies from 8 to 26 percent of the dry weight of the plant (Foster et al., 1979). Most researchers expect that plants bred for commercial production will have at least a 20 percent rubber content. Reported yields from experimental plots have varied from 146 to 900 pounds per acre per year (section 7.5 Yields).

In addition to producing rubber, guayule also is a source of resins, wax, and bagasse. The value of the resins and wax is uncertain: Some researchers claim that they are more valuable than the rubber, and others claim that the cost of extracting these products exceeds their worth. The bagasse could be burned to produce steam or electricity to run the guayule processing plant, it could be used to produce paper (if mixed with wood pulp), it may be possible to process it to make alcohol, or it could be returned to the soil to maintain soil fertility.

Some problems with the development of guayule include the following:

1) Guayule is very frost sensitive and therefore its cultivation is limited to the extreme southwestern United States.

2) Efforts to germinate guayule seed directly in the field have been unsuccessful.

3) Guayule is susceptible to several soil pathogens, although it may be possible to develop disease resistant varieties.

The economics of guayule rubber are promising (section 7.19 Economic Analysis). At full scale production levels, it appears that guayule would currently be economically feasible. However, guayule production is not currently at full scale, and funds for research and development and for start-up costs will be required to reach full scale production. Since rubber is a strategic and critical resource, the Federal Emergency Management Agency (FEMA) is considering the funding of guayule research and development; funding may include support of a planting program.

The energy saving potential of guayule rubber is not substantial (section 7.20 Energy Analysis). There is a small net gain if byproduct resins, pulp, and leaves are used for fuel or petrochemical feedstock. The major energy savings are due to the increased fuel economy and life of radial tires, which require a larger percentage of natural rubber than synthetic rubber tires. Therefore, the largest energy impact of guayule rubber would occur if there is a shortfall in Hevea natural rubber, and guayule rubber is used as a replacement for synthetic rubber (appendix 1).

We recommend that the commercial development of guayule as a source of domestic natural rubber be pursued, but not to the exclusion of other sources of rubber, particularly those that may have a wider geographical distribution.

The most important research areas include the following:

1) Field germination of guayule seed.

2) Increased disease resistance.

3) Increased cold tolerance.

1.5 Chrysothamnus nauseosus

Most of the data available concerning this plant is from Hall and Goodspeed's 1919 report (section 8.0 Rabbit Brush). These authors concluded that rabbit brush was very promising as a source of rubber, and they recommended that further research be done. Despite the fact that rubber yields of rabbit brush are lower than those of guayule, the reasons that these authors cited for continuing this research are still valid today.

Rabbit brush is much larger than guayule: It averages 6 pounds (fresh weight of woody parts only) per bush, and plants of 40 pounds or more are not uncommon, while guayule averages 1.5 to 3 pounds. Chrysothamnus nauseosus is also much more cold tolerant than guayule and grows in a much wider geographical range. It is more tolerant of alkaline soils than guayule. Hall and Goodspeed also state that the plant seed germinates easily in the field (guayule seed will not germinate directly in the field) and that the water requirements are lower and the rubber quality higher for rabbit brush than for guayule. These statements were not accompanied by data and should be researched further.

In summary, if a high yielding strain of Chrysothamnus nauseosus could be developed, it would have many advantages over guayule. We recommend that its potential as a domestic source of natural rubber be investigated by determining the following:

1) The genetic potential for increasing the rubber content of this plant,

2) The agronomy of growing this plant,

3) The disease resistance of the plant, and

4) The water efficiency of the plant.

1.6 Jojoba

The jojoba plant produces seeds that contain a liquid wax (section 9.0 Jojoba), which is referred to as jojoba oil. Jojoba oil is a high quality lubricant that is similar to sperm oil, and it comprises about 50 percent of the seed weight (section 9.2 Quality Parameters). Jojoba oil can also be cracked into liquid fuel and chemical feedstocks.

Jojoba is a shrub that is native to arid regions of the southwest and is well adapted to this environment. However, it is even more sensitive to frost damage than guayule, and its range is therefore limited.

The jojoba plant first produces seeds when 2 to 5 years old (section 9.4 Life Cycle), and continues to produce seed for 100 to 250 years. Maximum seed production occurs in about 8 to 12 years. This long period before a crop is produced greatly increases start up costs. Because of the long life cycle of the plant, yields of mature plants from experimental and commercial plots are not yet known (section 9.5 Yields). Estimates for mature stands range from 1500 to 2250 pounds of oil per acre per year. Genetic variability appears to be high (section 9.13 Breeding Potential), but it is not known whether oil and seed yields can be increased without increasing water requirements.

The cultivation of jojoba shrubs is highly labor intensive. The lower branches of the plant tend to grow close to the ground. These branches must be tied in an upright position or removed in order to harvest the seeds. Mechanical harvesting methods have not been perfected, and much of the harvesting is currently done by hand. Further, male and female flowers occur on separate plants. Since fewer male flowers are required than female (a few male flowers can produce enough pollen to fertilize many female flowers), the excess male plants must be rogued from the field and replaced by female plants.

Jojoba oil is a premium product (section 9.15 Economic Analysis), and given current yields and costs, it will remain a premium product. Its principal uses are and probably will continue to be in cosmetics, pharmaceuticals, and as a high quality additive to motor oils and lubricants. Given that jojoba is a highly labor intensive crop and that the areas in which it can be cultivated are limited, oil costs will probably remain high. Therefore, barring a catastrophic oil price increase (to at least $150 per barrel), there is little likelihood that jojoba will be used as a fuel or petrochemical feedstock in the foreseeable future.

In addition, jojoba is being commercially developed by the private sector. About 10,000 acres are planted and a rapid expansion is planned. The Federal Emergency Management Agency may be interested in jojoba oil as a critical and strategic material, but it is not known whether or not they will provide funding.

The following are our recommendations for commercially developing jojoba:

1) Develop a plant that is adapted to mechanized cultivation and harvesting,

2) Increase disease resistance by selecting for disease resistant strains,

3) Increase cold tolerance by selecting for cold tolerant strains, and

4) Develop and improve agronomy techniques to facilitate harvesting and to optimize yields.

1.7 Meadow Foam

There is not enough information on Limnanthes alba (section 10.0 Meadow Foam) to assess its economic or technical potential as a source of seed oil. We recommend that yields be obtained from areas in which it could be potentially cultivated. We also recommend that more extensive chemical analyses of this oil be conducted to determine its worth as an industrial lubricant.

1.8 Other Hydrocarbon Producing Plants

Many other plants have been analyzed to determine their hydrocarbon content; however, there is insufficient data available to do even a preliminary assessment of these plants (section 11.0 Other Hydrocarbon Producing Plants).

We recommend that a variety of other plants be investigated as potential sources of hydrocarbon and rubber before substantial resources are committed to the development of any one plant.

1.9 Institutional Barriers

It has been proposed in the literature (Johnson and Hinman, 1980) that 8 to 12 million hectares (20 to 30 million acres) of semi-arid or arid land, most of which has never been cultivated, is suitable for growing energy crops. Therefore, we have examined some of the major institutional barriers that may be encountered by developers of presently uncultivated land in the southwest.

From our assessment of available data of hydrocarbon and rubber producing plants (Part A), we are not convinced that the cultivation of any of these energy crops on arid lands will be possible without irrigation. In addition, it is our opinion that the problems arising from the lack of water and the rights to water supplies in the southwest will prevent any large-scale development of presently uncultivated lands.

1.10 Institutional Barriers - Recommendations

Our analysis of the water situation in the southwestern United States (which included consideration of three recent reports:[1] Arizona Water Commission, 1977;[2] U.S. Water Resources Council, 1978;[3] Congressional Research Service, 1980) indicates that the cultivation of large amounts of unfarmed arid land in the southwest would be unlikely. This conclusion is based on the following facts:

- All of the desert and semi-arid plants examined to date require some irrigation for large-scale cultivation, especially when initially establishing the plant (Part A).

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[1] abbreviated AWC in remainder of discussion
[2] abbreviated WRC in remainder of discussion
[3] abbreviated CRS in remainder of discussion

- Dryland farming of these plants in the southwest is unproven; in any case, it is clear that yields from unirrigated crops in arid lands would be greatly reduced.

- Most hydrocarbon or rubber producing plants require 15 to 24 inches of rainfall per year; therefore, some irrigation will be necessary to grow them in the southwest.

- Water supplies are extremely limited in the southwest. For example, in Arizona, groundwater provides most of the water for irrigation, and these supplies are being depleted at the rate of 2.2 million acre-feet (maf) per year.

- As a result of scarce supplies, water use is highly restricted in the southwest (see appendix A at the end of Part B).

Therefore, given that the gross annual water requirements of native desert plants are lower than those of traditional crop plants*, and that water resources are extremely limited in the southwestern United States (see section 2.0, Part B), we conclude that arid-land crops will be grown primarily as replacement crops. That is, they will be grown on lands that otherwise would have gone out of production because they were no longer economic for traditional crops. There may be one exception to this conclusion. Some arid-land crops may be more tolerant of saline irrigation water and salinized soils than traditional crops, and therefore, grown on marginal lands with lower quality irrigation water.

Hydrocarbon and rubber are not the only products that can be derived from desert plants. For example, Karpiscak et al. (1980) have suggested that Salsola kali L. (Russian thistle or tumbleweed) be developed for arid lands as a source of burnable biomass. Other desert plants that have been investigated for their value as forage plants, such as Artemisia, Atriplex, Ceanothus, Ceratonia, Dalbergia, Eurotia, Lucaena, Lupinus, Morginga,

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*In Pinal County, Arizona, cotton consumes 40 inches of water year and alfalfa, 70 inches (AWC, 1977).

Prosopis, Pureria, Quercus, Salix, Sesbania, Sutherlandia, and Opuntia (Goodin and McKell, 1971), may have some yet undiscovered value as an energy crop for either burnable biomass or bioconversion to alcohol.

Therefore, we recommend that a net energy to water efficiency -- that is, the ratio of net Btu's produced to the amount of water consumed -- be experimentally determined for each potential arid crop species. This efficiency, together with the economic value of the energy product, would greatly aid in assessing the potential of all kinds of energy crops for arid lands. In some cases, the economic value of the product may be weighted more heavily than the net energy to water efficiency. For example, since rubber is considered a strategic and critical resource, its economic value is at a premium, and rubber-producing plants might be grown instead of plants that have a higher net energy to water efficiency, but produce less valuable products.

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2.0 Gopher Plant: Euphorbia lathyris (Euphorbiaceae)

2.1 Products

Euphorbia lathyris produces hydrocarbons, most of which are located in the leaf tissue. These hydrocarbon products are isoprenoids: Tetra- and pentacyclic triterpenoids functionalized as alcohols, ketones, or fatty acid esters (Nemethy et al., 1980b). Most are C_{30} compounds with molecular weights of 400 to 500, and they account for an average of 5%* of the dry weight of the plant (Nemethy et al., 1980b; McLaughlin and Peoples, personal communication).

Twenty percent of the dry weight of the plant is simple sugars, or hexoses, which can be fermented to alcohol by using Montrachet yeast (Nemethy, 1980a and 1980b). The remainder of the plant is bagasse, which can be used to produce steam.

Two cocarcinogens, or carcinogenic promoters, are also produced in small quantities by the plant: ingenol and phorbal esters. Both of these compounds are deactivated by air-oxidation, heat, acid, and alkali (Kohan and Wilhelm, 1980).

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*There is some discrepancy in the literature as to what constitutes the "hydrocarbon" fraction of the plant. Researchers at the University of Arizona report the hydrocarbon fraction as being that portion of the plant that can be extracted with hexane (or heptane or cyclohexane) plus the fraction that is extracted with ethanol. University of California researchers generally only cite the hexane extraction when referring to hydrocarbon content. Throughout this report, we have adopted the latter convention. (Refer to Quality Parameters section for an explanation.)

Therefore, when discussing the University of Arizona's results, we have not used their reported values for percent hydrocarbon. Instead, we multiplied their dry plant weight yields by 5% to obtain percent hydrocarbon values.

2.2 Life Cycle

E. lathyris can be grown as an annual, biennial, or perennial, depending on the climate in which it is grown. There is no chilling requirement for the seed; ripe, one year old seed should be used (Sachs, 1980). Flowering is induced by cold temperatures; plants will flower if subjected to temperatures below 50°F for twelve weeks (Sachs and Mock, 1980; Sachs, 1980). Seed will not germinate at less than 54°F. It germinates best when temperatures are at least 79°F (Sachs, 1980).

In temperate climates, such as northern California, two different growing strategies are followed that depend upon whether seed or hydrocarbon is to be produced. For seed production, the plant is treated as a biennial: It is sown in the fall, and seed is harvested in the spring. For hydrocarbon production, the plants cannot be sown in the fall because they will flower in the spring. Once the plant flowers, it produces little of both biomass and hydrocarbon (Sachs, 1980). Nemethy et al. (1980b) suggest planting in early spring and harvesting in November or December.

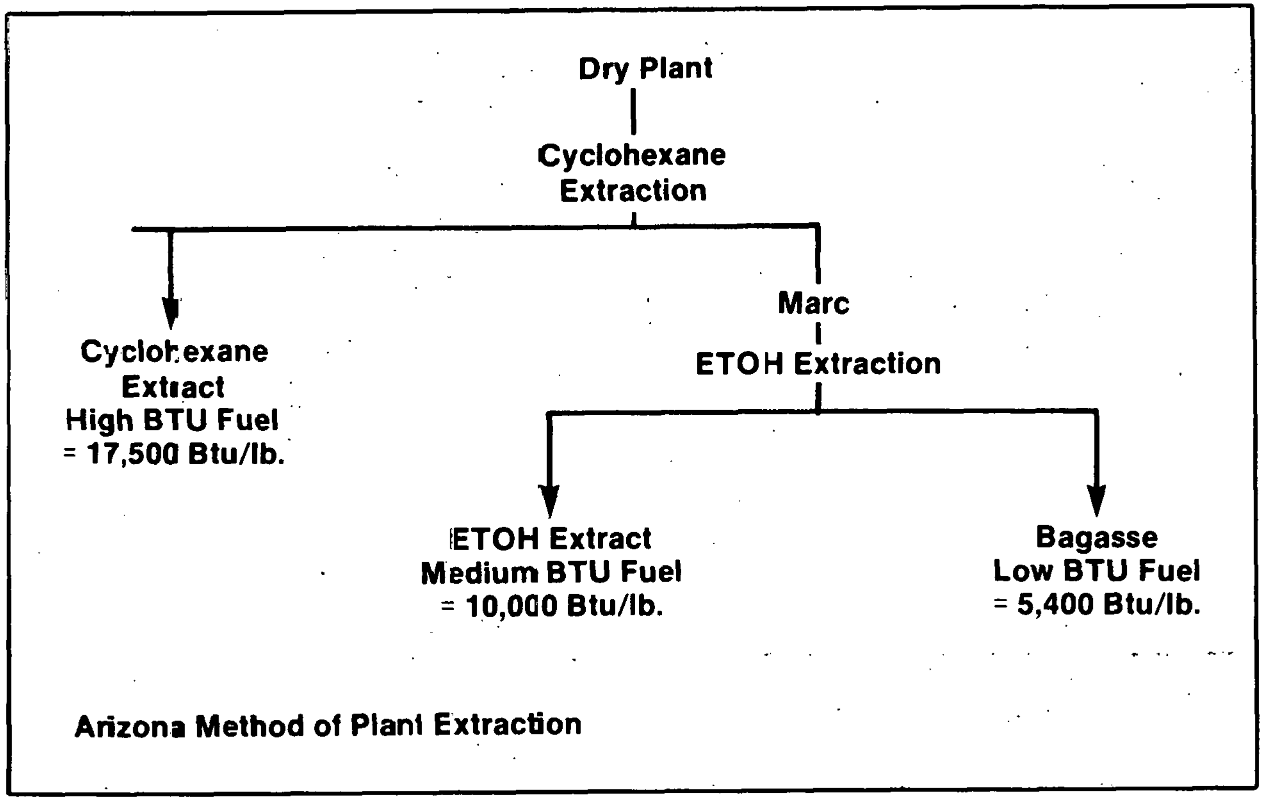
In arid climates, such as Arizona (and the southwest in general), E. lathyris can only be planted as a winter crop because it cannot withstand the soil pathogens present in the summmer. It is therefore sown in September or October and harvested in April, May, or June (J. Johnson and McLaughlin, personal communications).

2.3 Processing/Refining

Euphorbia lathyris is about 70% water (Sachs, personal communication). Therefore, drying the plant could require a major energy and economic input. Current practice is to field dry the material (2 to 4 weeks) and then oven-dry it at 70°C for 48 hours (Sachs, personal communication, and Nemethy et al., 1980a). It may be possible to use accelerated drying methods developed for field drying grapes (anonymous, 1980d). For example, a water emulsion spray of a vegetable oil derivative has been tested on grapes. The spray alters the outer waxy layer of the grapes and allows the internal moisture to escape faster. In addition, several types of inexpensive solar collectors have been used to dry grapes (anonymous, 1980d). E. lathyris also has a waxy outer layer that prevents internal moisture from escaping.

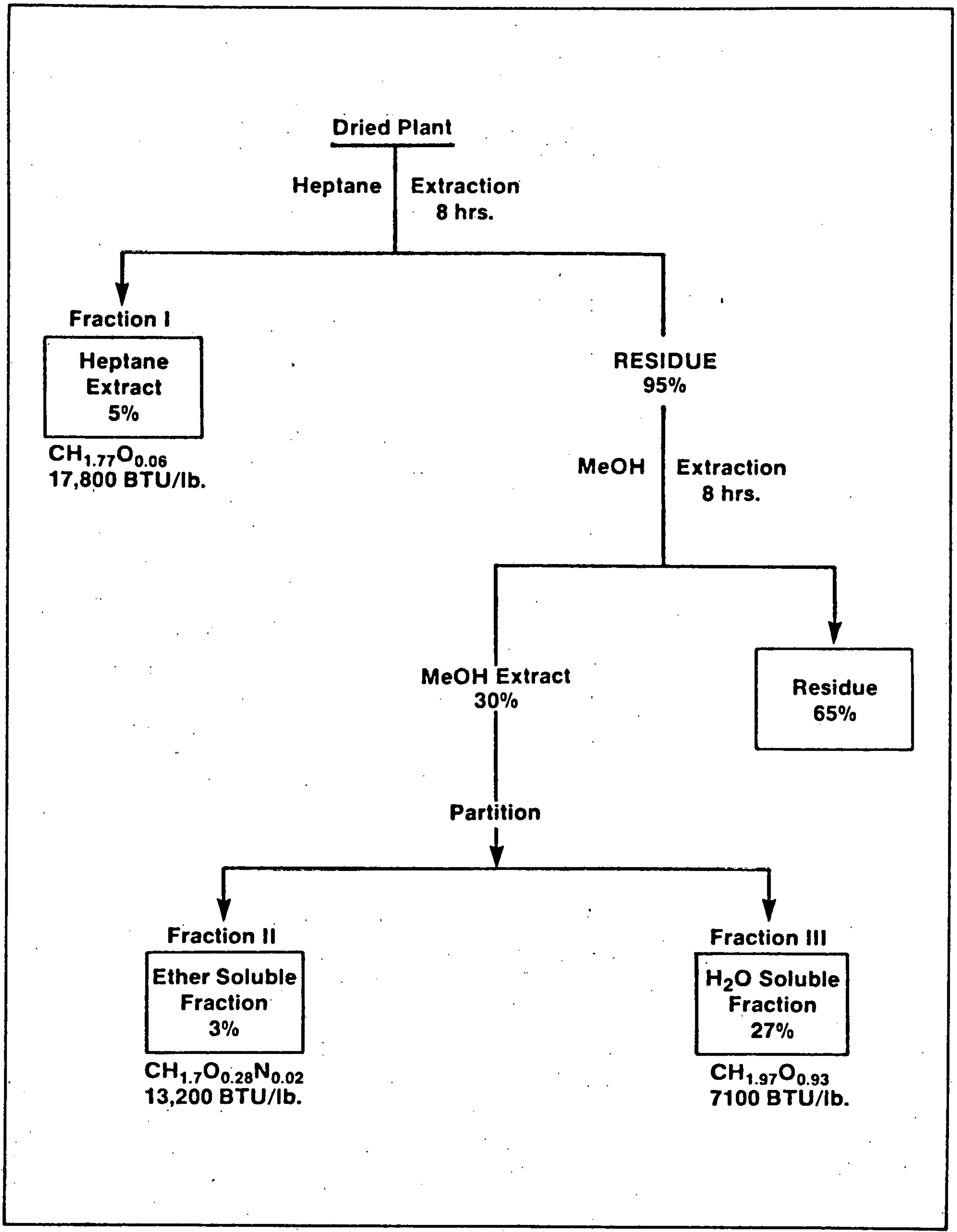
After drying, the plants are then ground to a coarse powder with particles about 2 mm in size (Sachs and Mock, 1980; Nemethy et al., 1980a). To obtain the hydrocarbon fraction, the plants are extracted in a non-polar solvent such as hexane, heptane, or cyclohexane, for 8 hours (Nemethy et al., 1980a and 1980b; Sachs, 1980). This extraction is followed by extraction with a polar solvent, such as ethanol or methanol, which characteristically dissolves sugars and other water-soluble carbohydrates (Sachs, 1980). Acetone is used by some researchers instead of hexane, but acetone also dissolves some of the sugars and water soluble carbohydrates (Sachs, 1980).

Two possible extraction schemes are shown in figures 2-1 and 2-2. The first is used by the University of Arizona, and the second by the University of California.



From: Hinman et al., (1980)

Figure 2-1. Arizona Method of Plant Extraction



(from Nemethy et al., 1980a)

Figure 2-2. California Method of Plant Extraction

2.4 Quality Parameters

To our knowledge, only Mobil Research and Development Corporation has cracked the crude hydrocarbon of E. lathyris. Therefore, only this process is discussed, although other processes may be as good or better for cracking this crude.

Mobil cracked the acetone extractable crude oil (which accounts for 6% of the dry plant weight) on a zeolite-charged fluid bed at 500°C (Hinman et al., 1980). This crude is equivalent to fraction I and part of fraction II of the heptane/methanol extraction scheme used by the University of California, Berkeley, and depicted in the Processing/Refining section of this paper.

Fraction II consists mainly of carbohydrates. Most of these carbohydrates are converted into CO_2 and H_2O when cracked by the catalyst. A small fraction, however, is cracked into hydrocarbons. Mobil (Weisz et al., 1980) found that the following products were produced from cracking:

PRODUCT	PERCENT
Ethylene	10
Propylene	10
Toluenes	18.5
Xylenes	14.0
Fuel Oil	22.8
LPG	5.2
Butylene	1.7
Coke	4.8
Benzenes	13.0

Benzenes, toluenes, and xylenes (BTX) are all valuable for gasoline blending. Ethylene, propylene, and BTX are all valuable chemical feedstocks. Our calculations, which assume the coke produced is used to furnish process heat, indicate an economic value of 125% to 140% that of a barrel of petroleum crude. This finding conforms with Hinman et al. (1980), who found it to be 25% more valuable than crude. The price premium results from the much higher proportion of BTX and olefins in the output.

Various Btu values have been reported for the heptane (hexane and cyclohexane can also be used) extract of E. lathyris, including 16,500 to 17,800 Btu/lb (Kohan and Wilhelm, 1980; Calvin, 1978a; Peoples and Johnson, 1980; Nemethy et al., 1980a). In comparison, the Btu content of petroleum crude is about 19,000 Btu/lb (Nemethy et al., 1980b).

The heptane extraction is followed by either an ethanol extraction or a methanol extraction (see Processing/Refining section). The ethanol/methanol extract has a much lower Btu content than the heptane extract, and much of it consists of simple sugars (Nemethy et al., 1980b). Therefore, we will refer only to the heptane (hexane or cyclohexane) extract when referring to the hydrocarbon content of E. lathyris. Mobil has not cracked the ethanol extract on the zeolite catalyst.

2.5 Yields

Reported dry-plant yields appear to be very different for E. lathyris grown in California (Sachs, Nemethy, and Calvin) and for E. lathyris grown in Arizona (Peoples, Johnson, McLaughlin, Hoffman and Hinman), as evidenced by table 2-1 of results.

Note that in plots having about the same plant density (refer to the two Davis plots with 52,000 plants per acre and the Arizona plot with 53,000 plants per acre), the unirrigated Davis plot yielded 2 to 3 tons more biomass than the Arizona plot, which was irrigated.

There are many possible reasons for these wide differences. However, the most significant difference is probably the arid climate of Arizona: E. lathyris does not appear to be well adapted to this environment. Other parameters that caused differences in the yield data are probably not as significant.

Table 2-1. Reported Hydrocarbon Yields

Site	Density Plants/Acre	Yield Tons/Acre	Age	bbl Crude/Acre (Based on 5% Extractable Hydrocarbons)
[1]Santa Ana, CA	42,000	6-8	8-10 months	1.9-3.0
Davis, CA				
[2]irrigated	52,000	8.6 (maximum)	7 months	2.7
[2]nonirrigated	52,000	3-4	7 months	1-1.2
[3]unthinned-irrigated	76,900	6.6-7.8		2.4
[3]unthinned-unirrigated	76,900	2.3-4.1		1.2
[4]Arizona	12,000	0.6		0.2*
	28,000	0.9		0.3
	53,000	1.0		0.3
	101,000	1.3		0.4
	210,000	2.6		0.8

* See note on page 1.

[1]Sachs and Mock, 1980

[2]Sachs, personal communication

[3]Sachs et al., 1981

[4]Peoples and Johnson, 1980

For example, Sachs and Peoples grew different ecotypes of E. lathyris. Sachs planted the northern California cultivar, which is more cold tolerant than the southern cultivar planted by Peoples and Johnson (1980). Sachs and Peoples also used very different agronomy practices (personal communication), although the total water received by the irrigated plots was about 20 inches (51 cm). In Davis, Sachs grew plants about 3 to 4 inches (7.7 to 10.3 cm) apart within a row, with about 30 inches (77 cm) between rows (Low, personal communication). Peoples grew the plants in 15-inch wide beds, which had two rows of plants in each bed. These rows were 10 inches (26 cm) apart, and the plants were grown 1 inch (2.6 cm) apart within a row. Beds were 25 inches (64 cm) apart to allow for furrow irrigation. Therefore, the Davis plot containing 52,000 plants per acre was actually much less densely planted than the Arizona plot, which contained 53,000 plants per acre. Peoples believes that the optimum density for Arizona has not been attained, and he plans to double the maximum density to 420,000 plants per acre.

Yield is highly dependent on available genetic stock for a particular area. Since E. lathyris is a temperate weed and is not an arid plant (Peoples and Johnson, 1980; Hinman et al., 1980), it is not surprising that available genotypes are not well adapted to the Arizona climate. Before this can be determined, more standardized, replicated experiments will need to be conducted to determine precise yields under various conditions.

2.6 Temperature

E. lathyris appears to be very tolerant to a wide range of temperatures. According to Shetler and Skog (1978), it grows in western and eastern Canada, and from Maine to Virginia, and in the southwestern United States, including California.

2.7 Agronomy

Seed beds are prepared by one or two discings. Raised beds should be used to ensure rapid drainage (Sachs and Mock, 1980).

In California, seed should be planted in early spring when the soil temperature at 4 inches (10 cm) is at least 54°F. Seedlings will emerge in two weeks (Sachs and Mock, 1980).

In Arizona, Peoples and Johnson (1980) suggest planting seed when the daily soil temperature is 61° to 79°F for four days. They report 70% germination; plants emerge in 10 to 14 days, and they recommend planting in the fall (October) and harvesting in the winter or spring to avoid the soil pathogens present in the summer.

2.8 Irrigation

Sachs and Mock (1980) recommend row and furrow irrigation for *E. lathyris*. Flood irrigation is not recommended because it may increase infection by *Pythium sp*. (Sachs and Mock, 1980). Sprinkler irrigation has also been successfully used (Sachs et al., 1981).

The data are not conclusive as to the optimum amount and timing of irrigation; it will probably vary, depending on which cultivar is used, where it is grown, and whether it is grown as a winter crop or summer crop.

Generally, 20 to 24 inches (51 to 62 cm) of total water is considered necessary for sufficient biomass production of *E. lathyris*. According to McLaughlin (personal communication), water stress may increase the percent hydrocarbon content. Some of the plants at Davis (Sachs, personal communication) received no water after the initial irrigation in the spring to establish the plant. These plants were still alive as of November, although they were one-third the size of irrigated plants.

2.9 Soil Requirements

Euphorbia lathyris should be grown on well-drained soil (Sachs and Moch, 1980).

Soil sodicity (sodium ion concentration) values lower than 700 ppm had no effect on germination (Hinman et al., 1980), although a sodicity of 1200 ppm reduced germination by 50%.

2.10 Fertilizers

There are not enough data available on nutrient requirements to determine the amount of fertilizer that will be required to grow these plants commercially. Further, the data that are available are conflicting.

Peoples and Johnson (1980) reported an increase in biomass in response to phosphorus; they did not find a positive response to nitrogen. Hinman et al. (1980) report that high nitrogen levels may actually inhibit dry matter production.

Sachs and Mock (1980) have taken the opposite viewpoint. They recommend applying 100 pounds (45 kg) of nitrogen per acre under the assumption that

- nitrogen promotes leaf development, and
- the leaves contain the highest percentage of latex.

Therefore, they believe nitrogen will increase latex yields.

However, none of these researchers have substantiated their results by reporting the experimental conditions, such as sample size, variance of response, and in some cases, level of treatment.

2.11 Diseases/Pests

No pesticides or herbicides are commercially registered for use on *E. lathyris*.

Sachs has lost some plants that were infected with *Pythium sp.*, a water borne fungus. Seedlings can be protected by dusting seeds with Dexon, a commercial fungicide (Sachs, 1980, Sachs and Mock, 1980).

In Arizona plantings, three soil pathogens have been identified from infected plants: *Rhizotonia solani*, *Macrophomina phaseolina*, and *Pythium aphandermatum*. Planting crops in the fall and harvesting in the spring avoids infection from these fungi (Peoples and Johnson, 1980).

No pre-emergent herbicides have been tested on E. lathyris. Sachs and Mock (1980) have spot-sprayed contact herbicides that will damage E. lathyris if sprayed on the plant. Herbicides are needed because E. lathyris does not grow fast and is easily shaded out by weeds.

Peoples and Johnson (personal communication) hope to greatly reduce the need for herbicides by densely planting E. lathyris over the entire available surface area.

2.12 Geographic Range

E. lathyris is a native of the Mediterranean region. According to Bailey (1949), E. lathyris is naturalized in the Eastern United States and in California.

2.13 Breeding Potential

The average hydrocarbon content of E. lathyris is reported to be 5% on a dry weight basis (Nemethy et al., 1980a and 1980b; Sachs 1980a; McLaughlin and Peoples, personal communication). With selective breeding, this percent could probably be increased, but it is not known by how much.

The highest percent hydrocarbon (of samples from approximately 2,500 plants) found by the University of California, Davis, was 7% (Low, personal communication). Ten percent is the highest percent hydrocarbon found by the University of Arizona, Tucson, in the green tissues of a plant that had not flowered (McLaughlin, personal communication). One plant with a 16% hydrocarbon content was found by the University of Arizona, Tucson (McLaughlin, personal communication), but this plant had gone to seed and was senescent. It is not known whether this high hydrocarbon percent represents a true total hydrocarbon increase or merely the fact that biomass was decreasing while hydrocarbon content remained the same. In addition, the quality of the hydrocarbon present in the seeds is not known. University of Arizona researchers would not state the number of plants sampled in obtaining these values.

The prospects for increasing the hydrocarbon content of E. lathyris solely through selection are unknown. It is possible that hydrocarbon content could be increased above that found in any plants to date, but there is no data to support or negate their hypothesis.

Sachs et al. (1981) states that because the natural genetic variability found in this species is low (5 to 6% hexane extractables), and hydrocarbon levels in other genera are characteristically low, that there may be physiologically determined upper limits for whole plant hydrocarbons. This may be true for E. lathyris, however, Hevea is an example of a hydrocarbon-producing plant that has been extensively bred for genetic improvement. Breeding of Hevea to increase hydrocarbon yield (that is, rubber yield) has been very successful (Imle, 1978). Hevea plants have been developed with much higher yields than that of the original (unimproved) genetic pool. Both Hevea and E. lathyris are in the same family -- the Euphorbiaceae.

In addition to traditional breeding methods, several researchers and companies have plans to increase the hydrocarbon content of Euphorbia lathyris by using genetic engineering methods.

The lack of genetic resistance to soil pathogens may be a greater obstacle to developing a commercially viable E. lathyris plant than its low hydrocarbon content. According to Alder (personal communication), E. lathyris has been attacked by soil pathogens everywhere it has been planted. Unless a disease resistant variety can be developed, this plant will probably never gain commercial status.

2.14 Breeding Goals

Two goals are foremost in the breeding of Euphorbia lathyris: To increase the hydrocarbon yield of the plant, and to increase its disease resistance. Other breeding goals would depend upon the region in which

Euphorbia is grown. For example, if cultivation on desert soils is pursued, a plant that is adapted to this environment must be developed. Finally, future breeding goals may include developing a plant that produces a more homogenous, higher quality hydrocarbon.

2.15 Environmental Impacts

The latex and seed oils of E. lathyris contain ingenol and phorbal esters, which are carcinogenic promoters and irritants (Kohan and Wilhelm, 1980). According to Nemethy et al. (1980b), these substances are minor components (about 0.1%) of E. lathyris.

Nevertheless, special handling procedures would probably be required in order to comply with Occupational Safety and Health Administration regulations. These handling procedures will probably not be a significant obstacle to the development of this technology because

- These promoters are easily deactivated by air oxidation, heat, acid, and alkali (Kohan and Wilhelm, 1980).
- They are not strong promoters, and they are found in small quantities in the plant (Nemethy et al., 1980b).

2.16 Economics

The hydrocarbon fraction of E. lathyris is a premium product. When refined, it yields large proportions of high-priced olefins and benzenes. Table 2-2 shows recent prices of petrochemicals (which, except for styrene, are readily refined from E. lathyris hydrocarbon). The corresponding price of crude petroleum is about 10 cents per pound.

This hydrocarbon fraction of E. lathyris has been refined by Mobil Research and Development Corporation using its zeolite (ZSM-5) catalyst over a fluidized bed (Haag et al., 1980). Table 2-3 shows the fractional yield

Table 2-2. Prices of Principal Petrochemicals

Chemical	Price in Cents per Pound
Ethylene	22.3
Propylene	18.5
Butadiene	32.0
Styrene	34.0
Benzene	22.4
Toluene	17.5
Xylene	17.5

(Chemical Marketing Report, November 13, 1980)

Table 2-3. Refined Euphorbia Oil Products and Their Current Value

Products*	Fraction (%)	Value Per bbl of Oil
Benzenes	13.0	$ 8.40
Toluenes	18.5	$10.00
Xylenes	14	$ 7.35
Ethylene	10	$ 6.70
Propylene	10	$ 5.55
Butylene	1.7	$ 1.60
LPG	5.2	$ 1.70
Fuel Oils	22.8	$ 7.66
Coke	4.8	- - -
	Total Per bbl	$48.96

*Euphorbia oil products obtained by using a ZSM-5 catalyst over a fluidized bed (Haag, et al., 1980).

of principal components and their current economic value as chemical feedstocks and fuel. The coke fraction is estimated to provide the necessary process energy.* The total net value per barrel of rosin, when costs of petroleum processing are deducted, indicate that the rosin is worth 20 to 50% more than a barrel of crude petroleum, which ranged from $27 to $38 per barrel in mid-1980. This is in agreement with the finding of Hinman et al. (1980). These researches reported a 25% greater economic value of Euphorbia rosin over crude petroleum.

The future price of petroleum is difficult to project. The Energy Information Administration has three price scenarios for 1995, but the lowest of these is below the current price and therefore is unlikely. The middle and high price projections for 1995 are roughly $50 and $70 per barrel (in 1980 dollars). These projections were extrapolated to the year 2000 by assuming a constant real price growth rate. Therefore, price levels of $60 and $80 per barrel in year 2000 will be used for this analysis ($60 per barrel for the year 2000 price estimate was used in DOE's recent Planning, Programming, and Budgeting System exercise).

The economic analysis is critically dependent upon yields of Euphorbia rosin. Table 2-4 shows the salable products per ton used in this analysis. The eight percent rosin yield that we assumed is well above current average yields of 4% (Sachs, 1980). However, there is some potential for increasing yields through plant breeding (see Breeding Potential section).

The ethanol yield is based on Kohan and Wilhelm's assumption (1980) that 20% of the 26% sugar content is C_6 sugars and therefore is fermentable. The use of conventional processing techniques results in production of 28.5 gallons of ethanol from about 400 pounds of sugar (Kohan and Wilhelm, 1980).

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*The reaction takes place in a fluidized bed reactor at 500°C. To raise a pound of rosin to 500°C takes about 900 Btu. The energy content of the 4.8% coke fraction is 960 Btu. When firing efficiency and heat recovery are considered, this rough equivalence should continue. Therefore, it is assumed that the energy in the petroleum coke is sufficient to provide processing needs.

Table 2-4. Estimated Yields of E. Lathyris Used in Economic Analysis

(8.5 Dry Tons of Plant Per Acre)

Salable Product	Percentage
Tri-Terpenoid Product (Rosin)	8.0
Mixed Sugars	26.0
Cellulosic Materials	58.7
Salable Product	**Per Ton of Dry Weight**
Tri-Terpenoid Product (Rosin)	160 pounds
Ethanol (From Sugars)	28.5 gallons
Pulp	110 pounds

We assumed the energy required to run the ethanol production plant is roughly equal to 120 pounds of sugar per 400 pounds of fermentables. This is based on requirements for a corn-alcohol plant when there is no saccharification step of byproduct drying (Kinderman et al., 1980). The pulp identified as "salable" in Kohan and Wilhelm's report (1980) is based on the remaining pulp from the process shown in figure 2-3, or that which is not used to run the processing plant. However, we assume that about 40% of this pulp is used for drying the E. lathyris, which is not a good candidate for field drying: The water retention properties that allow E. lathyris to withstand periods of drought also prevent it from losing water. Thus, Kohan and Wilhelm's assumption that E. lathyris can be field dried to 20% moisture is unlikely.* Instead, we assume field drying reduces moisture from 70% to about 45%, with the remaining drying energy supplied by pulp combustion. The analysis also

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*It may be possible to accelerate field drying of E. lathyris by using methods developed for drying grapes (Anonymous, 1980d). A water emulsion of a vegetable oil derivative is sprayed on the grapes. The spray alters the outer waxy layer of the grapes so that internal moisture can escape faster.

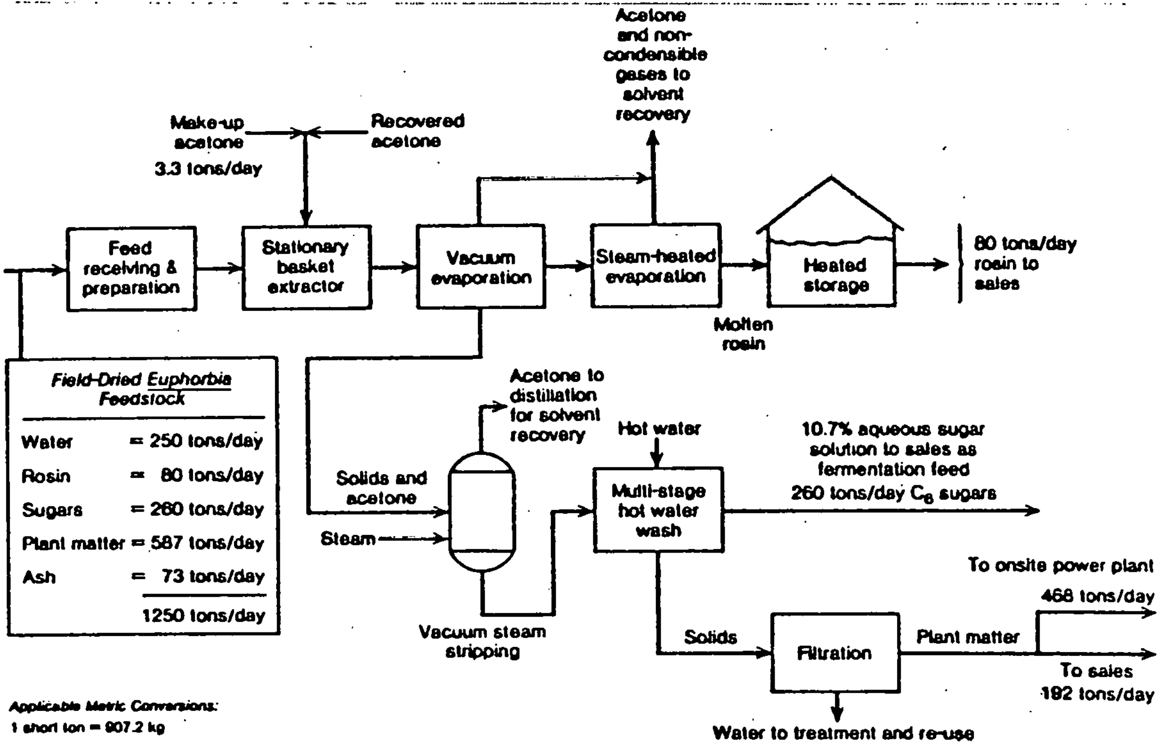
assumes a yield of 8.5 tons per acre, which is the maximum yield obtained, with irrigation, from semi-arid University of California - Davis plots (Sachs, 1981; Sachs, personal communication). Arid plots, particularly those in Arizona, have had dramatically lower yields and may never come close to this goal of 8.5 tons per acre.

Table 2-5 shows the estimated cost to produce E. lathyris by using the process shown in figure 2-3 (Kohan and Wilhelm, 1980). There are three major costs: feedstock, recovery of rosins and sugars, and ethanol production from sugars. The difference in production costs (largest fraction of feedstock costs) between Calfornia (irrigated land) and central and southern states (unirrigated land) is primarily due to the costs of irrigation, although some of this difference is due to higher land costs in California. It is assumed that Euphorbia lathyris could be commercially grown in central and southern states, although there is no reported data to confirm this assumption. The energy costs of processing (recovery of rosin and sugars) are met by the pulp. This pulp could instead be used to produce ethanol, although this does not seem economic (see appendix 1 at the end of this section). Utilities, electricity, and water are purchased.

The prime processing cost is the capital embedded in the plant complexes. This is an unregulated enterprise; therefore, a return on investment of 15% is assumed. Including amortization, total return is 23.5%.

Cogeneration of electricity by using pulp could eliminate the need for purchases and provide a source of revenue from sales (see appendix 2 at the end of this section). Cogeneration and the use of pulp for ethanol are both possible; however, our basic analysis does not consider them. Instead, we use the assumptions of Kohan and Wilhelm, who do not consider these factors.

Finally, to determine the cost of E. lathyris rosin, we must determine the value of the byproducts. When petroleum reaches $60 per barrel, ethanol should be worth about $2.00 per gallon, based on current industrial ethanol prices. The pulp, which has 7,300 Btu per pound, (Kohan and Wilhelm, 1980) would be worth about the same as the delivered price of coal, or about $2.60



(from Kohan and Wilhelm, 1980)

Figure 2-3. Conceptual Processing Sequence to Recover Rosin and C_6 Sugars from Euphorbia

Table 2-5. Estimated Cost to Produce *E. Lathyris* (in 1980 Dollars)*

Location	Cost of Feedstock
California	$615/acre or $75.5/dry ton
Central and Southern USA	$245/acre or $29/dry ton
Recovery of Rosins and Sugars	**Cost Per Dry Ton**
Purchased Utilities	$ 5.40
Operating and Maintenance	$ 4.33
Labor	$ 4.43
Capital and Administrative	$33.37
Producing Ethanol From Sugar	**Cost Per Dry Ton**
Capital Costs	$10.34
All Other Costs	$ 7.08

*Based on Kohan and Wilhelm, (1980)

per million Btu. For the $80 per barrel of petroleum crude scenario, these alcohol prices should be multiplied by 1.33 ($80/$60) and pulp would be worth about $3.00 per million Btu, assuming that coal is $3.00 per million Btu.

The base case required revenue is shown in table 2-6. The base case is encouraging for *E. lathyris* in the central and southern moist areas, if the plant can be grown there with the stated yields. The revenue requirement at $60 per barrel is well below the $75 per barrel equivalent value of the rosin. At the same time these results are discouraging when irrigation is required, i.e., in arid and semi-arid lands. Even at $80 per barrel, *E. lathyris* rosin is 15% too expensive.*

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*Our analysis does not consider the case of growing *E. lathyris* on non-irrigated, semi-arid or arid lands because the yields, to date, have been extremely low. In fact, the analysis is based on yields from irrigated semi-arid, *not* arid lands.

Table 2-6. Required Revenues for E. lathyris Rosin to Break Even Financially

	The Base Case at 8.5 dry tons/acre	
Price of Crude Petroleum	Feed Stock Price	Revenue Required Per Barrel of Rosin
$60	$615/acre irrigated land $249/acre non-irrigated land	$147.10 $ 70.55
$80	$615/acre irrigated land $249/acre non-irrigated land	$111.75 $ 30.27

We also examined the sensitivity of these conclusions to the values assumed for the following parameters: percent rosin, yield per acre of E. lathyris, and required return on investment.

The effect upon prices of increasing the rosin yield is shown in table 2-7. This analysis assumes pessimistically that all increases in percent rosin yield come at the expense of alcohol production instead of pulp. For non- irrigated land, a decrease in percent alcohol, which is a high value, and an increase in per cent rosin result in an increase in the required revenue per barrel of rosin, when crude petroleum is $80 per bbl. As the rosin level rises from 8 to 10%, the alcohol per barrel of rosin drops from 53.4 to 38.5 gallons. This reduces the ethanol revenues sufficiently to increase the per barrel rosin revenue requirement. This increase in revenue requirement does not mean that increasing rosin level at the expense of ethanol reduces total revenue per acre. At 8.5 dry tons per acre and a 25% premium for rosin, total revenue per dry ton is $131.94 at 8% rosin yield, $137.72 at 10%, and $143.50 at 12%.

If the gains in rosin yield come at the expense of pulp, required revenue drops slightly. For example, at $60 a barrel and $29 per dry ton, required revenue falls to $54.88 from $60.51, or about $5.00 per barrel. For $615 per acre, the drop in revenue is from $123.76 to $118.46.

Increasing the dry tonnage yield per acre is equivalent to reducing the production cost per acre. For example, if costs fall to $523 per acre, at yields of 8.5 dry tons, the cost per dry ton is $61.50. This is the same as

Table 2-7. Sensitivity of the Break-Even Price of *E. lathyris* Rosin to Change in % Rosin Yield: Assume Crop Yield of 8.5 Dry Tons Per Acre (in 1980 $ per bbl)

		Required Revenue Per bbl Hydrocarbon at Three Levels of % Yield of Hydrocarbon		
Price of Crude Oil	Feedstock	8%	10%	12%
$60	$615/acre irrigated land	$147.10	$126.36	$112.53
	$249/acre non-irrigated	$ 65.55	$ 61.11	$ 58.15
$80	$615/acre irrigated land	$111.75	$101.21	$ 93.94
	$249/acre non-irrigated	$ 30.22	$ 35.85	$ 39.56

if yield rises from 8.5 to 10 dry tons per acre. Table 2-8 shows the sensitivity of required revenue to increases in per acre yield (or reduced feedstock agricultural costs).

A 15% rate of return on equity plus amortization may be too high for a constant dollar analysis. If Office of Management and Budget projections are correct, then the rate used should be 10% rather than 15%. Table 2-9 shows sensitivity to this change in the required return on investment.

The results of all three sensitivity analyses are unambiguous. At $60 per barrel for crude oil, *E. lathyris* is not economic when grown on irrigated lands. Even assuming a 10% rosin yield, 11 tons per acre yield, and the low return on investment, the required rosin revenue exceeds $78 per barrel (over $3 above the economic value of $75/bbl for this premium product). At $80 per barrel of crude, any modest favorable change from the base case makes rosin economic. For non-irrigated, that is, non-arid land, *Euphorbia* rosin is economically viable at 8.5 tons/acre yield and 8% hydrocarbon content. Again, whether or not *E. lathyris* can be grown on these lands at these yields is still not known.

Table 2-8. Sensitivity of the Break-Even Price of E. lathyris Rosin to Changes in Dry Ton Yield (or in costs) per Acre (in 1980 $ per bbl) Assuming 8% Rosin Content, 15% Return on Investment

		Required Revenue Per bbl at Three Yields (dry ton/acre)		
Price of Crude Oil	Base Cost Per Acre	8.5	10	11
$60	$615 (irrigated land)	$147.60 ($615)*	$126.49 ($523)	$116.00 ($475)
	$249	$ 65.55 ($249)	$ 58.86 ($212)	$ 53.62 ($192)
$80	$615 (irrigated land)	$111.75 ($615)	$ 91.21 ($323)	$ 80.72 ($475)
	$249	$ 30.27 ($249)	$ 22.58 ($212)	$ 18.33 ($192)

*numbers in parentheses indicate the reduced production costs/acre to achieve that break-even price at 8.5 tons/acre.

Table 2-9. Sensitivity of the Break-Even Price of E. lathyris Rosin to Changes in the Required Return on Investment

Price of Crude Oil	Cost Per Acre	Return on Investment	Break-Even Price
$60	$615 (irrigated land)	15%	$147.10
		10%	$119.78
	$249	15%	$ 65.55
		10%	$ 38.59
$80	$615 (irrigated land)	15%	$112.25
		10%	$ 84.93
	$249	15%	$ 30.27
		10%	$ 2.36

2.17 Energy Analysis

There are five factors in the energy analysis: ethanol produced from sugars, E. lathyris rosin, pulp, energy required for agriculture, and energy required for processing. Energy analysis of each of these factors involves looking at the energy inputs and outputs of the entire process for producing that energy source and using it; this data is then compared with alternatives. For example, it is not enough to look at the Btu content of a gallon of ethanol. A more exact analysis uses its crude oil replacement value.

Ethanol has less Btu per gallon than gasoline, but a higher octane rating. There are many claims but no consensus about the relative efficiency of ethanol as an extender of gasoline in gasohol. It is not likely that gasohol delivers better mileage than gasoline, although if it delivers less mileage, the difference is small (Chambers, 1979). Therefore, we assume that a gallon of gasohol will get the same mileage as a gallon of gasoline.

Because refining petroleum crude takes about 10% of the energy in a barrel of crude (Gaines and Shen, 1980), a gallon of gasoline takes 125,000 x 1.1 Btu of crude oil to produce, or 137,500 Btu. Therefore, we assume each gallon of ethanol is worth 137,500 Btu of petroleum even though a gallon of ethanol is actually only 91,000 Btu.

The net energy values of the components of refined Euphorbia lathyris rosin, (that is, all outputs but coke) were adopted from Gaines and Shen (1980), as were the values for benzene, xylene, toluene (BXT); LPG; and fuel oil. For the olefins -- ethylene, propylene, and butylene -- production is assumed to be from heavy petroleum liquid (gas oil), which is the marginal feedstock at present and for the foreseeable future.

No premium is allowed for the high blending octane of BXT because energy savings are very small unless engines are redesigned. In addition, if a base case is assumed in which ethanol is widely used, the high blending value of ethanol would eliminate much of any BXT credit. Therefore, the conservative approach of no credit has been adopted.

The following table 2-10 shows the rosin products of E. lathyris, the oil energy content, and other processing energy requirements per barrel of petroleum oil (300 pounds).

Table 2-10. Net Energy Embodied in the Products of E. lathyris Rosin Catalytic Cracking

(Energy: 1000 Btu)

Product	From Petroleum Oil: Btu/lb	From Other Sources Btu/lb	Btu/bbl of Product in Petroleum	Total Btu/bbl of Product in E. lathyris
Ethylene	24,321	-	731	731
Propylene	24,321	-	731	731
Butylene	24,321	-	124	124
Xylene	18,380	5,290	773	996
Toluene	18,380	5,290	1,022	1,316
Benzene	18,950	6,360	740	989
LPG	22,325	-	352	352
Fuel Oil	20,100	-	1,377	1,377
Total Net Energy Per Barrel			5,850	6,616

When these values are compared with the net energy of crude oil, which is 5,192,000 Btu per barrel, the E. lathyris rosin has a petroleum replacement content of 1.13 per barrel and a total energy to net energy from crude ratio of 1.27. Considering the 10% refinery credit discussed previously, a barrel of E. lathyris equals 6,435,000 Btu of crude petroleum.

The pulp energy content is based on a net of 110 pounds of combustible pulp per ton of dry E. lathyris. This pulp has a Btu content of 7,300 Btu/ton (Kohan and Wilhelm, 1980). Therefore, 8.5 tons/acre (considering refinery credit) embodies 6.83 million Btu.

All processing requirements are met by the combustion of pulp and non-fermentable sugars. With the exception of irrigation, pumping energy requirements are 16.5 million Btu per acre (McLaughlin and Hoffman, 1980), which includes the energy embodied in the irrigation system. Irrigation energy was calculated at 10.95 million Btu per acre. It was estimated based on a 350-foot pumping requirement typical of Arizona, a two-acre-foot water requirement, and an 80 percent pump efficiency. The electricity, including line losses, requires 12,000 Btu per delivered kWh.

The above estimates of energy values for ethanol and E. lathyris were used to determine the net energy per acre (table 2-11). This net energy assumes a yield of 8.5 dry tons per acre, 8% rosin yield, 26% sugar yield -- of which 20% is net ethanol -- and 59% pulp yield. It should be remembered that these yields are far above those obtained to date in arid climates such as Arizona.

Energy production from Euphorbia rosin would be considerable at these yields, though far less than the claims of some proponents. The net production is about 15 million Btu higher if irrigation is not required (that is, where irrigation is not needed; in central and southern lands). This energy production is extremely speculative; it must be verified and compared with other potential energy crops for the lands in question (see appendix 3 at the end of this section).

Table 2-11. Net Energy for an Acre of *E. lathyris* (Composite Table Based on Results of Previous Economic Analyses)

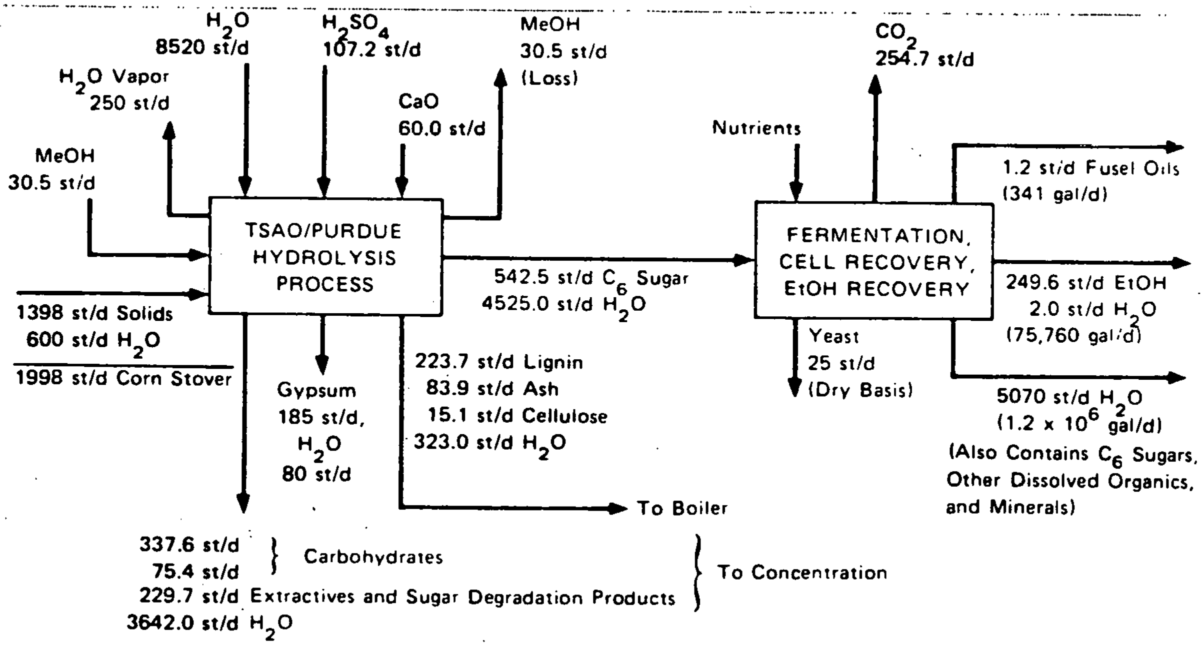
Net Products	Oil Btu (in 10^6)	Total Btu (in 10^6)
Rosin	29.17	32.64
Ethanol	31.35	31.35
Pulp	-	6.83
Total Output	60.52	70.82
Requirements		
Agriculture Except Irrigation (California)		17.10
Irrigation, Electricity, and System	3.37	10.65
Other Processing	met by pulp and non-fermentable sugar	
Total Net Requirements	3.37	27.75
Net Gain Per Acre	57.15	43.07
Net Gain in Bbl of Crude Oil Equivalent	9.85	7.42

Appendix 1. Ethanol from E. lathryis Pulp

No formal analyses of ethanol production from E. lathyris pulp have been reported to date. Conversions of other forms of lignocellulose to ethanol have been studied. For example, a detailed study of producing ethanol from corn stover was recently completed (Kinderman et al., 1980). For this analysis, we assume that the costs and process efficiencies of converting E. lathyris pulp to alcohol are the same as those for corn stover.

The conversion process is both long and costly. Figure A-1 is an approximate mass flow for the conversion of corn stover to ethanol. The estimated cost of this process (in 1980 constant dollars) for E. lathyris pulp, excluding feedstock costs, is $1.26 per gallon. This includes byproduct credits, a small capital cost reduction for feedstock handling for E. lathyris pulp, and an adjustment of the capital recovery factor used by Kinderman et al. (1980) to a constant dollar basis (zero inflation). At a petroleum price of $60 per barrel, ethanol is estimated to be worth $2.00 per gallon. Thus, the ethanol producer could pay up to $0.74 per gallon for feedstock. A million Btu of feedstock will produce 3.65 gallons of ethanol, which is worth $2.70. By contrast, a million Btu of pulp is worth $2.60 for fuel. This is a very small difference: A 20% increase in capital costs would more than wipe out this advantage.

First of a kind plants usually cost considerably more to build than subsequent plants; therefore, it is unlikely that the small potential savings is justifiable. If oil is $80 per barrel, then the economics for ethanol production become much more favorable; a million Btu of feedstock pulp is worth $5.00 when converted to alcohol and about $3.00 as direct boiler fuel. At $80 per barrel of oil, alcohol production may be desirable, provided sufficient water is available for processing (2 million gallons per day).



(from Kinderman et al., 1980)

Figure A-1. Approximate Mass Flows for Major Feedstocks, Products, and By-Products for Production of Ethanol from Corn Stover by the TSAO/Purdue Acid Hydrolysis Process

Appendix 2. Cogeneration

To date, extraction of E. lathyris hydrocarbons has occurred only in the laboratory. However, cogeneration would be possible with a Euphorbia lathyris processing plant, which will require a capacity of about 200,000 pounds of biomass per hour.* Cogenerating by a low pressure steam user results in incremental heat rates of about 5,000 Btu per kWh to generate electricity (Bernow, et al., 1978). If a low pressure steam user were to cogenerate, then processing plant capacity could be expanded by one-third to provide high pressure steam for cogeneration without affecting the capability to meet process requirements. Thus, boiler capacity could easily be increased about 65,000 pounds per hour. Boiler efficiency for plants of this size is typically about 80 to 85% (Marciniak, personal communication). Net output of electricity, therefore, is about 15 MW per hour.

This output is worth the equivalent cost of production to an electric utility.** An E. lathyris processing plant should operate over 80% of the time. Therefore, it would replace a capital intensive base load unit, which is a coal-fired unit in the southwest. After accounting for line losses, operation and maintenance costs, and fuel (at 10,000 Btu per kWh), the cost to the utility is 3.0 cents per kWh (this assumes oil to be $60 per barrel

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*This is a very large-scale plant, and it may not be technically or economically feasible.

**Section 210 of the Public Utility Regulatory Policy Act (PURPA) of 1978 mandates utilities to offer payment to cogenerators (among others) with capacity less than 30 MW. These payments must:

1. Be just and reasonable for the electric utility's consumer,
2. Not discriminate against such suppliers, and
3. Not exceed the incremental cost of alternative supplies of electricity to the utility.

These requirements are usually interpreted as meaning that the utility should pay avoided costs to cogenerators.

Cogeneration also results in a savings on investment. A coal-fired plant costs about $1,200 per kW in 1980 dollars (Stern, personal communication). Adding the necessary boiler capacity and turbines to produce electricity from this E. lathyris processing plant would cost $600 to $1,000 per kW (Bernow, 1978). Since a typical coal-fired base load unit operates about 65% of the time (5,694 hours per year), it is assumed that the utility return per dollar of investment saved equals the required return per dollar invested by E. lathyris processing plant owners.

To determine net payment, we assumed that cogeneration costs are about $800 per kW. The utility capital charge factor with constant dollars is about 8% (Cicchetti, et al., 1976). The capacity credit therefore is $7.05 per acre per year, and the net value to the utility is $48.00 per acre year.

The value of the pulp as pulp is $17.76 per acre per year (at $60 per barrel for oil). If this pulp is used to generate electricity, the value to the utility would be equivalent to $48 per acre per year. Therefore, the potential net gain from cogeneration is $30.24 per acre per year, or a reduction of $6.67 per barrel in the cost of E. lathyris hydrocarbon. These potential savings imply that any large-scale biomass to hydrocarbon processing plant that requires steam should seriously investigate the potential economic value of cogeneration.

Appendix 3. A Comparison of the Energy Potential of E. lathyris with Corn in the Southeast

At present, only corn is being used to provide petroleum substitutes on any large scale. Therefore, this analysis compares the potential energy produced from E. lathyris with that from corn.

To simplify the analysis, it is assumed that processing requirements are met either with E. lathyris pulp or corn stover. Corn yield is the average per acre yield currently obtained in North Carolina (Agricultural Statistics, 1976), which is 2.34 tons of corn per acre per year and 1.36 tons of dried corn stover* per acre per year (table A-1). E. lathyris has never been grown on other than small experimental plots in the southeast, and these data have not been published. Because potential yields are speculative, yields ranging from 1 and 8.5 tons per acre per year are analyzed (table A-2). The latter is the best yield achieved to date on a small, irrigated plot in California; the former reflects yields in Arizona with irrigation.

To calculate the total energy produced from these crops, corn was credited for the energy embodied in distillers dry grain. According to our analysis, the total energy of current corn yields is equivalent to a yield of 5 tons per acre per year of E. lathyris, or about 3 tons of E. lathyris in potential vehicle fuels.

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*The removal of this amount of corn stover may cause adverse effects on some soils.

Table A-1. Net Energy from Average North Carolina Corn Acreage Used for Energy Production

Biomass Yield per Acre* tons/acre/year		Energy Production**	10^6 Btu
		Ethanol	18.35
Corn	2.34	Corn Stover (net after processing)	8.50
Corn Stover	1.36		
		Distillers Dry Grain	12.19
		TOTAL	39.04

*Derived from Agricultural Statistics, 1976 USDA
**Derived from Kohan and Wilhelm, 1980

Table A-2. Net Energy of <u>E. lathyris</u>

Net Btu from Various Yields (Dry Weight) of E. lathyris (Yield in dry tons/acre/year)				
Net Products	1	3	5	8.5
Rosin	3.84	11.52	19.20	32.64
Ethanol	3.69	11.06	18.44	31.35
Pulp	0.80	2.41	4.02	6.83
Total Output	8.33	24.99	41.65	70.82

3.0 Introduction to the Milkweed Family: Asclepiadaceae

There are 46 species of milkweed that are native to the United States (Hall and Long, 1921). We have assessed three of these species: *Asclepias syriaca* (common milkweed), *A. speciosa* (showy milkweed), and *A. subulata* (desert milkweed).

These plants have been investigated as potential sources of rubber and hydrocarbon. The hydrocarbon and rubber are extracted from the vegetative parts of the plant. Byproducts may include floss and fiber; however, floss is obtained only if the plant is allowed to produce fruit (the fruit is a pod). For hydrocarbon production, the plant is harvested before it flowers.

In general, there is very little data available on any of these species. Therefore, we have not assessed their economic potential in detail. Table 3-1 indicates the rubber content of several milkweed species that were not assessed (Hall and Long, 1921). These species may be valuable as a source of germ plasm for breeding, or some may merit development into commercial crops. At this time, there is not enough data available to make this assessment.

Table 3-1. Rubber Content (Percent of Dry Weight) of Seven Milkweed Species

Species	Number of Accessions Analyzed	Rubber Content (%)	Rubber Content of Stems	Rubber Content of Leaves (%)
A. brachystephana	4	2.1 to 3.0	1.7 to 2.9	2.1 to 2.9
A. californica	4		0.7 to 7.5	0.9 to 4.1
A. decumbens	5	0.8 to 1.3	0.4 to 0.5	1.0 to 1.7
A. galioides	3	1.5	0.85	0.62 to 5.2
A. latifolia	8		0.5 to 0.7	1.0 to 3.7
A. mexicana	16	1.5 to 2.4	0.5 to 2.3	1.4 to 4.8
A. sullivanti	19		0.1 to 8.2	1.2 to 8.1

4.0 Desert Milkweed: Asclepias subulata (Asclepiadaceae family)

Of the 64 plant species examined by Hall and Long (1921), Asclepias subulata appeared to be the most promising source of natural rubber. This species may actually include two subspecies or races (Hall and Long, 1921), which will be referred to as the woody type and the stooling type. Hall and Long (1921) are the only authors to distinguish between these two types.

The woody type grows mostly on the bench-lands (former river floodplains) and stony slopes. It is more drought resistant than the stooling type. As its name suggests, this type is woody (lower portion of the stem).

The stooling type grows chiefly in the dry streamways and depressions, where there is probably more moisture than the sites containing the woody type. The stooling type is only woody at the base of the plant.

4.1 Products

To our knowledge, Asclepias subulata has not been extensively studied since Beckett and Stitt (1935). Because extraction techniques have improved significantly since that time, it is not certain which hydrocarbon products would be emphasized for commercially developing this plant. However, this plant does produce natural rubber (produced largely in the bark of the plant). Because this is the product that was of interest in both the Beckett and Stitt study (1935) and the Hall and Long study (1921), it is the focus of the present discussion. Further research may indicate that the plant is more suitable for liquid hydrocarbon production or for both rubber and liquid hydrocarbon production.

The byproducts include some resins, but the type and quantity have not been reported. Fiber may prove to be an important byproduct of A. subulata. Hall and Long (1921) report that the pulp of this species can be used to make paper.

4.2 Life Cycle

A. subulata is a perennial herb that has many rush-like stems that grow from a central crown. Beckett and Stitt (1935) report 150 to 200 stems per plant; Hall and Long (1921) report 100 to 600 or more stems per plant. The stems have a woody base and are 0.25 to 0.75 inches (0.64 to 1.92 cm) in diameter. The plants are 2 to 8 feet (0.6 to 2.5 meters) in height (Beckett and Stitt, 1935; Hall and Long, 1921), and according to Beckett and Stitt, the average height is 4 feet (1.2 meters), with a circumference of one foot (0.3 meters).

Beckett and Stitt (1935) report that there are two flowering periods: One in May and June and a second in September, although few pods from the September flowering reached maturity. Hall and Long (1921) report that the plant flowers after rains regardless of the season.

Unlike the other species of Asclepias, A. subulata has a long, single taproot that does not appear to be connected with the roots of other plants (Hall and Long, 1921).

4.3 Processing/Refining

This plant can probably be processed with the same techniques used to process guayule, if rubber production is to emphasized, or with techniques used to process E. lathyris, if hydrocarbon content proves to be the most economical. Extraction methods have been improved since both the Beckett and Stitt study (1935) and the Hall and Long study (1921).

Hall and Long (1921) first extracted the resins from the ground plant material with acetone to remove the resins and then extracted the rubber with benzene. Although this is basically the same procedure as those used by Buchanan et al. (1978a) and Weihe and Nivert (1980), the latter are more sophisticated and undoubtedly would increase the processing yield and quality of the rubber and hydrocarbon (see Processing/Refining under guayule section as well as Buchanan et al., 1978a). The Weihe and Nivert process has never been used for A. subulata and therefore may require modification.

4.4 Quality Parameters

Hall and Long (1921) reported that rubber from Asclepias is of low quality. Current extraction and processing methods may invalidate this observation, but this is an area for further research. At present, the quality of the rubber is not known.

4.5 Yields

Based on the analysis of three wild Asclepias subulata plants collected in Arizona, California, and Mexico, the rubber content was 0.5 to 6% of the dry plant weight, with a mean of 2.9% (Beckett and Stitt, 1935). Hall and Long (1921) found a similar range for rubber content (hydrocarbon fraction that is soluble in benzene after acetone extraction): 0.8 to 6.5%. This range was found in 21 accessions from California and Arizona.

Buchanan et al. (1978a, 1978b) did not state the number of accessions analyzed; however, they report a 1.39% rubber content and an 11.4% content of oils and polyphenols. Cultivated A. subulata reached its maximum size in 3 years and its maximum rubber content in 4 years. Rubber content of 15 cultivated plants, which were harvested in the dormant season of their fourth year, ranged from 1.95 to 3.76% of the dry plant weight (Beckett and Stitt, 1935).

The Beckett and Stitt experiments indicated that closely spaced plants (unthinned, rows one foot apart) produced larger yields of rubber than widely spaced plants (plants three feet apart, rows four feet apart): 212 pounds per acre (238 kg/ha), compared with 71 pounds per acre (80 kg/ha). These studies were based on an experimental plot of 10 rows, which were 165 feet (51 m) long. A 12 foot (3.7 m) section across the rows was sampled. The plants in the unthinned plots were smaller in size and weight; however, the greater number of plants in the unthinned plots resulted in a higher biomass per acre yield than in the plots with widely spaced plants.

The acetone extractable fraction, which includes the resins, hydrocarbons, and carbohydrates, ranged from 4.7 to 18.6% in 21 accessions analyzed by Hall and Long (1921).

4.6 Factors that Influence Rubber Yield in A. subulata

Beckett and Stitt (1935) found that the rubber content of *A. subulata* decreased significantly during flowering and was highest when the plant was dormant. Experiments further indicated that the plant can be stored for long periods of time (two years) without affecting the rubber content of the cut plants as long as they are kept dry and in partial darkness. It was not stated whether or not the quality of the rubber decreased with storage.

Optimum time of harvest is yet to be determined. The period of maximum rubber content occurs when the plant is dormant, and the minimum when the plant is flowering. Harvest will probably occur between January and March. Of the four harvest times that Beckett and Stitt investigated (January, April, July, and October), plants harvested in January and April had the best regrowth, and those harvested in October had the worst regrowth and survival. Because the plants are dormant until April or May, harvesting will probably occur between January and March.

4.7 Temperature

A. subulata is found growing where temperature ranges from 15 to 120°F (Beckett and Stitt, 1935), however, the temperature sensitivity of the plant has not been reported.

4.8 Agronomy

Agronomy techniques have not been clearly defined. In general, the plant will resprout after cutting, seed can be germinated directly in the field, and unthinned plants appear to produce the highest yields per acre of rubber and biomass. Attempts to vegetatively propagate (buddings, cuttings, and root-crown divisions) the plant were not successful (Beckett and Stitt, 1935).

4.9 Irrigation

Water requirements are not known. In nature, the plant is found where the annual rainfall is 3.5 to 8.6 inches (9 to 22 cm), and it can withstand long periods of drought (Hall and Long, 1921).

In the Beckett and Stitt study (1935), the plants were given water "as needed": The amount was not stated. Beds were preirrigated before seeding.

4.10 Soil Requirements

In nature, A. subulata occurs on dry, stony stream beds, which flow only after the occassional rains, and in depressions of mesas, where water accumulates after rains (Beckett and Stitt, 1935).

4.11 Fertilizer

Nutrient requirements are unknown, but it was observed that plants on fairly fertile soil were much larger than those on barren slopes (Beckett and Stitt, 1935).

4.12 Diseases and Pests

A. subulata was found to be relatively free of pests (Beckett and Stitt, 1935); however, pests and diseases may be more of a problem when plants are grown in larger plots. Three pests were observed to damage desert milkweed:

1. Aphis nerii -- An aphid that can cause extensive damage to seedlings. Probably can be controlled with modern pesticides.

2. Oncopeltus fasciatus -- This is a sucking insect that feeds on the pods in the fall and damages the seeds. It appears in the late summer after a majority of the pods have matured, so it probably will not be a problem.

3. Danaus menippe -- This is the monarch butterfly, or milkweed butterfly. The larvae caused some damage to small plants. Insects were not abundant and probably can be controlled with modern techniques. (In some areas, the monarch butterfly is protected by law).

4.13 Potential Cultivation Sites

The natural distribution of A. subulata extends from southern Nevada to Baja California, Mexico, and from southeastern Arizona to the coast of southern California (Beckett and Stitt, 1935).

4.14 Breeding Potential

The pollination mechanism for milkweeds is very complex, and breeding by traditional methods is likely to be a long and difficult process for the following reasons:

1. This species, as with most other milkweeds, will not self-fertilize

2. Artificial pollination is tedious

3. Vegetative propagation of A. subulata has not been successful, to our knowledge.

Given the above, it is likely that genetic improvement using tissue culture techniques will be more practical in the long run than traditional breeding methods. Two species of milkweed, A. syriaca and A. tuberosa, have been regenerated from both tissue culture and from cell suspension culture (Groet and Kidd, 1981). It may be possible to use the same or similar media for culturing A. subulata and regenerating it.

According to Hall and Long (1921), there are over 100 species of milkweed. It may be possible to use these species as sources of germ plasm for improving A. subulata.

4.15 Breeding Goals

Given that the highest percent rubber found in A. subulata to date is about 6.5% (Hall and Long, 1921) and that the maximum for guayule is over 20% rubber, it seems clear that the rubber content of A. subulata must be increased significantly for this plant to be considered a potential source of NR. This would probably be the foremost goal of any breeding program.

Little is known about the hydrocarbon quality or quantity in this plant. However, if this plant is to be developed as a source of hydrocarbon, one of the breeding goals would undoubtedly be to increase the amount of hydrocarbon in the plant.

The following breeding goals are simply that -- goals. It is not known if the native population of A. subulata includes any of these characteristics.

- Develop a plant that will self-fertilize -- A self-fertilizing plant would be of tremendous benefit in breeding.

- Develop a plant that only flowers once a year -- Since rubber content decreases when the plant flowers, it would be an advantage to decrease the number of flowerings.

- Extend the range of *A. subulata* -- Currently, the range of *A. subulata* is about the same as the range of guayule. However, since the range of *A. speciosa* extends over most of western North America, this plant may be a source of germ plasm for increasing the cold tolerance of *A. subulata*.

Because little is known about this plant, it is difficult to recommend specific breeding goals.

4.16 Environmental Impacts

We know of no environmental impacts other than those associated with cultivation on desert soils.

5.0 Common Milkweed: Asclepias syriaca (Asclepiadaceae)

5.1 Products

Asclepias syriaca produces hydrocarbons, some rubber, and fiber, and it has a high sugar content, which probably can be used to produce alcohol (Groet, personal communication). The hydrocarbon and rubber are derived from the plant latex, which is produced in lacitifers of the leaves and stalks (Wilson and Mahlberg, 1977). The floss was used for life preservers during World War II (Berkman, 1949).

If this plant is developed as a commercial energy crop, its hydrocarbon production will probably be emphasized rather than its rubber production. However, the early studies of this plant investigated its potential for rubber production. We have included these studies in this analysis.

5.2 Life Cycle

Asclepias syriaca is a perennial, which is 3 to 7 feet (0.9 to 2.1 m) high (Hall and Long, 1921). The plant flowers in mid June to August (Andreas and Cooperrider, 1980) and produces seed 5 to 6 weeks after flowering (Evetts and Burnside, 1973b). The seeds have a dormancy requirement, which can be broken by alternating temperatures or by kinetin and gibberellic acid. IAA (indole acetic acid) did not stimulate germination (Evetts and Burnside, 1972).

This plant reproduces vegetatively by sprouting from rhizomes.

5.3 Processing/Refining

According to Bollinger (personal communication), the method of extracting the hydrocarbon from Asclepias sp. is identical to that of Euphorbia lathyris.

5.4 Quality Parameters

Battelle Laboratories plans to emphasize the production of hydrocarbon rather than production of rubber from Asclepias. The precise components obtained from this hydrocarbon have not been defined.

Hall and Long (1921) report that the quality of rubber from milkweed is poor; however, this should be reexamined with current extraction and processing methods.

5.5 Yields

Most of the rubber in A. syriaca is produced in the leaves; the amount in the stems is very low, and that in the roots is negligible (Hall and Long, 1921).

A chemical analysis of 8 accessions of A. syriaca (Hall and Long, 1921) found the following range in rubber content: leaves, 0.53 to 4.4% rubber; stems, 0.21 to 0.5% rubber. From 4 accessions of plants, the acetone extraction, which probably includes resins, hydrocarbons, and some carbohydrates, ranged from 8.6 to 11.8% (leaves) and from 4.4 to 11.6% (stems). Therefore, the range of percent hydrocarbon yield is less than these values.

Buchanan et al. (1978a) and Buchanan and Otey (1979) report a dry yield of 12,329 kg/ha/yr, or 11004 lbs/acre/yr, and a rubber yield of 173 kg/ha/yr, or 154 lbs/acre/yr. This paper also states that the oil fraction is 4.28% and the rubber fraction is 1.39%. This paper does not state how these biomass values were calculated and the experimental conditions used, nor does it state the number of accessions analyzed in deriving the hydrocarbon and rubber content.

According to Berkman (1949), the podshells of milkweed contain 10% wax and gums (the wax is similar to caranauba wax and has a high melting point). Berkman also states that a higher yield of fruit is obtained on poor, sandy soil.

5.6 Temperature

This plant has a wide range, which includes most of eastern North America. Therefore, its tolerance to temperature extremes is also wide. For example, it is found growing where the mean July temperatures are 64 to 90°F (Evetts and Burnside, 1972).

5.7 Agronomy

The plant can be pollarded when it is 7.5 to 12.0 centimeters tall (2.9 to 4.7 inches, Evetts and Burnside, 1972). It also can be pollarded 2 to 3 times per growing season (Bollinger, personal communication).

Jeffrey and Robinson (1971) found that 100 percent of the plants resprouted after being clipped. As the age of the seedlings increased, their ability to resprout increased, and the time to resprout decreased.

Seed dormancy is broken by a few moist days of low temperature (Jeffrey and Robinson, 1971). Seedling emergence is best when seeds are planted 1 to 2 centimeters deep (0.4 to 0.8 inches).

Gaertner (1979) reported that plants from seed were stronger and more prolific than plants from running roots (vegetative propagation).

Slightly modified alfalfa machinery can be used to plant and harvest *Aslepias syriaca* and *A. speciosa* (Alder, personal communication).

Finally, *A. syriaca* is resistant to commonly used herbicides (Jeffrey and Robinson, 1971).

5.8 Irrigation

A. syriaca is a temperate plant that grows chiefly in the eastern United States. Evetts and Burnside (1972) reported that *A. syriaca* is more susceptible to moisture stress than kochia, sugarbeets, and sorghum, but more tolerant than sunflower, honeyvine milkweed, and hemp dogbane. According to Berkman (1949), A. syriaca requires 20 inches (51 cm) of rainfall per year. A. syriaca is also limited to areas with at least 8 inches (20 cm) of rainfall in the three summer months (Evetts and Burnside, 1972).

5.9 Soil/Fertilizer Requirements

Timmons (1946) found milkweed on acidic soils in northern Michigan. Evetts and Burnside (1972) reported that milkweed is adapted to soils with a pH range of 4.0 to 7.0.

Bhowmik (1978) reported that A. syriaca germinated better in muck or sandy soil than in clay soil. Berkman (1949) also reported that milkweed grows well on sand and gravel, however, it requires boron. Berkman recommended a complete fertilizer for common milkweed. Others have suggested that this plant could grow on soil presently unsuited for food crops (Buchanan et al., 1978a). The following remarks by Hall and Long (1921) should be kept in mind:

> "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."

5.10 Diseases/Pests

Most sources in the literature indicate that A. syriaca is almost entirely free from diseases and pests. Since this plant has never been cultivated on a large scale, its resistance to diseases and pests remains uncertain.

5.11 Geographic Range

A. syriaca is the most abundant milkweed in the eastern United States and Canada. It grows from New Brunswick to North Carolina and west as far as Kansas and Saskatchewan (Hall and Long, 1921).

5.12 Breeding Potential

All species of Asclepias are very difficult to breed by conventional methods because they are all cross pollinated, chiefly by insert pollination. If Asclepias is to be bred by conventional methods, breeding techniques will have to be developed. According to Alder (personal communication), no researchers are currently breeding Asclepias. Genetic improvement might be achieved through tissue culture methods.

Much of the preliminary work for tissue culturing A. syriaca has been completed. Groet and Kidd (1981) have developed media for growing A. syriaca and A. tuberosa on tissue culture media and for regenerating these cultures into plantlets. The next step will be to use these methods for the genetic improvement of this and other species of milkweed.

5.13 Breeding Goals

The foremost breeding goal will be to increase the hydrocarbon yield of A. syriaca. To date, the percent hydrocarbon of A. syriaca is roughly comparable with that of E. lathyris. Biomass yields are unknown but will probably fall within the range used for the analysis of E. lathyris. Therefore, the chief breeding goal will be to increase both percent hydrocarbon yield and biomass yield per acre. In addition, if these plants are to be grown on marginal land, drought tolerance will also be a primary goal. It should be emphasized that this is a temperate plant; it may be possible to increase its drought resistance, but it will probably not be possible to make it a plant adapted for growth under arid conditions.

Other breeding goals, as stated in the assessment of A. subulata, may include the following:

- To develop a plant that will self-fertilize
- To develop a plant that flowers once per season (in the fall)

5.14 Environmental Impact

According to Evetts and Burnside (1972), A. syriaca caused an average loss in yield of sorghum of 720 kg/ha/yr (643 lbs/acre/yr). In addition, as the population of milkweed increased, the yield of sorghum decreased.

One state (Hawaii) has declared milkweed a noxious weed; however, farmers would probably oppose growing this plant on a largescale.

We know of no other environmental impacts associated with the cultivation of this plant.

6.0 Showy Milkweed: Asclepias speciosa (Asclepiadaceae)

6.1 Products

Asclepias speciosa has been considered as a potential source of rubber (Hall and Long, 1921) and of hydrocarbon (Plant Resources Institute, 1981). Both of these products are components of the latex of the plant. This plant is also a potential source of floss, however, if hydrocarbon production is emphasized, the plant must be harvested before it flowers. Therefore, no seeds or pods and no floss are produced.

6.2 Life Cycle

A. speciosa is a perennial herb, which is 4 to 6 feet (1.2 to 1.8 m) high. It reproduces sexually by seeds and vegetatively by buds in the horizontal roots (Hall and Long, 1921).

6.3 Processing/Refining

To extract the hydrocarbon, Plant Resources Institute (PRI) first dried and ground the plant. The hydrocarbon was then extracted with hexane in a Soxhlet extractor.

6.4 Quality Parameters

To our knowledge, the hydrocarbon of this species has not been cracked. Therefore, the quality of the product and its potential uses are not known.

The rubber of milkweeds was reported to be of poor quality (Hall and Long, 1921), but improved processing techniques may modify this conclusion.

6.5 Yield

According to an analysis of 7 accessions by Hall and Long (1921), this species has a very low yield of rubber: stems, 0.19 to 2.6%; leaves, 0.99 to 3.0%. Because of these low yields, the authors dismissed this plant as a potential source of rubber.

A study by Plant Resources Institute (PRI, 1981) indicated that the yield of hydrocarbon would have to be increased in order for this plant to become an economic source of fuel and chemical feedstocks. Table 6-1 shows actual yields obtained by PRI on irrigated and unirrigated land, and the projected yields for a hypothetical plant with increased biomass and a higher percent of hydrocarbon.

Table 6-1. Yields of *Asclepias speciosa*: Dryland Versus Irrigated Seedlings

	Plants/ Hectare	Grams/ Plant	Tons/ Acre	% Hydrocarbon	Bbl/ Hectare	Bbl/ Acre
Irrigated						
(Actual)	111,000	28	1.4	5.5	1.14	0.46
(PRI Projected)	156,250	109	7.6	27.5	31.2	12.63
*Unirrigated	111,000	16	0.8	8.0	0.95	0.38
Precipitation was 11.25 cm (4.39 inches) density of hydrocarbon = 0.944 kg/l or 7.88 lbs/gal						

*This plot was irrigated in the first growing season but received only natural rainfall in the second season.

One caveat should be mentioned. Several articles in the popular science literature (Savoye, 1980; Kessler, 1981) have claimed that PRI studies have obtained hydrocarbon yields of 4.8 bbl/acre and combined alcohol/hydrocarbon yields of 26 bbl/acre. These yields are not supported by PRI's most recent report (PRI, 1981). Their projected yields, which are based on a hypothetical, high yielding plant, do surpass these claims; however, this yield is based on the following hypothetical improvements:

1. An increase in the hydrocarbon content from the present 5.3% average (to date, 8% of the population has been found to have over 7% hydrocarbon content) to 27.5%.

2. An increase in the biomass yield from the present 3.4 tons/acre to 7.6 tons/acre.

3. An increase in the planting density from about 45,000 plants/acre (111,000 plants/hectare) to 63,000 plants/acre (156,250 plants/hectare).

4. An increase in the per plant weight from 0.06 pounds/plant to 0.24 pounds per plant.

Achieving all four of these goals would be very difficult: an increase in planting density usually reduces the per plant biomass.

6.6 Temperature

A. speciosa grows in a wide geographic range that extends throughout most of western North America (Hall and Long, 1921). Therefore, it is very tolerant to a wide range of temperatures.

6.7 Agronomy

The only recent research concerning the cultivation of *A. speciosa* is that of the Plant Resources Institute (PRI, 1981). According to this study, the planting and harvesting of milkweed is similar to that of alfalfa, and alfalfa machinery can be used for milkweed.

PRI plans to harvest this plant before flowers and fruits are formed. Once flowering begins, the lower leaves fall off the stems; this decreases the biomass and therefore the hydrocarbon yield.

In addition, if plants are harvested before fruiting occurs the plants will resprout and produce another mature crop in approximately eight weeks in Utah. In climates with a longer growing season, additional crops will probably be feasible.

Each time the plant is harvested, the number of stems per plant increases. Therefore, PRI suggests multiple harvesting as a means of increasing biomass yields.

6.8 Irrigation

According to Hall and Long (1921), this species has very narrow moisture requirements, even though its geographic distribution is widespread (see section on Geographic Range). It requires moist, fairly fertile soil.

The results of a Plant Resources Institute study (PRI, 1981) confirm this observation. In establishing two plots of A. speciosa, PRI periodically irrigated the plants for the first year. During the second growing season, irrigation was continued in one plot and terminated in the other plot. After 60 days, the irrigated plants produced almost twice the biomass of the nonirrigated plants. Because the nonirrigated plants produced a higher percentage of hydrocarbon, the difference in hydrocarbon yield per acre appears to be small (0.38 bbl/acre compared with 0.46 bbl/acre). However, in subsequent years, the biomass yields from the unirrigated plants would probably be even lower than these results indicate. In the second growing season, there was probably a reserve of water in the soil as a result of irrigation during the first growing season. Therefore, these studies should be extended to determine whether A. speciosa could survive without irrigation in subsequent years. Further, it is unlikely that these plants could be established without irrigation (Alder, personal communication).

6.9 Soil/Fertilizer Requirements

Specific nutrient and soil requirements for this plant are not known. Plant Resources Institute used "good farmland" and fertilized with 56 kg/ha (50 lbs/acre) available nitrogen and 56 kg/ha (50 lbs/acre) available phosphorus.

In addition, Hall and Long (1921) noted that this plant is found on "fairly good soil."

6.10 Diseases/Pests

To date, PRI has found this plant to be relatively free from pests. Relatively minor damage has resulted from Monarch butterfly larvae browsing, and germination of seedlings has been reduced by damping-off (a fungal infection that attacks the new shoots at the soil line; PRI, 1981). However, this plant has not been cultivated in large plots; therefore, it is not known whether other pests will damage the plant.

6.11 Geographic Range

A. speciosa is the most widely distributed species of milkweed in the western United States and Canada. It ranges from Alberta and Minnesota to Iowa, Texas, Arizona, California, and British Columbia. It grows in a wide variety of environments, from the hot, low valleys of St. George, Utah, to the moderately cool mountain meadows in New Mexico (Hall and Long, 1921).

6.12 Breeding Potential

The section entitled "Breeding Potential" under *Asclepias syriaca* also applies to *A. speciosa*.

6.13 Breeding Goals

The section entitled "Breeding Goals" under A. syriaca also applies to A. speciosa.

Its best use may be as a source of germ plasm for A. subulata, especially for increasing its range.

6.14 Environmental Impact

This plant has been classified as a noxious weed in some states. However, for hydrocarbon production, the plant is harvested before it flowers. Therefore, this is probably not a significant institutional barrier, because the crop would be harvested before it could spread to neighboring fields.

6.15 Economics

We have not done an economic analysis of the potential of A. speciosa as a source of rubber because very little information is available on yields. Almost no research has been done since the 1920's, probably because it appears to have a low rubber content.

We also have not done a detailed economic analysis of this plant as a source of hydrocarbon. This appears to be unnecessary, given that the yields of this plant are less than those of E. lathyris grown on irrigated land in California and Arizona: E. lathyris, 0.8 bbl per acre in Arizona, and 2.4 to 2.7 bbl per acre in California; A. speciosa, 0.46 bbl per acre in Utah. Therefore, the economics of A. speciosa are probably no more favorable than the economics of E. lathyris.

7.0 Guayule: Parthenium argentatum (Compositae)

A tremendous amount of detailed information has been published on guayule. We have not attempted to duplicate these efforts. We reviewed the available material, and the following overview was used as the basis of our assessment.

7.1 Products

Guayule produces three basic products: Natural rubber, resins, and bagasse (see table 7-1). The rubber is located in individual cells of the plant; therefore, the entire plant must be harvested to obtain the rubber. The resins contain low molecular terpenes and essential oils such as parthenyl cinnamate and partheniol, betaine, fatty acids, and other constituents (Foster et al., 1979). It has been reported that the resins may be as important economically as the rubber (Yokoyama and Hayman, 1977); however, according to Lawrence (personal communication) of Goodyear, the cost of processing and recovering these compounds is more than their value (see Economics section).

Guayule leaves contain a hard wax that constitutes 2.5% of the plant (on a dry weight basis). This wax has one of the highest melting points (169°F) for a natural wax (NAS, 1977a). It has been suggested as a substitute or extender for carnauba wax, however, it may not be economically feasible to recover because of the small quantity available and the high cost of the solvent extraction required (Foster et al., 1979; Lawrence, personal communication).

7.2 Life Cycle

Guayule is a perennial shrub that grows to about three feet in height. It can be pollarded, and 90 to 95% of the plants will resprout (D. Johnson,

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*Abbreviated NAS in remainder of report.

Table 7-1. Components of Harvested Guayule Shrubs (Dry Weight Basis Except for Moisture)

	Percent
Moisture	45-60
Rubber	8-26
Resins	5-15
Bagasse	50-55
Leaves	15-20
Cork	1-3
Water Solubles	10-12
Dirt and Rocks	variable

(from National Academy of Sciences*, 1977a)

personal communication). The optimum harvesting schedule has not been determined, but it probably will be harvested once every 3 to 5 years (see Agronomy section).

7.3 Processing/Refining

Guayule rubber can be extracted by two methods: solvent extraction or agglomeration. The following summary of these processes is from Weihe and Nivert (1980). Both of these processes are depicted in figure 7-1. The agglomeration method is presently being used in a pilot plant in Saltillo, Coahiula, Mexico. However, both Firestone Natural Rubber and Latex Company (Wise, personal communication) and Goodyear Tire Company (Lawrence, personal communication) consider both of these processes to be in the development stage.

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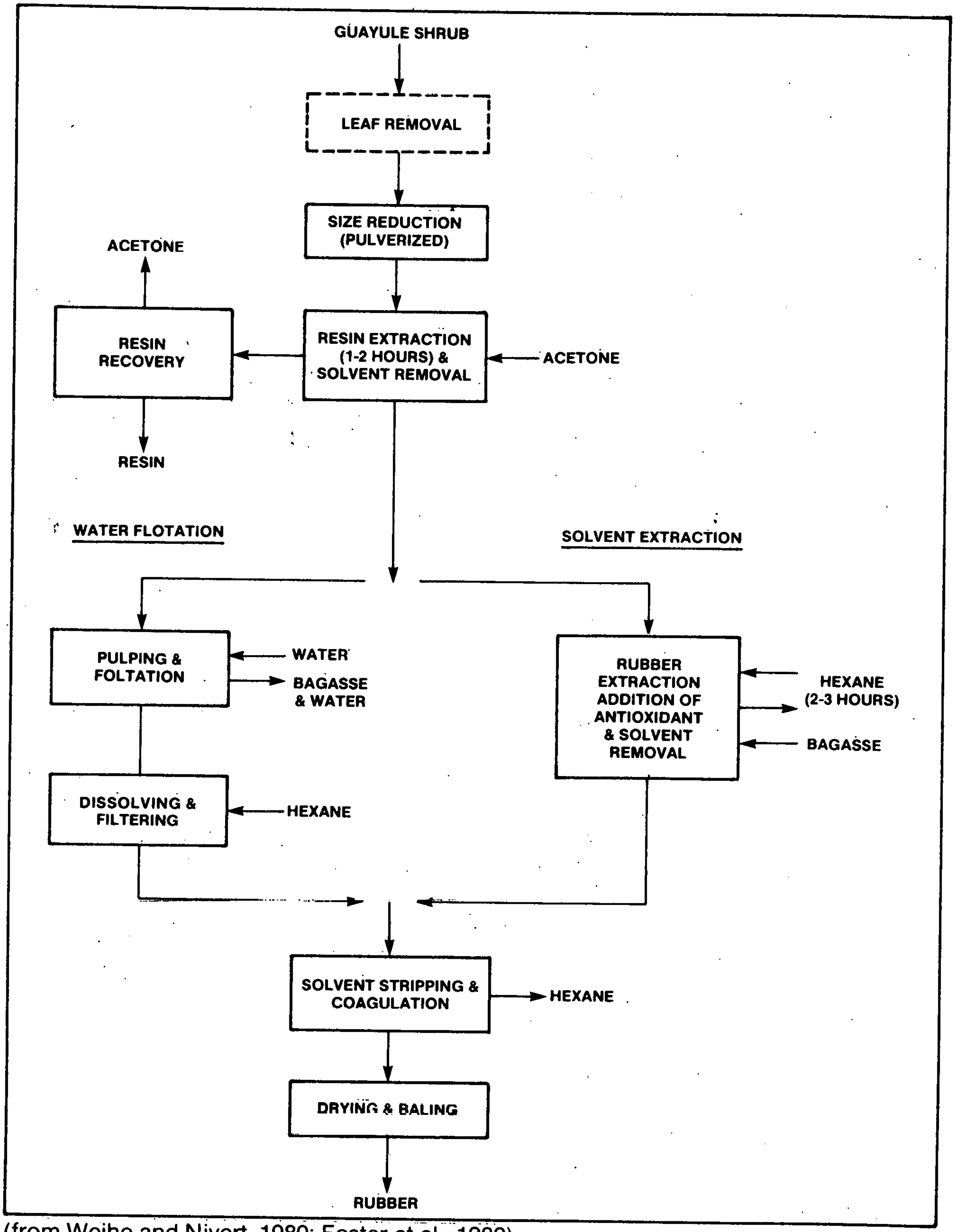
*Abbreviated NAS in remainder of report.



(from Weihe and Nivert, 1980; Foster et al., 1980)

Figure 7-1. Rubber Extraction Processes for Guayule

For both processes, the following initial steps are performed. First, the leaves must be removed before the rubber is extracted because they contain trace metals that promote the oxidation of the rubber (NAS, 1977a). It has not been decided whether or not the shrub will be defoliated in the field or in the pilot plant.

The shrub is then ground in a hammermill, and the resins are extracted with acetone (resin yield -- greater than 90%). The ground shrub is then desolventized; at this point, the water flotation (or agglomeration) method and the solvent extraction method differ. For the water flotation method, the shrub is pulped in a water slurry, which goes through several mixing and flotation steps, such that the rubber agglomerates and floats, and the bagasse becomes water-logged and sinks. Recovered rubber is dissolved in hexane and filtered to remove debris.

For the solvent extraction process, the deresinated shrub is continuously extracted with hexane. The final rubber solution is filtered and the rubber recovered, and the bagasse is desolventized.

The solvent extraction process will probably be emphasized for commercial rubber production because the water flotation method uses large amounts of water, which is scarce in the southwest.

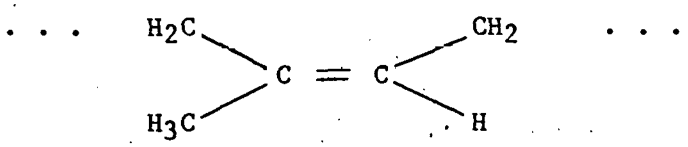
The reported efficiencies of these processes has varied. According to Foster et al. (1980), the water flotation method recovers up to 98.5% of the rubber. However, according to Firestone (Weihe and Nivert, 1980), both of these processes recover about 90% of the rubber.

7.4 Quality Parameters

Guayule rubber varies in quality (Tipton, personal communication). Therefore, breeders must select for guayule with a high quality rubber.

In general, the quality of guayule rubber is almost equal to that of *Hevea* rubber. Tires consisting of 30 to 40% guayule rubber passed all Department of Transportation tests (Johnson and Hinman, 1980). In addition, a truck tire carcass made of 100% guayule NR with synthetic tread was shown to match *Hevea* tires under tests by the Office of Rubber Reserve, Camp Bullis, Texas (NAS, 1977a).

As with *Hevea* rubber, guayule rubber is made up of long chains of cis - 1,4 isoprene units.



Unlike synthetic rubber, which contains 1 to 8% polyisoprenes that are not cis 1,4 - isoprene units, guayule and *Hevea* rubber have only this one structure (NAS, 1977a).

In *Hevea*, there are two peaks in the molecular weight of these chains: 500,000 and 2,000,000 (Foster, 1979). Guayule has a molecular weight of 1,280,000 (Swanson et al., 1979).

Hevea latex includes proteins, amino acids, and polypeptides that accelerate vulcanization. Guayule latex does not include these accelerators, but they can be added.

Green strength is a measure of a rubber's strength during processing, or how well a tire will hold its shape before vulcanization. It does not affect the quality of the final product (NAS, 1977a). The green strength of guayule rubber is intermediate between that of *Hevea* and synthetic polyisoprenes (NAS, 1977a) but it can be made equal to *Hevea* with additives (Warren, personal communication).

The Mooney viscosity of guayule rubber is equivalent to that of *Hevea* rubber. This index reflects the plasticity of a rubber, or the amount of softening required during milling.

Guayule rubber is also equal to Hevea rubber in building tack, which measures the ability of the layers of raw rubber to stick together before vulcanization.

The plasticity-retention index of guayule rubber is in the range of that for Hevea rubber. This measurement reflects the rubber's resistance to aging and breakdown (Clark, 1948; NAS, 1977a).

Both guayule and Hevea rubber are superior to synthetic polyisoprenes in all these characteristics, with the exception of their plasticities (Mooney viscosity). Therefore, they are more difficult to process than synthetic rubber.

In sum, the excellent flow and tack characteristics of guayule rubber should make it suitable for manufacturing tires.

The resins in guayule include the following compounds: essential oils (α - pinene, sabinene, β-myrcene, limonene, terpilolene, β-ocimene and ocimene; Scora and Kumamoto, 1979), parthenyl, cinnamate and partheniol, betaine, fatty acids, and an unidentified wax and other chemical constituents (Foster et al., 1979). The highest use of these resins is probably as tacifiers in the manufacture of tires (Nivert, personal communication); however, they can also be cracked and used as fuel or chemical feedstocks. (For a discussion of the value of the resins, refer to the Economic Analysis section.)

The bagasse can be burned to produce steam and electricity to run the processing plant, or it can be used for paper if mixed with wood pulp (Hanson, personal communication). It probably also could be processed to make alcohol, or it can be returned to the soil to maintain soil fertility.

7.5 Yields

It is generally believed that in order for guayule rubber to be economical, the plant must contain 20% rubber (dry weight basis) and produce 1000 lbs of rubber/acre/yr, or 1120 kg/ha/yr, (Rubis, 1979a).

The entire guayule plant must be harvested in order to extract the rubber, which accumulates with time and is not metabolized by the plant once it is produced. Since rubber does not accumulate at the same rate every year, harvest timing is critical to the economics of guayule rubber production. The following yield data (table 7-2), which appeared in Foster et al. (1979), is from U.S. House of Representatives Report No. 2098. Tables 7-3 and 7-4 compare the yields reported in the literature.

Table 7-2. Crude-Rubber Yield With Increasing Guayule Age In California Plantations

Field Age (years)	Total Rubber Yield Pounds/Acre		Rubber Yield Per Year Pounds/Acre/Year	
	Irrigated	Unirrigated	Irrigated	Unirrigated
1	140-240	49-70	140-240	49-70
2	550-900	280-450	245-450	140-275
3	1100-1700	600-1050	367-567	200-350
4	1700-2700	900-1600	425-675	225-400

Table 7-3. Reported Percent Rubber Yields of Guayule

Source	Percent Rubber	Age of Plant - years
D. Johnson (personal communication)	10%	2
Tipton (personal communication)		
Cultivation	3-12%	3
Field	20% maximum	Unknown
Foster (1979)	8-26%	Not stated
Whitworth (1980)	4.6-8.7%	2

Table 7-4. Reported Rubber Yields from Guayule

Source	Yield Lbs/Acre/Year
Foster et al., 1980	500
D. Johnson (personal communication)	500-900
Metcalfe (1967)	240-450
Hanson et al. (1979)	750
Taylor (1979) (Variety 593)	166
Emergency Rubber Project (1940's)	430 (irrigated)
	208 to 270 (non-irrigated)
Kelley et al. (1946)	767
Mc Callum (1941)	240
Tingey (1952)	471 to 539 (densely planted)
	146 to 194 (sparsely planted)
Whitworth (1980)	86 to 391

[1] Based on 21 months

[2] Based on 33 months

Guayule can be harvested after 2 to 4 years (D. Johnson, personal communication); however, most researchers plan to harvest after 3 to 4 years.

The economics of guayule rubber can be significantly increased by mowing or pollarding the crop after 1 to 2 years and only extracting the rubber from the harvested shrub; allowing the stumps to resprout; and then harvesting the entire plant after 1 to 3 years. According to D. Johnson, yield can be increased 20% by mowing. In addition, it may be possible to mow guayule twice before harvesting the entire crop (Tipton, personal communication).

Mowing the plants and just processing the tops may reduce costs for planting the seedlings and digging up the crop. This will depend upon the harvesting schedule chosen.

Most of the rubber (75 to 80%) is located in the bark* of the branches and roots, with the branches containing about 67% of the total rubber (Hammond and Polhamus, 1965). There is essentially no rubber in the leaves (Hammond and Polhamus, 1965).

The use of guayule resins may be very important in the economics of commercialization. The resins have a high Btu content and they are also valuable feedstocks. Therefore, depending on market conditions, the resins could be burned to run the processing plant or sold for feedstocks.

The resins constitute 5-15% of the dry plant weight (Foster, 1979) and D. Johnson (personal communication) has found 10-15% resins in two-year old plants. Johnson is selecting for both a high rubber and resin yield. Resin canals are located chiefly in the bark, although they can occur throughout the plant (Foster et al., 1979).

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*Specifically, most of the rubber in plants older than one year is in the vascular rays of the phloem and xylem, with smaller amounts in the primary cortex, pith, xylem parenchyma, and epithelial cells of the resin canals. In younger plants, most of the rubber is in these latter tissues (Hammond and Polhamus, 1965).

7.6 Factors that Influence Rubber Yield in Guayule

In general, percent rubber increases in response to stress, which can include the following:

- water stress (Hanson et al., 1979)
- nutrient stress (Tipton, personal communication)
- cold stress (Hanson et al., 1979).

The following factors decrease rubber yield (Hanson et al., 1979; Foster, 1979):

- high irrigation (over 25 inches per year)
- high plant growth rates
- high soil salinity

Optimum temperatures for rubber production have not been determined, however, if temperatures are so low that the plant is damaged, rubber does not increase (Foster, 1979). Similarly, guayule can withstand severe water stress, but if it ceases growing the maximum yield of rubber per plant will not be obtained. The higher rubber yields per plant have been obtained with shrubs that receive light irrigation--irrigating only when all the available moisture had been depleted to a depth of 3 feet--(Hammond and Polhamus, 1965). These plants were intermediate in both biomass and in percentage of rubber, but they had the highest rubber yield per acre.

Rubber yield increases as a function of chromosomes ploidy level (D. Johnson; G. Hanson, personal communication). Diploids have the lowest rubber yields, and yield increases with increasing ploidy levels: triploids, tetraploids, and hexaploids are all possible.

7.7 Temperature

Cold tolerance in guayule is significantly affected by moisture availability and active growth of the plant. To tolerate low temperatures, cultivated guayule must be "hardened-off" by eliminating irrigation for a period before cold temperatures begin. Cold tolerance is a genetic trait that can be selected for in guayule. Table 7-5 gives the general temperature ranges of guayule; however, these ranges will vary considerably, depending on moisture availability, climate, soil type, and strain of guayule.

7.8 Agronomy

Optimum agronomic practices have not been determined for guayule; however, agronomy data is available as a result of the extensive research done during the Emergency Rubber Project (ERP; refer to Hammond and Polhamus, 1965, for a detailed discussion, as well as McGinnies and Mills, undated; NAS, 1977a; Foster et al., 1979).

Agronomy and management techniques vary depending on environmental conditions. In Arizona and Texas, guayule should be planted from October to May or June. It should not be planted in summer because of problems with soil pathogens (D. Johnson, personal communication).

In California, soil pathogens are less of a constraint. However, it appears that the dormant or winter season is best for planting guayule. In California, this is considered to be October 15 to March 15 (McGinnies and Mills, undated).

Table 7-5. Temperature Sensitivity of Guayule

Source	Guayule Growth	Temperature °F
Hammond and Polhamus (1965) and Foster et al. (1979)	Optimum	90-100
	Significant decrease	<60
	No damage	120
	Often injured	<15
	Optimum for dryland farming	56-62 (mean) 15 (minimum)
	Optimum for irrigated culture	70 (mean) 25 (minimum)
Tipton (personal communication)	a few survived (Texas)	1-4
Hanson (personal communication)	no survival (California)	<10

Guayule can be harvested year-round because rubber is not metabolized by the plant once produced. If the shrubs are to be mowed, they should not be mowed during the summer in Arizona and Texas (D. Johnson, personal communication). In California, the best time to mow is the spring and fall. Winter is the worst time because the winter rains drown the plants (Hanson, personal communication). Generally, plants begin to resprout after two weeks.

There do not seem to be any special technical problems associated with mechanical planting and harvesting.

Currently, guayule is planted as a seedling, which must be started in a greenhouse and therefore is more costly than direct seeding. Research is being done on direct seeding procedures. D. Johnson (personal communication) considers direct seeding the most important problem in guayule commercialization.

The optimum planting density has not been determined for guayule. Tipton has planted 11,000 plants per acre; other researches plant 13,000 to 14,000 per acre. The Emergency Rubber Project obtained the highest yield per acre from the most densely planted sites, which were planted with 18,000 to 19,000 plants per acre (McGinnies and Mills, unpublished). This result is probably due to stresses caused by competition for water and nutrients.

A higher planting density also reduces the need for herbicides and irrigation, but may cause a higher rate of fungal infections.

7.9 Irrigation

Optimum water requirements will vary widely between different geographical areas. The timing of irrigation and precipitation, the type of soil, the climate, and the strain of guayule cultivated will influence the total amount of water required. This section covers some of these parameters in general; for a detailed discussion, refer to Hammond and Polhamus (1965).

With present technology, irrigation will probably be required in all potential cultivation areas, except for portions of California and south Texas (Foster et al., 1979). In fact, all experiments to grow guayule commercially have indicated that irrigation will be required.

However, several researchers are experimenting with dryland cultivation of desert shrubs (Felker, Goodin, McKell; personal communications). This technology is unproven to date, but even if it is possible, it is certain to result in extremely reduced yields. Whether or not the decrease in the cost of pumping irrigation water will compensate for reduced yields of rubber remains to be determined.

Guayule has two root systems: shallow surface roots collect water from rain showers, and a taproot collects deep moisture from the soil. The taproot penetrates 14 to 16 feet (4.3 to 4.9 m) by the second season and eventually reaches depths of 20 feet, or 6.1 meters (Foster et al., 1979).

In general, guayule requires at least 15 inches (39 cm) of water per year for growth, and 20 inches (51 cm) appears to be about optimum for rubber production (although, again, these values will vary considerably depending on the conditions).

Optimum vegetative growth is usually not found with maximum rubber content of the shrub (Foster et al., 1979). During the ERP it was found that dryland shrubs had a higher percentage of rubber, but they were smaller than irrigated shrubs (Foster et al., 1979). As a result, the rubber yields were higher from irrigated plots. In addition, irrigated plots can be planted more densely than dryland plots, which further increases the potential yield.

High levels of water can increase fungal infections (D. Johnson, Tipton, personal communications; Hammond and Polhamus, 1965). However, drought injury can also increase susceptibility to disease (Foster et al., 1979).

Water availability is particularly critical for seed germination: Irrigation should be frequent (Foster et al., 1979).

The timing of irrigation is as important as the amount. The ideal appears to be periodic rains (or irrigation) during late winter, spring, and early summer. Late summer and fall should be dry, especially where winter frost damage is a problem. The best conditions are for the soil moisture to be reduced slowly during this time so that the shrub has time to "harden-off" or go into a dormant stage (Foster et al., 1979). These conditions increase both cold tolerance and rubber production.

7.10 Soil Requirements

Guayule is very sensitive to soil conditions. It does well on sandstone and limestone soils (Hanson et al., 1979a). Generally, the soil should be permeable, well-drained, and well-aerated. Heavier soils with slow drainage may increase fungal infections (Hammond and Polhamus, 1965). In west Texas, Tipton (personal communication) lost almost an entire experimental plot due to charcoal rot. The drainage was very poor in this field because of a high clay content. D. Johnson (personal communication) also lost some plants to charcoal rot; however, only plants receiving high irrigation treatments (30 inches, or 0.8 meters) were affected.

Guayule is not highly tolerant of high soil salinity, especially during germination (Hammond and Polhamus, 1965). It tolerates up to 0.3% salinity; growth is severely retarded at 0.3% to 0.6%, and at greater than 0.6%, the plant will not survive (Hammond and Polhamus, 1965).

7.11 Fertilizer

Precise nutrient requirements are not known at this time; however nutrient stress may increase rubber production (D. Johnson, personal communication). Guayule appears to have low nutrient requirements (Hammond and

Polhamus, 1965; NAS, 1977a; Foster et al., 1979). However, if all of the leaves and bagasse are removed and used during processing (as is currently planned), an increase in the use of fertilizers will almost certainly be required.

7.12 Diseases/Pests

No pesticides or herbicides are registered for use on guayule.

Herbicides are very important in the first year of cultivation to help the plant compete against weeds. Guayule is very shade intolerant and is highly susceptible to weed competition. D. Johnson (personal communication) uses 1 pint Treflan/acre and 1 pound Diuron/acre; the total cost is about $10 to $11 per acre. The effect of these compounds on rubber yields is unknown. However, Rubis (1979b) is investigating the use of dinitroanilines as herbicides for guayule. The seedlings will tolerate these compounds; however, Rubis reports that they are only 50 to 60% effective on weeds.

Soil fungi that have been reported to infect and damage guayule include Sclerotium bataticola* (Foster et al., 1979), Phytophthora drechsleri, Phymatotrichum omnivorum, Pythium ultimum, and Verticillium albo-atrum.

Fungal diseases are best controlled by breeding for resistance and by management techniques that help prevent infection, such as controlling soil moisture, maintaining adequate drainage, and pruning (Foster et al., 1979; Hammond and Polhamus, 1965).

Several insects and other pests have been identified (McGinnies and Mills, undated) on guayule. So far, these pests have not created a serious problem (Foster et al., 1979), although grasshoppers and lygus bugs have been a serious problem in limited areas (Hammond and Polhamus, 1965). When

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*Macrophomina phaseoli is the pycnidial form of this fungus (Hammond and Polhamus, 1965). It has been observed by Tipton (personal communication).

guayule is grown commercially, pests may be more of a problem, but commercially available pesticides and insecticides should be able to provide control (NAS, 1977a).

Insect pests, such as lacebugs, thrips, loopers, and mites have been a problem in the greenhouse cultivation of seedlings (Hammond and Polhamus, 1965). Tipton (personal communication) has had good success with broad spectrum insecticides such as diazinon, malathion, and calthane.

7.13 Potential Cultivation Sites

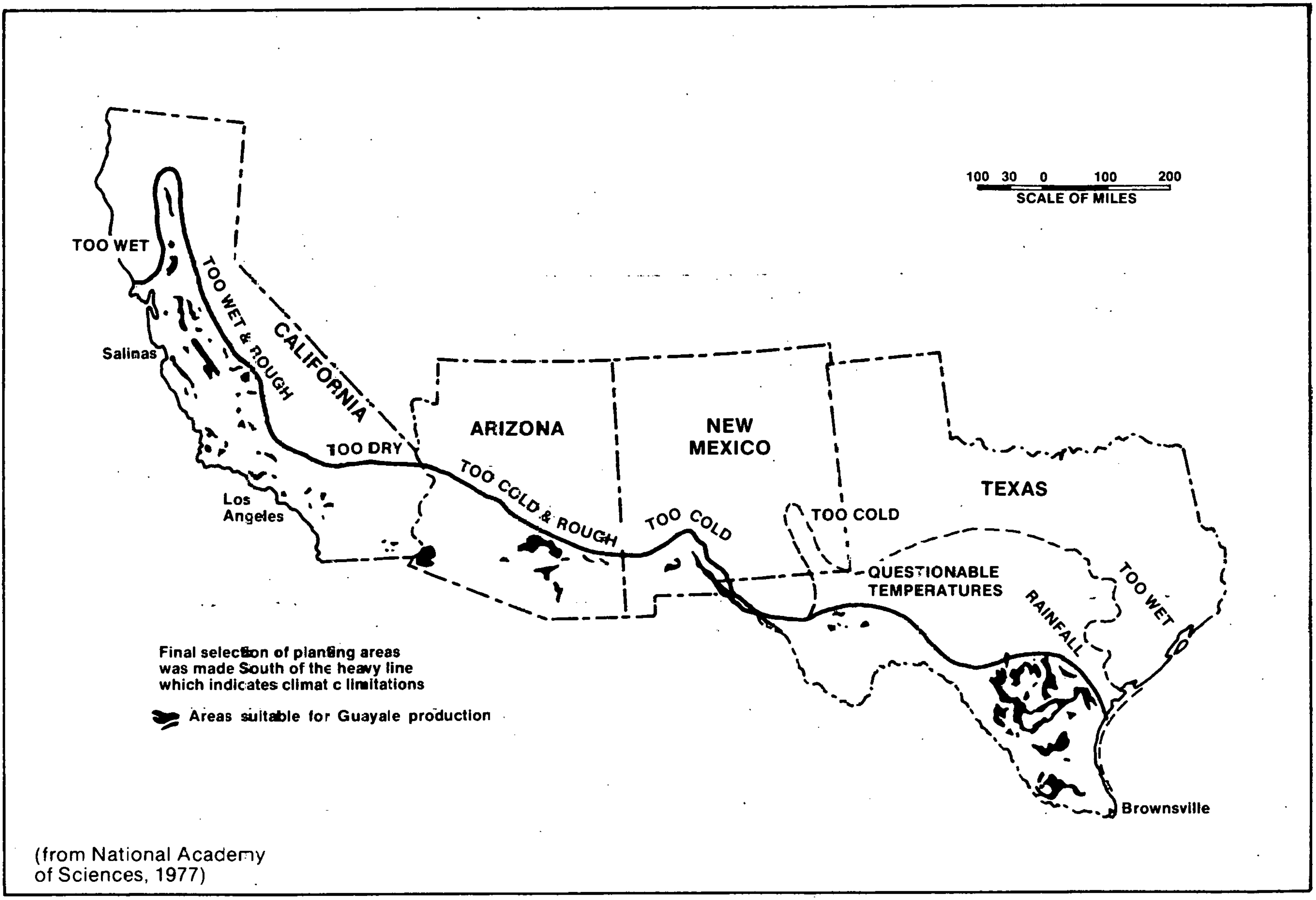
According to Foster, et al. (1979), four regions have potential for commercial cultivation: 1) California rainfall production areas: coastal valleys, Riverside and northern Sacramento Valley; 2) warm irrigated areas, including warmer and drier parts of California, Arizona, New Mexico, and northern Rio Grande Valley in Texas; 3) Texas rainfall farming areas, and; 4) the southern tip of Texas. Figure 7-2 shows the areas identified by the National Academy of Sciences as potential guayule cultivation sites.

7.14 Breeding Potential

The potential for genetically improving guayule through selection appears to be good.

The diploid number (2N) of chromosomes in guayule is 36. A diploid, or 2N, plant results from the fusion of an egg cell, containing one set of chromosomes (N), with a pollen cell, which also contains a complete set of chromosomes (N).

In guayule, polyploidy is common in nature and is very important in rubber production and breeding. A polyploid plant has some multiple of the N number of chromosomes. Therefore, a triploid (3N) has 3 sets, a tetraploid, 4 sets, and a hexaploid, 6 sets. In guayule, polyploids are found at all of these levels, and plants with 36, 54, 72 and 108 chromosomes have been found.



(from National Academy of Sciences, 1977)

Figure 7-2. Suitable Areas for the Cultivation of Guayale

In fact, according to Foster et al. (1980), a guayule plant with 144 chromosomes (8N) has been developed through breeding. Polyploidy can be induced with a chemical called colchicine.

Polyploidy is important in guayule because researchers (Hanson, personal communication; D. Johnson, personal communication) have observed a correlation between rubber production and ploidy level: The higher the ploidy level, the higher the rubber content of the plant.

Polyploids are important in guayule breeding for another reason. They reproduce almost exclusively by a type of asexual reproduction called apomixis. In apomictic flowers, seeds are formed, but they are not the result of an egg cell fusing with a pollen cell. In fact, an apomictic seed is the exact genotype of the parent plant. Because apomictic flowers are difficult to distinguish from sexual flowers, breeding guayule is challenging.

Apomicitic flowers, however, are important for guayule breeding because they ensure that a plant with superior characteristics will breed true. In plants that do not produce apomictic flowers, selection for plants that breed true is a very lengthy process.

High rubber yielding plants can be identified by their common morphological characteristics: leaf margins that are entire or have two teeth, and an inflorescence axis with the branch extending beyond the main axis of the inflorescence (Mehta et al., 1979). Plants with these characteristics average 17% rubber, while the range for guayule is 5 to 19% (these studies were based on 87 samples of guayule and P. incanum (mariola) collected at random from 53 locations distributed throughout the range of guayule in Mexico).

Guayule also has a large source of germ plasm, which increases its breeding potential. Guayule is closely related to several other species of Parthenium, and it hybridizes with all of them, including P. incanum, P. tomentosum, P. stramonium (sometimes called P. tomentosum var. stramonium) and P. hysterophorus. These hybrids are more vigorous and disease resistant than guayule, but so far, they also have a lower rubber content. Plant breeders are attempting to produce hydrids that combine all of the desired qualities; vigor, disease resistance, high rubber quality and quantity, cold tolerance, etc.

Guayule is essentially an undomesticated species, and breeding will take time. According to D. Johnson (personal communication), the plant must be at least 3 years old before the content and quality of rubber can be determined. It will probably take at least 10 years, or perhaps 20 years, before improved varieties are developed (Foster et al., 1979).

7.15 Breeding Goals

Breeding goals should emphasize the following:

- Increase the yield of rubber per plant, both by increasing the percent of rubber and increasing the biomass per plant.
- Increase disease resistance
- Select for high quality rubber
- Select for cold tolerant strains

7.16 Environmental Impacts

One possible environmental consideration is the use of plant growth regulators (PGRs) in increasing rubber production of guayule. PGRs, such as 2-(3, 4-dichlorophenoxy) triethylamine, are chlorinated hydrocarbons, which are known to be extremely persistant compounds when released into the environment.

In addition, Parthenium hysterophorus, one of the species that hydridizes with guayule, contains oleoresins that can cause severe respiratory and dermatological reactions (Foster et al., 1980).

7.17 The Elastomer Market

Guayule rubber will have to compete in the elastomer market both with natural rubber (NR) from Hevea brasiliensis and with synthetic rubbers. Table 7-6 lists the key properties of both natural rubbers and of the three synthetic rubbers that comprise the bulk of the synthetic rubber market: styrene butadiene (SBR), which amounts to 57% of synthetic production, polybutadiene, 16%, and butyl, 17% (Larsen, 1980).

Table 7-6. Key Properties of Various Rubbers

	Natural Rubbers		Synthetic Rubbers		
Property	Hevea	Guayule	Styrene Butadiene (SBR)	Polybutadiene	Butyl
Green Strength (psi)	200	200	50	25	40
Processing Ease (Hevea = 100)	100	100	85	95	95
Tensile Strength (psi)	4050	3650	3500	2500	3000
Tack (Hevea = 100)	100	100	85	95	95
Source: Larsen (1980)					

The most important properties for quality rubber are green strength and tack. Guayule rubber is somewhat lower than Hevea rubber in natural green strength, but can be made its equal with additives. No synthetic has been developed that comes near NR in green strength. Green strength is crucial in sticking raw tires together, especially radials (Warren, personal communication). Consequently, radial tires are 30 to 40% NR. Guayule rubber also has good flex capability, appears to be better than Hevea rubber at retaining shape after deformation, and has low heat buildup under severe flexing. This last characteristic is crucial for tires used with airplanes, heavy equipment, and trucks. Use of guayule rubber in a 5000-pound earthmover tire in place of Hevea rubber has demonstrated that, unlike synthetic rubber, guayule may be substituted for Hevea (anonymous, 1980c).

Present and projected U.S. rubber consumption is shown in table 7-7. This indicates the continuing demand for NR. The price of tire grade natural rubber in early January 1981 was 58 cents per pound, while SBR was about 50 cents per pound (Nivert, personal communication). For higher grade ribbed smoked sheet rubber, the price is currently about 66 cents per pound (Wall Street Journal, March 16, 1981). This price has been dropping for about a year. It reflects the declining demand for rubber due to the worldwide economic slowdown and high prices for vehicle fuels, which reduce the vehicle miles traveled and therefore the demand for radial tires.

Table 7-7. U.S. Rubber Consumption (in 000 tons)

Rubber Type	Year		
	1978[1]	1990[2]	2000[2]
Natural Rubber	750	1008	1265
SBR, Polybutadiene and polyisoprene	1853	2277	2783
Other	580	747	1014
TOTAL	3182	4032	5062
[1]Rubber World, May 1980			
[2]Based on Forecast of International Institute of Synthetic Rubber Producers			
Assumes Natural Rubber = 25% of Total Demand.			

Foster et al. (1979) projected that worldwide demand for natural rubber would exceed supply by 20 to 35% in the year 2000.

forecast estimated world consumption in 2000 to be 1/3 less than the earlier forecast (Sievers, 1980). If this forecast is correct, then there will be no shortfall, and U.S. year 2000 requirements will be 25% lower than projected in table 7-6. This is still a 50% increase in total consumption over the next 20 years. Ching (1980) forecasts a 39% increase in NR production between 1980 and 1990. It is reasonable to assume that at least an 11% increase in production will occur from 1990 to 2000. However, a shortfall in the *Hevea* natural rubber supply could result from disease infestation or from political instability in producing countries (see next section -- Supply Considerations). The energy saved by using guayule NR in the event of an NR shortfall is discussed in the appendix 1 at the end of this section. The demand for NR will remain high, and therefore, the commercial success of guayule rubber depends on price.

7.18 Supply Considerations

Rubber is a strategic material. It is on the list of materials being considered by the Reagan administration for stockpiling (Blundell, 1981) and the Federal Emergency Management Agency has proposed a 10 year $200 million development program (see section 1.0 on FEMA under Government Agency Support).

At present, natural rubber is supplied mostly from southeast Asia, with Africa being the second most important source. The political security of these supplies is not assured for the following reasons: There was recently a military coup in Liberia, which is one of the principal African producers. There is a continued low level threat of insurrection from communist guerrillas in Malayasia, the leading rubber producer. In the event of major warfare, it is likely that the sea lanes providing supplies would be closed.

Another threat to continued supplies of NR is the South American Leaf Blight. Large scale production of *Hevea* rubber is almost completely absent in Brazil due to this fungus, even though *Hevea* originated from Brazil. If this fungus ever spread to other producing areas, rubber production would probably be severely decreased.

7.19 Economic Analysis

The cost of growing guayule is not well defined, in part, because the harvest cycle has not been determined. It may be three, four, or five years, or even longer with pollarding. The cost studies performed to date (such as Foster et al., 1979) have assumed an annual yield of 500 pounds per acre. In fact, the World War II ERP almost reached this level, which is half the 1000-pound goal. As evidenced by the ten-fold increase in NR yields from Hevea (Imle, 1978) it is possible to increase yields of whole-plant hydrocarbons. It is unlikely that increases in guayule will be this great*, however, 1,000 pounds per acre seems a realistic long-term goal. (U.S.D.A. anticipates that their certified guayule seed will yield 500 lbs/acre/year.) Without any agricultural profit, costs were estimated at 34 to 50 cents per pound at a yield of 500 pounds per acre (Foster et al., 1979). This variation is partially due to disparities in land and water costs.

What would the costs be for 1,000 pounds of guayule rubber per acre? This depends on the land chosen and the portion of the expenses that do not vary with yield. We estimated these invariant costs at one-third of total expenses -- this is a conservative estimate that assumes the above estimates of agricultural costs are correct. Adding a farming profit of $50 per acre, we estimate the cost to be from 34 to 46 cents per pound. Processing costs, including a 12% profit on total expenditures, have been estimated as 28 to 38 cents (in 1980 dollars; Foster et al., 1979). We estimate production costs of guayule rubber for 1,000 pounds per acre to be 62 to 84 cents per pound (based on sum of agricultural costs plus processing costs).

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*Guayule yields may never reach Hevea yields for several reasons: 1) Hevea trees are commercially productive for 35 to 40 years. Extremely high producing plants (8000 lbs per acre) can be developed by grafting a robust root stock onto a high-producing trunk, and grafting a disease resistant canopy onto this trunk. Therefore, each tree is derived from 3 genetically distinct trees. This kind of horticultural engineering would never be economical for guayule. 2) Hevea has few disease problems in producing countries such as Malaysia because it originated in Brazil, and to date, the diseases of Hevea have not reached southeast Asia. Conversely, guayule is susceptible to several diseases in its native southwestern United States.

There are three important byproducts from guayule: resins, leaves, and pulp. Resin production is estimated at 0.45 pounds per pound of rubber (Foster et al., 1979). There is considerable debate over the value of these resins. Some experts claim they can be used as tackifiers and therefore have a high value (currently 34 cents per pound -- Nivert, personal communications). Others claim they are worth no more than naval stores, or significantly less than 34 cents per pound (Foster et al., 1979). A more conservative estimate is to evaluate resins based on their value when cracked and used as fuel, or 12 cents per pound, which is equal to the price of crude oil. Since our analyses are based on oil prices between $60 and $80 per barrel (projected year 2000 prices), the equivalent value of resins would be 20 cents per pound. Therefore, at $60 per barrel of oil, the resins would have a value of 9 cents per pound of rubber.

The highest value of guayule leaves may be as fertilizer, however, a conservative assumption is that the leaves will be blended with pulp and used for boiler fuel. The latter, valued equivalent to coal, would be worth about 4 cents per pound of guayule rubber. We estimate the total byproduct value in 2000 year to be 13 cents per pound of guayule, which reduces net costs to 49 to 71 cents per pound.

Current prices of rubber are 50 cents for tire grade SBR and 58 cents for Hevea natural rubber (Nivert, personal communication). However, SBR prices will rise substantially due to increased petroleum prices. SBR production requires about 27,500 Btu of petroleum per pound of rubber and an additional 10,800 Btu per pound of other less expensive fuels (Gaines and Shen, 1980). Early 1981 prices of 50 cents per pound SBR were based on average U.S. petroleum prices of about $30 per barrel. A rise to $60 per barrel therefore would be expected to raise the price of SBR by 17 cents a pound to 67 cents per pound. Therefore, guayule rubber with estimated costs of 49 to 71 cents per pound should be economically competitive with SBR at projected year 2000 prices.*

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*This analysis is far more pessimistic for economic prospects than Weihe and Nivert (1980). They estimate costs of production at 58 to 60¢ per pound with byproduct credits of almost 30¢ per pound.

7.20 Energy Analysis

There are three ways for guayule rubber production to save energy: 1) from replacement of synthetic rubber in the event of an Hevea rubber shortfall, 2) from direct substitution for synthetic rubber, and 3) from energy content of byproducts. A shortfall in Hevea NR would maximize the potential energy savings from guayule NR. Substitution of guayule for synthetic rubber requires that the price of guayule rubber be about the same or lower than synthetic. As discussed in the economics section, it is likely that the price of SBR will exceed the cost of guayule rubber by year 2000. However, natural rubber, because of its premium qualities, will probably retain a price premium over SBR, although that difference could be quite small (1 or 2 cents per pound).* Under these conditions, the introduction of guayule rubber into the market will result in some reduction of SBR and Hevea demand. The net reduction of total rubber demand will be slightly less than 1 pound per pound of guayule rubber produced. To determine the maximum energy savings from this substitution, we assume a pound for pound replacement of SBR. Finally, the energy content of the byproducts must be included.

Figure 7-3 outlines the process and energy requirements for the production of SBR (Gaines and Shen, 1980). By analyzing the styrene and butadiene production processes and assuming all exogenous fuel inputs can be provided by nonpetroleum products, we estimate that these energy inputs can be apportioned as 27,500 Btu per pound of petroleum and 10,000 Btu per pound of other fuels.

Figure 7-4 is a flow diagram of a hypothetical guayule extraction plant considered in this analysis with a rubber capacity of 25 million pounds per year. If we assume that pulp and leaves are combined and used for fuel, then 1.95 pounds of residue and 0.45 pounds of resin are available for each pound of guayule rubber after processing. Agricultural residue typically has a energy content of about 7,000 Btu per pound, and the resin a value of 16,000 Btu per pound (Warren, personal communication). The total energy value of

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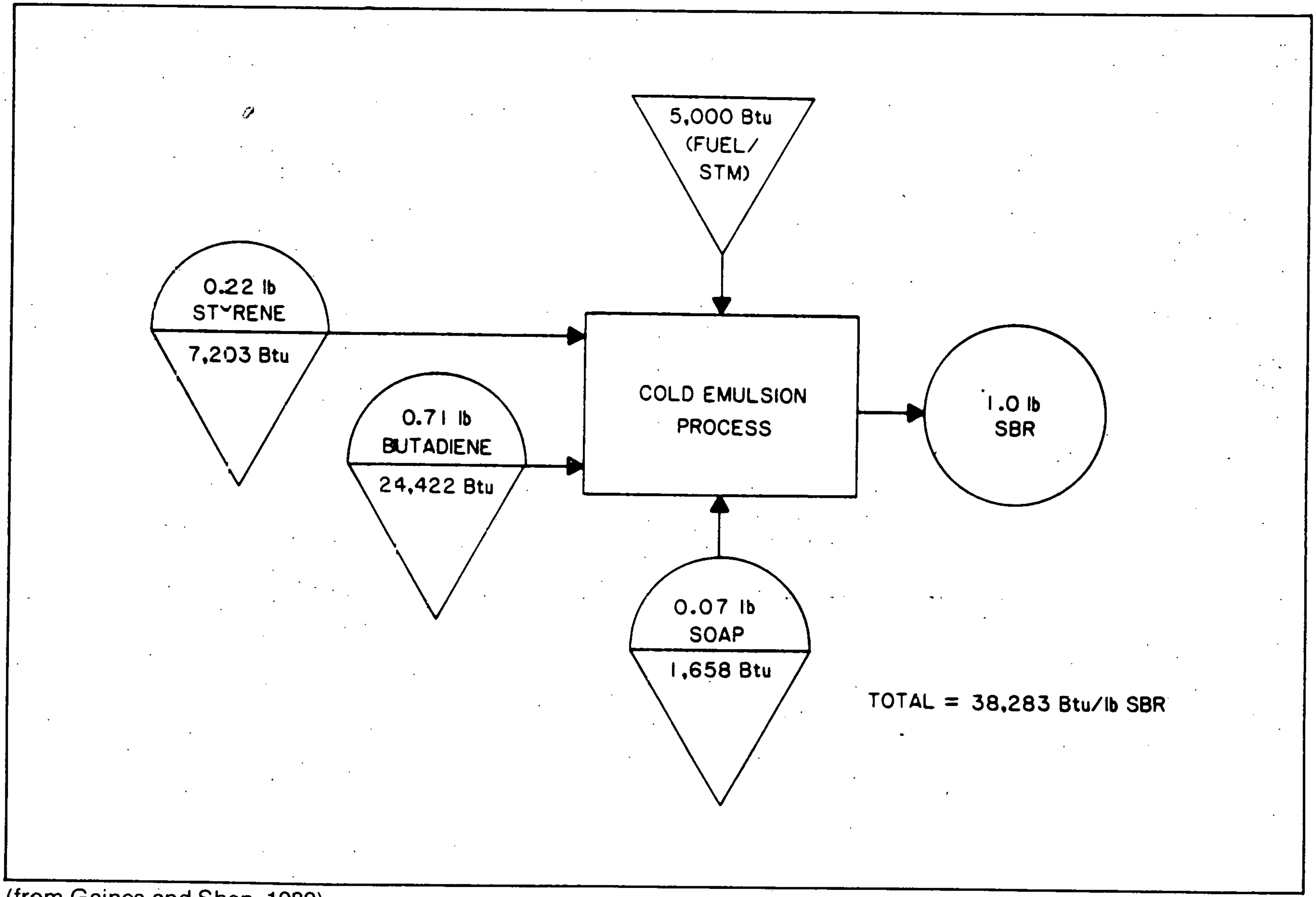
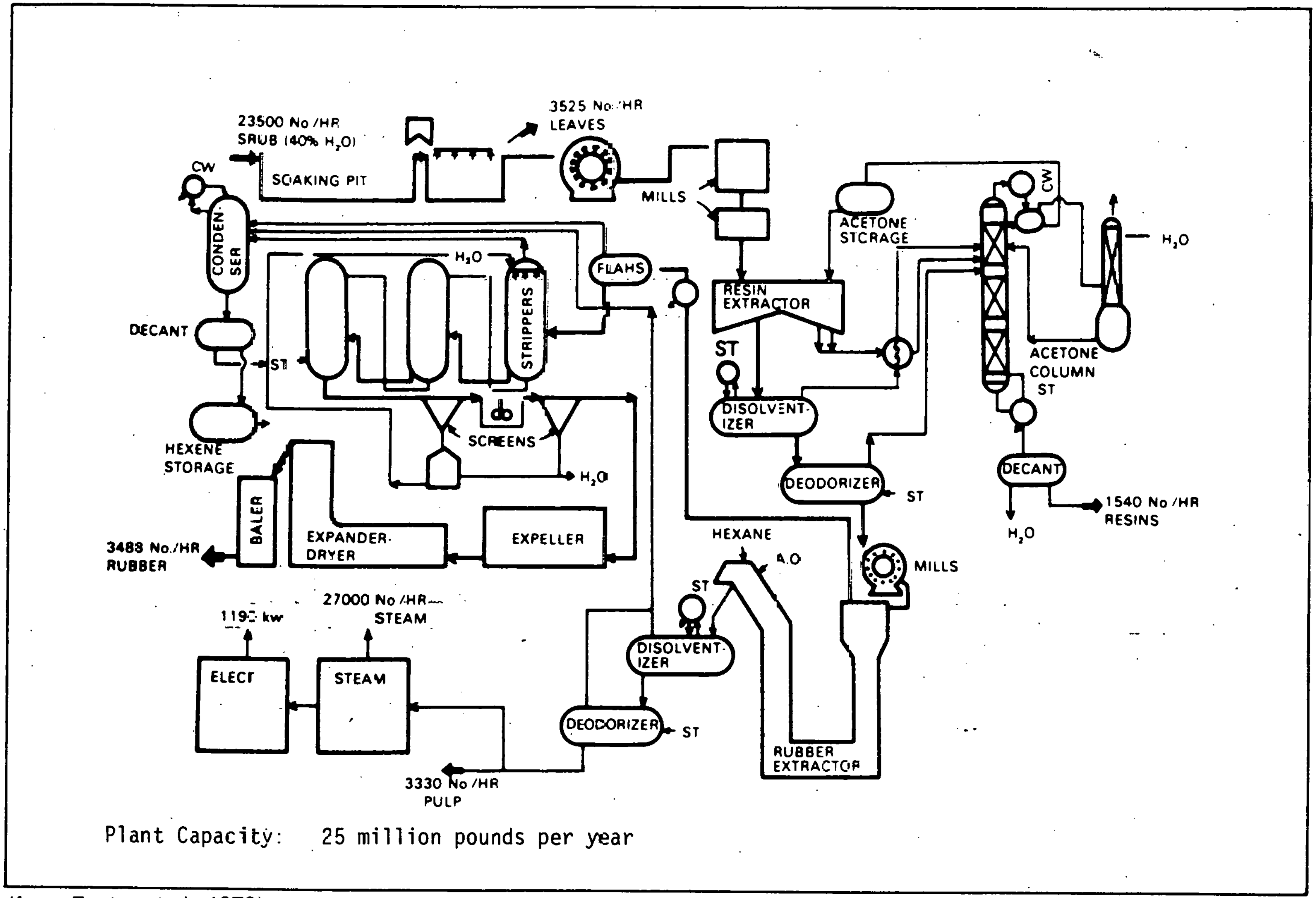
*The various rubbers are close substitutes. As the price of SBR rises near the price of NR, NR would be substituted for SBR. Thus, the high price of SBR would increase demand for NR and raise the price of NR.



(from Gaines and Shen, 1980)

Figure 7-3. Principal Inputs in the Production of Styrene Butadiene Rubber (SBR)



Plant Capacity: 25 million pounds per year

(from Foster et al., 1979)

Figure 7-4. Flow Diagram of Guayule Rubber Extraction Plant these byproducts is 20,850 Btu per pound of guayule rubber: 7,200 Btu is a direct petroleum replacement.

The energy required to produce guayule rubber includes the energy to raise the crop and to process the shrub. All processing requirements are met by burning the pulp (figure 7-4). Agricultural requirements have been estimated at 11,000 Btu per pound of guayule rubber (Weihe and Nivert, 1980).

Table 7-8 shows the energy balance for guayule rubber. The savings are not insignificant, and virtually all net savings are due to the energy saved by substituting guayule for SBR. For example, if only half the guayule substitutes for SBR, petroleum savings decrease 40%, and total energy decreases 45%.

Table 7-8. Energy Balance of Guayule Rubber

Products	Petroleum (Btu)	Total Energy (Btu)
Guayule Rubber (as a pound for pound SBR substitute)	27,500	38,300
Resin	7,200	7,200
Residue	-	13,650
TOTAL	34,700	59,150
Requirements		
Agricultural	7,000	11,000
Processing	met by residue	
TOTAL	7,000	11.000
Net Gain Per Pound	27,700	48,150
Net in Barrels of Oil Equivalent per Acre	4.8	8.7

Appendix 1. Guayule Rubber Energy Savings in the Event of a Natural Rubber Shortfall

Two reports (Foster et al., 1979; NAS, 1977a) have predicted a shortfall in the supply of natural rubber during the next 20 years. The following is analysis of the energy impact of a shortfall occurring in year 2000.

In the event of a natural rubber (NR) shortfall, there would either be rationing or the price would rise dramatically. In both cases, NR would be used primarily for essential uses: military applications; tires for trucks, airplanes, and heavy equipment; and critical industrial products. NR for automotive tires would, therefore, comprise a substantial portion of the shortfall.

Natural rubber is a critical ingredient in radial tires, which contain 30 to 40% (Warren, personal communication). It is also a key component in standard and quality belted tires. Quality belted tires contain 15% of the rubber as NR (Warren, personal communication). It is possible to make a belted tire with NR, but the tire life would be substantially reduced (Warren, personal communication). Table A-1 lists tire life for a quality belted tire, a steel belted radial, and an all synthetic tire.

Table A-1. Expected Miles Per Tire Lifetime

Steel Belted Radial**	44,000
Quality Belted Tire**	35,000
All Synthetic Belted Tire	22,000
**Source, Sears Winter 1980-81 Catalog.	

Radial tires increase gas mileage by 5 to 7% over belted tires (Warren, personal communication). Average annual vehicle miles traveled are currently

10,800 and are not expected to change significantly in the next 20 years (Millar, personal communication), and average vehicle fuel consumption in year 2000 is estimated to be 338 gallons (M. Millar, personal communication). If an NR shortfall occurs and radials are unavailable, the annual energy consumption would increase to 355 gallons, if driving patterns are held constant and radials are assumed to increase gas mileage by 5%.

Based upon current tire weights and trends, the typical year 2000 tire is expected to weigh 20.5 pounds, of which 17.5 pounds is rubber. The non-rubber components are steel and the nylon casing. In steel belted radials, the steel content is about 1.5 pounds and, it is about 0.5 pounds in belted tires (Gaines, personal communication). Only the energy content of nylon is included. The tire components and their petroleum contents are found in table A-2 for radial tires with 30% total weight NR and for quality belted tires containing 10% and 15% NR. Zinc oxide is assumed to have no energy content, and compounding chemicals are estimated to require the same amount of energy as oil. Carbon black is currently made from oil but it can also be made from coal.

The estimated fuel savings from radials is 17 gallons per automobile per year. At the expected annual miles traveled, each tire should last about four years, or one tire per year will need to be replaced. One radial requires 6.2 pounds of NR. Therefore, production of guayule radials instead of bias tires results in a savings of 2.75 gallons of gasoline per pound of guayule rubber. Including a refinery energy loss factor of 10%, this is equal to 380,000 Btu.

There are also energy savings from the increased tire life of radials and direct substitution of NR for SBR. The 6.2 pounds of NR directly substitutes for 6.2 pounds of SBR. In addition, basic radials are estimated to last twice as long as all synthetic tires. Therefore, the use of radial tires will save the materials in table A-1 plus nylon. Nylon has an energy content of 90,000 Btu per lb -- 38,000 Btu of which is oil (Gaines and Shen, 1980) -- although nylon can also be made from biomass. The total energy savings is 98,000 Btu of petroleum and 36,000 Btu of other fuels per pound of guayule.

Table A-2. Estimated Average Passenger Tire Rubber and Compounding Constituents for Year 2000 Tires*

Weight in Pounds					
Constituent	Radial Tire	Belted Tire		Energy Content: Btu per pound	
	30% NR	10% NR	15% NR	Oil	Non-Oil
Hevea Natural Rubber	6.2	2.1	3.1	--	--
SBR	2.5	6.6	5.6	27,000	10,800
Carbon Black	5.0	5.0	5.0	24,000	--
Oil	3.0	3.0	3.0	20,000	--
Compounding Chemicals	0.3	0.3	0.3	20,000	--
Zinc Oxide	0.5	0.5	0.5	--	--

*Based on Bradley et al. (1979)

There is also a slight energy savings from guayule byproducts -- about 9,850 Btu per pound -- less than half of which is petroleum.

The total savings per pound of guayule, therefore, is 520,000 Btu, of which 475,000 Btu is petroleum. At a yield of 1000 pounds per acre, this is an energy savings equivalent to 90 barrels of oil, 81 barrels of which would actually be oil. (If nylon and carbon black production were not made from oil, subtract 5 barrels).

Another option would be to divert more NR from radials to make quality belted tires. For belted tires containing 10% NR, it would require diverting the NR in 1.7 radials to save the NR in one radial tire. For belted tires containing 15% NR, this diversion factor rises to 2.67. Therefore, based on fuel savings alone, diverting NR from radials to quality belted tires requires a substantial increase in petroleum use: over 75,000 Btu per pound of NR for 10% NR belted tires, and over 1,000,000 Btu per pound for 15% NR belted tires. Clearly, from an energy standpoint, production of all synthetic tires would be preferable to diverting NR from radial tires to quality belted tires.

8.0 *Rabbit Brush: Chrysothamnus nauseosus (Compositae)

8.1 Products

Rabbit brush produces rubber, which is located in the individual cells of the plant. As with guayule, rabbit brush rubber is not derived from latex. The plant also produces resins and fiber, although it is not known whether these products would be commercially useful.

8.2 Life Cycle

Rabbit brush is a perennial shrub with numerous branches. The shrub has several trunks that originate from a single base and a deep taproot, which normally has few main laterals.

Part of the plant dies back each year, but there is a net gain in wood. The plant grows from seed and reaches maturity in six to eight years. The flowering season extends from August to October.

8.3 Processing/Refining

The rubber is produced in individual cells of the plant; therefore, the entire plant must be harvested, finely ground, and extracted. Hall and Goodspeed (1919a) extracted the resins with acetone and the rubber with benzene. Currently, improved processing methods used for guayule could probably be used, with modifications, for C. nauseosus.

The young stems, leaves, and all but the uppermost part of the roots do not contain rubber. Therefore, this material would not be processed. Most of the rubber is located in the older portions of the stems and roots.

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*Unless otherwise indicated, the source for the material in this section was Hall and Goodspeed (1919a).

The plant can be stored for at least 10 months with minimal loss of rubber.

8.4 Quality Parameters

According to Hall and Goodspeed, the rubber from rabbit brush is of considerably higher quality than that from guayule. There is no evidence given for this statement. In addition, it would have to be confirmed by using the processing techniques available today. Hall and Goodspeed also state that rabbit brush rubber vulcanizes easily.

8.5 Yields

Chrysothamnus nauseosus has not been cultivated in large experimental plots, to our knowledge. Therefore, there are no accurate data available on yields. However, some general comments can be made.

The plants are 3 to 8 feet in both height and width, however, plants have been found that are 16 feet in height. The following values for average percent rubber content of different varieties of Chrysothamnus nauseosus are based on an analysis of over 180 plants:

C. nauseosus var. hololeucus -- 2.83%

C. nauseosus var. pinifolius -- 2.69%

C. nauseosus var. viridulus -- 2.52%

C. nauseosus var. consimilis -- 1.97%

These are the most common varieties of rabbit brush, and they also have the highest percentage of rubber. The highest percent rubber found in a plant is 6.57%, from a variety of consimilis. The highest yield from viridulus is 5.56% rubber.

The rubber is located in the stems that are at least three years old. An average mature plant weighs from 5 to 15 pounds (2.3 to 6.8 kg), and shrubs weighing 20 to 40 pounds are not uncommon. An exceptionally large plant, exclusive of twigs, weighed 60 pounds (24 kg). However, Hall and Goodspeed estimate the average weight of a shrub to be 6 pounds (2.7 kg). This estimate is based on measurements of thousands of plant samples and includes the root to a depth of 4 inches (10 cm).

As with guayule, the rubber in C. nauseosus is found in the parenchymatous elements of the cortex and in the medullary rays -- in other words, in the soft or inner bark. The rubber occurs in the greatest amount in or near the soil line to the upper limits of the main trunk. The portion of the root nearest the soil line also contains rubber and negligible amounts are found in the root that is deeper than 6 to 8 inches (15 to 20 cm). In addition, negligible amounts are found in the leaves, twigs, and stems three years or younger.

In guayule, rubber is produced during the dormant season and is not produced during active growth. Hall and Goodspeed have not found this to be the case with C. nauseosus. Based on preliminary results, the amount of rubber was found to decrease during the dormant period and the resins and other acetone-soluble substances increased. (These data were based on 13 accessions of three varieties of Chrysothamnus.)

8.6 Factors that Influence Natural Rubber Yield in C. nauseous

Little is known about the factors that influence rubber yield in C. nauseosus, however, the plants with the highest percent rubber are found on highly alkaline soils. This is an area for further research. In addition, the authors found no difference in the rubber content of plants from the hot interior valleys, where the temperatures reach 110°F, and those from the cold mountain valleys of Colorado, where the temperature drops to -20°F and the snow accumulates to several feet deep.

8.7 Temperature

As stated above, the plant grows under a wide range of temperatures, from the hot interior valleys (temperatures of 110°F) to the valleys of Colorado, where the temperatures drop to -20°F.

8.8 Agronomy

C. nauseosus is a perennial, and it will resprout when cut. Therefore, this plant will probably be clipped and only the branches harvested. The plant will not resprout if clipped below the roots juncture with the stem (this statement is based on experiments of over 300 plants of C. nauseosus). In addition, pruning the plant greatly increases the number and weight of the rubber bearing stems. It is not known if it would be economical to harvest the roots every few years and then replant the shrub. The roots only contain rubber from the soil line to about 4 inches (10 cm) below the soil.

8.9 Irrigation

Water and irrigation requirements are not known, however, Hall and Goodspeed report that C. nauseosus requires much less water than guayule and can grow without irrigation. This is not proven, although C. nauseosus is found in areas with a lower rainfall than those in which guayule is found. Guayule produces more rubber than C. nauseosus; irrigation requirements would have to be compared based on the amount of rubber produced from each plant. Guayule has a higher percent content of rubber than C. nauseosus; therefore, irrigation requirements would have to be compared by calculating the amount of water required to produce a unit of rubber.

8.10 Soil

Soil and nutrient requirements have not been precisely established, although some general information is known. The most promising varieties of

C. nauseosus were found to grow on sandy soil that is moderately to strongly alkaline, however, Chrysothamnus has also been grown in heavy clay soil at the University of California, Berkeley, botanical gardens. Generally, C. nauseosus is found on soil that is too alkaline for upland plants. The better drained and scarcely alkaline slopes are inhabited by sagebrush (Artemisia tridentata), and the extremely alkaline soils are inhabited by grease wood (Sarcobatus).

8.11 Diseases/Pests

The susceptibility of C. nauseosus to diseases and pests is not well known because the plant has never been cultivated in large experimental plots. In nature, the plant seems to be susceptible to attacks by larvae and beetles, but their effect is not known. In addition, C. nauseosus has been observed to be a poor competitor and therefore will probably require herbicides when cultivated. In high alkaline soil it is outcompeted by more aggressive shrubs such as grease wood, and in low alkaline soils it is outcompeted by sage brush.

8.12 Geographic Range

Little is reported in the literature about the current distribution of Chrysothamnus nauseosus. In 1919, Hall and Goodspeed reported that the shrub was widely distributed in western North America with the following limits:

North: British Columbia, Alberta, and Saskatchewan

South: Western Texas, southern New Mexico, and southern Arizona, with possible extensions into Mexico or lower California

East: South Dakota and western Nebraska

In addition, the plant's range was reported to include desert basins, such as the Lower and Upper Sonoran desert, as well as mountainous areas (to 8,000 feet, or 2,438 m) in southern Colorado.

The plants were the most abundant and largest in size in the Great Basin area. The largest stands of native rabbit brush were in Colorado, Nevada, and Utah. The plants with the highest rubber content were from Nevada and California. The range of *C. nauseosus* may not be significantly different today, however, this should be determined.

8.13 Breeding Potential

Four of the 16 species of *Chrysothamnus* have been found to produce rubber: *C. nauseosus*, *C. turbinatus*, *C. teretifolius*, and *C. paniculatus*. Only *C. nauseosus* is of significance, however, the other species may have valuable characteristics that may be useful in breeding *C. nauseosus*.

C. nauseosus consists of 22 varieties. Natural rubber has been found in all of these varieties, however, *C. nauseosus* var. *hololeucus*, *C. nauseosus* var. *pinifolius*, *C. nauseosus* var. *viridulus*, and *C. nauseosus* var. *consimilis* are the most important for rubber production. The best rubber producing shrubs are those of the alkaline valley bottoms.

There is no evidence that the flowers are self-fertile. Flowers are visited by honey bees and other insects, and seed is produced in abundance and is highly viable.

8.14 Breeding Goals

The chief goal is to increase the rubber content. This plant, even though it has many advantages over guayule, will never be economically competitive unless the rubber yield is significantly improved.

9.0 Jojoba: Simmondsia chinensis (Buxaceae family)

9.1 Products

Jojoba seeds produce a liquid wax (molecular weight of 606; NAS, 1977b) that is often referred to as an oil, and that constitutes about 50% of the weed weight (Hogan, 1979). This oil is very similar to sperm oil. It consists of long-chain acid-alcohol esters (Hogan, 1979; NAS, 1977b). Jojoba oil is chemically very pure. Ninety-seven percent is liquid wax esters (sperm oil is only 75%), and over 83% of these alcohol and acid esters are C_{20} and C_{22} acids and alcohols. All seed oils other than jojoba are triglycerides, which have one molecule of glycerol esterified with three molecules of fatty acids (Hogan, 1979; NAS, 1977b). Jojoba has no glyceride esters, whereas sperm oil contains 25% glyceride esters (Walters et al., 1979).

Jojoba oil is an excellent lubricant, and it can be used as a petrochemical feedstock or as an oil additive (NAS, 1977b; Yermanos, 1980). Seed meal is also produced as a byproduct. This meal is high in protein, however, it is slightly toxic. Therefore, it is usually plowed back into soil. The toxin can be extracted and the meal used for animal feed, but it is probably not economic to do so.

9.2 Quality Parameters

Jojoba oil is a superior lubricant for several reasons:

- It has metallic wetting properties; that is, it leaves a film on metal surfaces that prevents wear of friction points (Yermanos, 1980, Walters et al., 1979).

- Its lubricity after sulphurization is superior to sperm oil (Daugherty et al., 1958; NAS, 1977b; Walters et al., 1979).

- It is non-drying and therefore prevents gumming and tackiness (Walters et el., 1979).

- Its high viscosity, high dielectric constant, high purity, and high flash and fire points make it valuable for select industrical uses (NAS, 1977b).

- It maintains a constant viscosity over a wide range of temperatures (Cruse, 1949).

- It is not easily oxidized or damaged by repeated heating up to temperatures above 285°C, or by heating to 370°C for four days (Daughtery et al., 1958; Turner et al., 1979).

- It is extremely stable and can be stored for years (Hogan, 1979).

Key Oil and Lubricants, Inc. uses jojoba oil in their engine, transmission, and differential lubricants. Fuel mileage increases of 10 to 40% have been claimed by users of these products (Fuchs, 1974; anonymous, 1977a); however, to our knowledge, no scientific studies with replicated experiments have been performed. The fuel mileage obtained with synthetic oil additives can equal that of jojoba oil, but jojoba oil has a longer life than synthetics (Miwa, personal communication).

Jojoba oil can be cracked into lower weight molecular compounds, including

- various aromatic compounds that can be used as chemical feedstocks

- gasoline having an octane range of 90 to 96.

Jojoba oil has been cracked by Mobil Research and Development Corporation on their zeolite catalyst (ZSM-5), which works by shape-selective hydrocarbon catalysis (Weisz, Haag, and Rodewald, 1979). Though technically feasible, it is unlikely that cracking jojoba oil would ever be economically feasible because of its high economic value (see Economics section).

Jojoba oil may also prove to be an important replacement for sperm oil in the leather industry. Sperm oil was used in the production of high quality leather products (Walters et al., 1979).

9.3 Processing/Refining

Jojoba oil can be extracted from the seeds by first grinding the seeds and then using a screw press or a solvent extraction, or both (Walters et al., 1979; Johnson and Lusas, 1980). Current extraction procedures are only about 52 to 85% efficient, but very little research has been done to improve them (Johnson and Lusas, 1980).

Currently, jojoba oil is extracted almost exclusively by screw pressing the ground seed. The ground seed can be pressed one, two, or three times, but with each press, the oils become darker. In addition, it is probably only economical to press the cake twice. This method of extraction is only about 52 to 73% efficient (Johnson and Lusas, 1980).

Solvent extraction probably increases processing efficiency, but little research has been done on this method (Johnson and Lusas, 1980). In addition, solvent extraction is only economically feasible when done on a large scale: about 100 tons of seed per day (Walters et al., 1979).

The most economical method of processing may be pressing followed by solvent extraction. Stubblefield and Wright (1977) state that oil yields of 50 to 53% of the seed weight could be obtained using this method. Only ripe seeds should be used. The oil pressed from green seeds was found to be high in peroxide and moisture.

9.4 Life Cycle

Jojoba is a perennial plant that is dioecious: Female flowers and male flowers are produced on separate plants. The female plant is wind pollinated and produces seed when 2 to 5 years old (Walters et al., 1979; Foster, 1980). Seed is then produced annually, and yields increase each year until the plant is 8 to 12 years old. At this age, seed production remains fairly constant (Walters et al., 1979). Female plants, in nature, produce seed for 100 to 250 years. Longevity data are not available for cultivated plants, but it is expected that plants will produce seed for several decades (Yermanos, 1980).

Jojoba plants grow slowly at first, but by 5 years old they are about 6 feet (1.8 m) tall. The average height of a mature plant is 15 feet (4.6 m), but a plant may reach 23 feet (7 m) with sufficient rain fall (staff report, 1980b).

In Arizona, flower buds form in late summer or fall, and pollination occurs in March. Jojoba seeds reach maturity in July and August (Hogan, 1979).

9.5 Yields

Jojoba seeds are 45 to 60% oil, with an average of about 50% oil (Hogan, 1979). Yields per acre will depend upon

- The efficiency of the extraction process
- The yield of seed per female plant
- The ratio of males to females planted
- The total number of plants per acre.

Yield also depends on the availability of water, but optimum levels are not known; however, in extremely dry years, seed is not produced (see Irrigation section).

At this time, data on yield of jojoba seeds are limited. A female plant takes 8 to 12 years to fully mature, and most commercial plantations are less than 3 years old (Yermanos, 1980; Walters et al., 1979; Bredahl, 1980).

Table 9-1 was prepared from data reported in the literature. It is apparent from this table that more data is necessary to make an accurate assessment of expected yields.

Table 9-1. Reported Yields of Jojoba

Source	Age of Plant (years)	Number Female Plants/Acre	lbs Seed per Plant	lbs Seed per Acre/Year*
Stubblefield and Wright (1977) estimated for Calif.	(10)	(750)	(5-6)	(3750-4500)
Yermanos (1980) Mexican plot	3		1-2	
Yermanos (1979)	4	900		4.5
California	5	900		(350)
(estimated)	(5)	(1800)		(700)
(estimated)	(9-10)			(3000)
National Academy of Science observed in wild (estimated)			0.25-10 (3)	(1415)
Walters et al. (1979) (estimated)				(2007)

*Values were not averaged over the life of the plant. This is the yield only for the year sampled.

In natural populations, Yermanos (1979) has observed up to 30 pounds (13.6 kg) of seed from one plant. These high yields were observed only on certain plants and in certain years having warm temperatures and a high rainfall. The mean of wild plants was 4 pounds (1.8 kg) of seed per plant.

Yield of cultivated plants has also varied from year to year; however, Yermanos (1979 and 1980) reports that the variation does not appear to be a typical alternate bearing cycle, in which there are tremendous cyclical variations in crop production.

Most researchers have planted a male to female ratio of 1:4 to 1:8 (Walters et al., 1979; Patzkill, 1980) with 1:5 being common. Yermanos (1980) considers a ratio of 1 male to 16 females sufficient for pollination as long as the males are staggered throughout the field. If it does not decrease fertilization, Yermanos' planting scheme could increase yield per acre by 13%. Since fruit is only produced on new growth, yield may be incresed by mechanically pruning the shrubs or by the use of chemical growth stimulators (Yermanos, 1980), although these methods have not been demonstrated.

9.6 Irrigation

Jojoba water requirements vary, depending upon the age of the plant. In the first two years of growth, the plant requires 24 to 30 inches (0.6 to 0.8 m) of water (Hogan, 1979). After the third year, most researchers report that jojoba grows best with 15 to 24 inches (0.4 to 0.6 m) of rainfall or irrigation (Walters et al., 1979; Yermanos, 1979 and 1980; Hogan, 1979; Foster and Wright, 1980).

The seasonal timing of water availability is important for both seedling survival and seed production. For seedling survival the timing of water is especially important during the first planting season. The first few weeks are critical:

- If the soil is allowed to dry out, transplanted seedlings may die because they have not been able to establish root systems.

- Seeds will not germinate unless they are kept moist (Palzkill, 1980).

Jojoba responds best to moisture during the winter and spring (Walters et al., 1979). Yermanos (1979) suggests a mid-summer irrigation during excessively dry years to ensure good flower production. Furrow or drip irrigation is recommended (Hogan, 1979).

According to Gentry (1958), winter-spring rains must be sufficient to provide deep soil moisture. Gentry did not quantify the water required, but reported that water availability influences seed maturation, size, and production. Gentry also reported that jojoba does not have shallow subsurface roots. Therefore, moisture from light rains probably is not available to jojoba. Jojoba has very long tap roots that use water deep within the soil.

Water requirements are also affected by temperature (Yermanos, 1979 and 1980):

- Yields are best following warm, wet years.

- New growth is stimulated by water, and new growth is damaged by cold temperatures. Therefore, in colder climates, jojoba requires a hardening-off period before winter: That is, a period when water is limited, and new growth is suppressed.

American Jojoba Industries (Fisher, 1980) has found that jojoba is very tolerant of poor water quality (parameters were not stated); however, the long term effects are unknown.

Jojoba can survive for long periods without water (Palzkill, personal communication). Therefore, if the economics are unfavorable or the cost of irrigation excessive in a particular year, irrigation can be stopped. The plants will not be damaged, although they also will not flower (Gentry, 1958).

9.7 Temperature

Adult plants can survive temperatures of 15°F, but flower buds are damaged at 23 to 25°F (Hogan et al., 1980). Young plants (less than 3 years old) are more susceptible to frost damage: Temperatures of 25°F may kill young plants (Walters et al., 1979; Hogan et al., 1979).

Planting should not be done until soil temperatures are 70 to 75°F (Palzkill, 1980); however, soil temperatures of 79°F are best for good germination (Hogan, 1979). In addition, jojoba should be planted no later than May, so that it has time to become established and harden-off before winter (Yermanos, 1980).

9.8 Soil Requirements

Jojoba grows best on well-drained, coarse desert soils and coarse mixtures of gravels and clays (Hogan, 1979; Foster, 1980). Jojoba will not grow on wet, heavy, or marshy soils (Walters et al., 1979; Hogan, 1980). In addition, the soil must be well-aerated (Hogan, 1980).

Jojoba is very tolerant of saline and alkaline soils (Yermanos, 1974), but it is not known how these factors affect seed production.

9.9 Fertilizer

Information on whether or not jojoba requires fertilizer is not consistent. Data from replicated experiments using varying levels of treatments are not available. For example, Fisher (1980) reports no response to nitrogen, phosphorus, or potassium in the field, but reports a response when grown in the nursery. However, no levels were stated and no data presented. Walters et al. (1979) report a positive response to nitrogen and no response to other fertilizers. Again, no levels or data were presented. Yermanos (1979) also found no response to nitrogen and phosphorus in the field (levels of 50 pounds of phosphorus per acre, 50 pounds of nitrogen per acre, and 50 pounds each of phosphorus and nitrogen per acre per year). Yermanos reports that "similar fertilization treatments" in the greenhouse showed a dramatic, positive response. Once again, no data were provided.

9.10 Diseases/Pest

The cost of disease and pest control can vary widely, depending on where the jojoba plants are grown (Fisher, 1980). For the first two years, seedlings must be protected from rabbits, deer, cattle, ground squirrels, and kangaroo rats (Hogan, 1979; Fisher, 1980). Seeds must also be protected from foraging by rodents (Gentry, 1958; Yermanos, 1980). In addition, certain ants will feed on jojoba plants and plastic irrigation systems; and aphids, lizards, and false chinchbugs will also damage jojoba (Fisher, 1980).

Although jojoba is usually considered to be relatively free of diseases, several pathogens have been reported (Palzhill, personal communication). Seeds can also be treated with captane to protect against pathogens. The following diseases could become more of a problem when jojoba is grown commercially; most are presently only a problem in the greenhouse (Stanghelli, 1977; Alcorn and Young, 1979; Hogan, 1979; Palzkill, personal communication).

1) Alternaria sp. has been associated with defoliation of cuttings.

2) Phytophthora parasitica and Pythium aphanidermatum: Preplant soil treatments should be used to protect against these pathogens.

3) Phymatotrichum omnivorum and Verticillium dahliae: It is difficult to protect jojoba from these pathogens; therefore, disease resistant stock should be used, or plants should be planted in soil that is free of these pathogens.

Insects have been only of minor importance to date (Hogan, 1979). Aparathion, a broad spectrum insecticide, is registered for use on jojoba (Palzkill, personal communication).

9.11 Agronomy

Many of the practices used by researchers would not be practical on a commercial scale. For instance, under natural conditions, the lower branches of jojoba grow very close to the ground, and therefore harvesting is difficult. Yermanos (1979 and 1980) has solved this problem in his research plots by wrapping the shrubs in a plastic screen, which forces the plant to grow upright. The screen is removed in 2 to 3 years. Yermanos (1974) has also hand-removed all of the side branches from the ground up to 3 to 4 feet, but this method may damage branches, which are extremely brittle. Both of these labor intensive practices would be prohibitively expensive on a commercial basis.

Several suggestions have been made to facilitate harvesting of jojoba:

1) Plant shrubs on at least a 14 inch high berm (Fisher, 1980).

2) Plant shrubs close together so that plants form a hedge; jojoba has a long taproot that probably extends 100 feet, and it has no lateral roots that can be damaged by close plantings (Yermanos, 1980).

3) Prune plants mechanically, beginning in the second year of growth, to promote upright growth (Fisher, 1980).

4) Develop chemicals that will do the following:

- prevent an early release of pollen before female buds are ready to be fertilized.

- ensure that fruits ripen and drop off of the plant at the same time to prevent the need for more than one harvest.

In native stands, depending on genotypes and environmental conditions, seed fall will occur over a period of one to seven weeks (Gentry, 1958). Therefore, unless cultivars are developed that simultaneously drop their seed over a very short period, it will be necessary to harvest seed several times a season.

Several harvesting systems could probably be modified for jojoba, including harvesters for grapes, pecans, blueberries, almonds, and walnuts.

These systems generally operate in one of two ways (Palzkill, personal communication; Yermanos, 1980):

1) They sweep or vacuum fallen seeds from underneath the plant.

2) They have a skirt that extends underneath the plant while the plant is mechanically shaken. The seeds then fall onto the skirt and are collected by the machine.

The problem with allowing the seed to drop to the ground is that various animals take it for food. The second type of harvester may be the more promising for jojoba.

Jojoba can be grown by direct seeding, transplanting seedlings, or transplanting rooted cuttings (Palzkill, 1980). Cuttings take about 30 to 60 days to root (Hogan, 1979). Tissue culture may eventually be possible, but so far, has had limited success with woody plants such as jojoba (Hogan, 1979). Plant Resources Institute (Alder, personal communication) is working on the propagation of jojoba via tissue culture.

Jojoba seedlings or seeds should be over-planted for two reasons (Hogan, 1979; Fisher, 1980):

1) Until superior germ plasm is available, unproductive female plants must be removed.

2) Since seedlings cannot be identified as male or female until they flower, excess males will have to be removed once they can be identified in the field.

Seed can be planted with a modified cotton planter (Hogan, 1979) and seedlings planted with commercially available equipment (Yermanos, 1980).

Jojoba competes poorly with weeds, and therefore, American Jojoba Industries recommends 4 to 5 cultivations per year, until the plants are large enough to compete (Fisher, 1980). Since cultivation is also necessary within the row, it is important that herbicides are developed for jojoba. Round-up herbicide can only be spot-sprayed because it will kill jojoba if it comes in contact (Palzkill, personal communication).

9.12 Potential Cultivation Sites

Natural stands of jojoba are found in southern California and Arizona (Foster, 1980). Cultivated plantations are found in Arizona, California, and Texas. Since the shrub is very frost sensitive, the potential cultivation sites are limited to the extreme southwestern United States.

9.13 Breeding Potential

One of the biggest problems facing the commercialization of jojoba is the unavailability of superior germ plasm. The potential for improving jojoba by selective breeding is very good; however, it will be time consuming. A large genetic variability has been reported by many, and Yermanos

(1974, 1979, 1980) has found and is planning to develop the following aberrant plants, which may be economically useful in the future:

1) a monoecious plant; this strain produces male and female flowers on the same shrub.

2) plants that produce multiple fruits at a node; most jojoba plants produce only one fruit at a node;

3) plants that produce fruit at every node; fruit is usually produced at alternate nodes.

These characteristics must be examined carefully. Gentry (1958) reports that clustered fruits are more frequently damaged by sunburn, have smaller seeds, and are more susceptible to inadequate moisture than are plants with one fruit at alternate nodes. It is likely that cultivars developed with clusters of fruit at each node will have higher water requirements than those with one fruit per node.

Other traits that can be genetically selected for in jojoba include

1) one seed rather than three seeds produced per fruit; one large seed has been found to contain more oil than three small seeds.

2) high oil content per seed

3) early seed production beginning before the fifth year

4) early flowering to reduce frost damage

5) consistently high production from year to year

6) upright growth habit

7) seeds that mature at the same time (Fisher, 1980)

8) plants having the same manner of dropping their seeds (Fisher, 1980) and plants that drop all seeds simultaneously

9) pollen that is released at the same time that female flowers are ready to accept it.

Some of these desirable characteristics probably can be incorporated into a cultivar in a relatively short time; however, the breeding of a superior variety containing many of these characteristics will require years of research (Yermanos, 1979).

Jojoba has 52 chromosomes and is probably already a polyploid (Hogan, 1979; Yermanos, 1980). Its long life cycle (2-5 years to produce seed) makes breeding a long process. Tissue culture techniques may speed up the breeding process.

9.14 Environmental Impact

The planting and harvesting of jojoba appears to have no environmental impacts other than those usually associated with farming.

9.15 Economic Analysis

The bulk of the current supply of jojoba oil is used by the cosmetics and pharmaceutical industries. These markets are able to pay a high price for the oil, which is a superior skin penetrating and absorbing medium.

Jojoba oil is also a superior industrial lubricant. Synthetic oils can match its metallic wetting properties, however, their lifetimes are less than half as long (Miwa, personal communication). This advantage results from a slight but significant chemical difference: Jojoba oil is an ester and synthetics are diesters. Jojoba can also be cracked and used as fuel, but given its value as a lubricant, it is unlikely that jojoba oil will be used as a fuel or chemical feedstock.

Jojoba is currently enjoying a boom, such that jojoba development is proceeding rapidly under impetus from the private sector. It is attracting considerable investment from the devotees of hard money and those seeking tax shelters (Lowenstein, 1981). Over 8,000 acres were predicted to be planted in Arizona by late 1980 (Fisher, 1979). Additional plantings in California undoubtedly will raise the total over 10,000 acres. This represents an investment of over $40 million, and more capital is being raised (Lowenstein, 1981).

An important factor in this interest is the high price of jojoba oil, currently about $9.00 per pound (Lowenstein, 1981), which is almost 100 times the price of petroleum. The market size for lubricants and energy at this price is severely limited. There have been some studies of the price/demand ratio. The largest demand in any of these studies, 121,500 tons per year (Foster et al., 1979), assumes a price of $0.55 per pound (or $165 per barrel). This demand is equivalent to 2,200 barrels of jojoba oil per day.

What is the likelihood that the price of jojoba oil will fall this low? The most optimistic of the economic studies is Foster and Wright's (1979) study. This report considered three levels of output per mature bush: 3, 6, and 10 lbs (bushes 12 years of age and over). The last figure is the highest reported yield for a bush in the wild. It is doubtful, therefore, that this yield could be attained on cultivated land from presently available plants. The study also considers two levels of plantings -- 575 and 750 yielding bushes per acre -- and three sizes of plantations -- 40, 200, and 500 acres. It assumed that economies of scale reduce costs with increasing plantation size.

Table 9-2 shows estimated break-even oil prices per pound of seed for years 4 through 20 for the most optimistic case: 10 lbs per bush, 750 bushes per acre, and a 500 acre plantation. The percent liquid oil in seeds ranges from 42 to 53% (Stubblefield and Wright, 1977). We assumed a net 50% oil yield, which requires attaining both high seed oil content and very efficient extractions. We estimate that extraction costs for a large scale plant are 2 cents per pound (Foster and Wright, 1979), and the pound of meal remaining

Table 9-2. Estimated Cost of Jojoba Seed

Adapted from Foster and Wright (1979). Adjusted from 1978 to 1980 by using the implicit price deflator of GNP, which is 18%. Estimated cost per pound of seeds on a 500-acre Jojoba plantation established on idle agricultural lands with 750-producing plants per acre yielding 10 pounds of seed each (in 1980 dollars).

Year	Costs per Pound of Seed (Bushes Grown from Seed)
1	-
2	-
3	-
4	4.08
5	2.01
6	1.31
7	0.97
8	0.77
9	0.64
10	0.54
11	0.34
12	0.32
13	0.29
14	0.27
15	0.21
16	0.24
17	0.22
18	0.21
19	0.20
20	0.20

after extraction is 6 to 10 cents per pound (Stubblefield and Wright, 1977). Thus, the price of oil under the most optimistic scenario would equal twice the price in table 9-2 (2 pounds of seed equals 1 pound of oil), less 8 cents (10 cents meal value - 2 cents extraction cost). There is no yield in years 1, 2, and 3, and therefore, no break-even price per pound. The break-even prices shown assume a seven-year amortization of establishment costs incurred in years 1, 2, and 3.

After 20 years, the price of seed is down to 20 cents per pound. This is equivalent to 32 cents per pound for oil, given the assumed value of meal, or $96 per barrel. Jojoba oil will probably be economical for lubricants by year 2000 at this price given future oil price estimates of $60 and $80 dollars per barrel, and by 2020, it may be economical for fuel. However, this assumes that prices were high enough in initial years to break even. While such circumstances are possible at present, once jojoba is established it is the steady state price that will be important: That is, the price in constant dollars that is required to break even over the investment period.

We calculated break-even prices of oil for constant 1980 dollars by using the data in the Foster and Wright (1979) study for yields of 6 and 10 pounds per bush. These prices are shown in table 9-3. They were calculated by equating net present value to zero for real discount rates of 6 and 10%. The 10% rate is the rate recommended by the Office of Management and Budget, while 6% is the average return for riskless projects from two recent studies of this topic (Ibbotsen and Sinquefield, 1976; and Townsend, 1979). This analysis only considers "real" costs, that is, interest on investment is eliminated because of the discounting, and equipment depreciation is used to reflect physical costs.* It also includes the optimistic assumptions of 50% net oil yield and 8 cents net credit from sale of byproducts. The analysis was performed for a thirty-year economic lifetime.

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*A piece of equipment maintains a resale value. Thus, if $100 is spent in year 1, and at year end $90 could be obtained by sale, the real cost of use is the $10 difference.

Table 9-3. Estimated Long Term Break-Even Price of Jojoba Oil

750 Yielding Bushes Per Acre on a 500 Acre Plantation		
Maximum Yield Per Acre	Break-Even Prices at Discount Rates of	
	6%	10%
4500 pounds	$0.72	$0.86
7500 pounds	$0.52	$0.68

Even the most optimistic scenario in table 9-3 implies that investors require a stable price for jojoba oil in excess of 50 cents per pound (or $150 per barrel) to make their investment worthwhile. This is clearly too high a price for jojoba oil to be attractive as a fuel in the forseeable future. Jojoba oil may be attractive at these prices as a lubricant or, more likely, as a lubricant additive.

There may be some interest in FEMA (Federal Emergency Management Agency) in declaring jojoba oil a strategic and critical resources because of its superior lubricating properties (Hines, personal communication). Castor oil, which is also used as a lubricant, is currently on FEMA's list of critical and strategic materials.

There are two obvious conclusions about jojoba:

1. It is being developed at a rapid rate by private investors.

2. It is extremely unlikely that the price will drop to levels that will make it attractive as a fuel in the next 40 years.

9.16 Energy Analysis

The high price of jojoba oil severely limits its capacity as an energy saver. Its most promising energy application at prospective prices would be as a transmission fluid additive. This would allow transmission fluid to last the life of an automobile (and for a much longer fraction of heavy truck and bus life) without replacement. However, even if it were used for all transmission fluid (assuming transmission fluid is replaced at suggested intervals), and no transmission fuel were recycled, gross U.S. energy savings would be under 2,500 barrels per day.

Estimating net energy impacts of jojoba is not yet possible because not enough is known about the energy requirements of both processing and irrigation. Whatever these requirements are, the net energy impact will be inherently low due to the low gross impact.

10.0 Meadow Foam: Limnanthes alba var. alba (Limnanthaceae)

Oregon State University and Bohemia Company are researching the possibility of replacing seed grass crops with Limnanthes alba var. alba. The range of this crop would probably be limited to the wet valleys of the pacific northwest.

10.1 Products

The seeds of Limnanthes alba are 25 to 33% oil (Miller et al., 1964). About 95% of the fatty acids are 20 to 22 carbon acids (Gentry and Miller, 1965).

The oil can also be hydrogenated; the resulting product is a solid wax that is very hard and has a high melting point (Gentry and Miller, 1965). The seed meal is 15 to 25% crude protein, which may be useful as a feed supplement (Gentry and Miller, 1965).

10.2 Life Cycle

Limnanthus alba var. alba is an herbaceous winter-spring annual (White, 1977; Cole, 1974) that grows to about 12 to 14 inches (4.7 to 5.5 cm) in height (Crane, personal communication).

10.3 Processing/Refining

The oil can be extracted either by screw pressing the seeds or by a solvent extraction system. Bohemia Company is investigating the processing of the seed. They are concentrating on the pressing method because of the high costs of hexane used in the solvent extraction system (there is always some loss of solvent in a commercial size extraction plant -- Motts, personal communication).

10.4 Quality Parameters

All four of the fatty acids found in Limnanthes oil have a higher molecular weight than common domestic vegetable oil (Gentry and Miller, 1965); however, Limnanthes oil is a triglyceride (Miwa, personal communication).

Ninety-five percent of the fatty acids are 20 to 22 carbon acids (Gentry and Miller, 1965). Unsaturation is primarily at the 5th carbon atom, and less frequently, at the 13th carbon atom (Gentry and Miller, 1965; Calhoun and Crane, 1978). According to Gentry and Miller (1965), Limnanthes oil can be converted to a product that is virtually identical to jojoba oil by using commercially available practices. However, Miwa (personal communications), does not agree. According to Miwa, Limnanthes oil is no more valuable as a lubricant than any other triglyceride oil, such as castor oil or soybean oil.

10.5 Yields

Limnanthes seeds are 25 to 33% oil (Miller et al. 1964). On initial test plots (20' by 7') Crane obtained yields of 1800 pounds of seed per acre. Under field conditions (5 acres or more) yields have been much lower -- 1000 pounds of seed per acre.

The biggest factor influencing yields is the number of seeds that do not develop. Each flower has the potential of producing 5 seeds. OSU yields have averaged 2 seeds per flower (Crane, personal communication). There is a slight size reduction in seeds when all five seeds mature, but the total seed weight per flower is greater than if only 2 mature (Crane, personal communication).

Oregon State University estimates that a potential of 4000 pounds of seed per acre is possible. This figure is based on the observed production of 8,400 flowers per yd^2 (10,000 flowers per m^2), with all 5 seeds maturing. If 4000 pounds of seed per acre is achieved, this represents approximately 3 to 3.5 bbl of oil per acre. Actual yields under field conditions have been less than 1 bbl of oil per acre.

10.6 Temperature

Given that this plant grows in a wide geographic area (Oregon, Maryland, Northern California, and Alaska; Higgins et al., 1971), it probably is tolerant to a wide range of temperatures.

10.7 Agronomy

Oregon State University plants 20 pounds of seed per acre (22 kg per hectare). Limnanthes alba var. alba fills in like alfalfa and produces about 10,000 flowers per square meter^2, or 8,400 flowers per yard^2 (Crane, personal communication). Compared with other varieties, the plant has superior seed retention (White, 1977), which is favorable for harvesting. However, seed retention requires improvement.

The seed of Limnanthes alba var. alba germinates best at 40° (83% germination) and germinates poorly at room temperature (at 70°F, germination was 11.3% -- Toy and Willingham, 1960). In fact, the optimum temperature for germination for all of the ten accessions (seven species) tested was between 40 to 60°F. Seed germination of all accessions at room temperature (72° to 78°F) was practically zero, and studies indicate that warm temperatures can induce secondary dormancy (Toy and Willingham, 1960 and 1967).

At 6 different treatments, consisting of 0 to 14 days at 80°F, germination decreased from 77 to 19% (Toy and Willingham, 1967). Even after seed was dried for 2.5 months, remoistened, and incubated at optimum temperatures, germination was 0%. In terms of commercially cultivating Limnanthes alba var. alba, this secondary dormancy induced by warm temperatures would be a distinct disadvantage (see Breeding Potential section).

The two cultivars (Foamore and 703A) developed and registered by Oregon State University have been selected to reduce secondary dormancy (Crane, personal communication).

10.8 Irrigation/Water Requirements

Limnanthes alba is endemic to Pacific coast states, where it grows along streams and ponds, and in meadows and moist depressions of grasslands (Gentry and Miller, 1965). Irrigation will not be necessary because the sites being considered for commercial production are poorly drained, wet soils in areas of high rainfall.

Meadow foam requires abundant moisture for germination and wet to moist soils for growth (Gentry and Miller, 1965; Calhoun and Crane, 1978).

10.9 Soil Requirements

Information on soil requirements is far from conclusive. The valleys where these plants will grow are not very fertile (Calhoun and Crane, 1978).

Determining the optimum nutrient and soil requirements may decrease the number of seeds that abort (Crane, personal communication). However, Oregon State University has observed a negative correlation between seed set and the addition of nitrogen fertilizers (Crane, personal communication; Crane, Calhoun, and Ayres, 1981). Based on a randomized complete block experimental design with four replications of five treatments (control, 50 kg/ha and 100 kg/ha of ammonium nitrate; 50 kg/ha and 100 kg/ha ammonium sulfate), the addition of nitrogen fertilizer decreased the seed oil content, and therefore, the yield of meadow-foam (Crane, Calhoun, and Ayres, 1981).

Limnanthes grows chiefly in acid soils with pH ranging from 5.5 to 6.7 (Gentry and Miller, 1965). It grows in wet soils and will tolerate standing water for several months as long as some leaves can grow above the water surface (Calhoun and Crane, 1978). Calhoun and Crane (1978) found that decreasing the water saturation of the soil in experimental plots did not increase seed production.

10.10 Diseases/Pests

To date, there have been no problems with diseases or pests (Crane, personal communication) but only small experimental and field plots have been planted. With larger plots, pests may be more of a problem.

White (1977) states that chemical weed control will be needed.

10.11 Breeding Potential

There are nine species and eleven varieties of *Limnanthes* (White, 1977). *Limnanthes alba* var. *alba* was chosen for development by Oregon State University (Crane, personal communication) because of its superior seed retention and upright growth. The other varieties and species are considered to be far inferior as potential crops; however, several have desirable traits that will be used in future genetic improvement work. For example, one of the problems with *L. alba* var. *alba* is that it has a low seed set. Low seed set may be due to inadequate pollination, since *L. alba* var. *alba* is not self-compatible (in other words, for fertilization to occur and a seed to be formed, the pollen must originate from a different plant than the plant bearing the flower). Oregon State University will attempt to breed self-compatibility into *L. alba* var. *alba* by cross fertilizing with *L. floccossa* var. *floccossa*, which will self pollinate (Crane, personal communication).

Oregon Agricultural Experimental Station has registered the cultivar "Foamore" (White, 1977). This plant was developed by Oregon State University. Two of its main advantages are its upright growth and seed retention (Princen, 1977).

OSU has also developed and registered another variety, which to date is not named (registered as 703A). This plant has fewer problems with secondary dormancy of seeds (see Agronomy section) than Foamore (Crane, personal communication). The breeding of this plant to reduce secondary dormancy was done totally by selection with *L. alba* var. *alba*. If secondary dormancy remains a problem with this cultivar, there are two species of *Limnanthes* that could be used for breeding: *L. alba* var. *versicolor* and *L. striata*. Both of these species have little or no secondary dormancy in seed (Toy and Willingham, 1967).

10.12 Breeding Goals

Breeding goals will vary and will depend upon where the cultivar is to be planted. Oregon, Maryland, Northern California, and Alaska appear to be possibilities. For example, early flowering may be selected for in cultivars grown in California in order to avoid the hot, dry summer (Higgins et al., 1971).

Other breeding goals for this plant may include the following:

1) Increase seed retention

2) Increase seed set

3) Increase seed yield

4) Select for upright growth

5) Break secondary seed dormancy

Other genetic characteristics may be required, however, very little research has been done to date.

10.13 Environmental Impacts

This crop is being investigated as a replacement for seed grass crops in the wet valleys of the Pacific Northwest. The Oregon Department of Environmental Quality is interested in replacing seed grasses because once the seed is harvested, the straw must be burned. This has exacerbated air pollution problems (Crane, personal communication).

Therefore, the environmental impacts known to date are largely positive.

11.0 Other Hydrocarbon Producing Plants

Numerous other plants have been suggested as sources of hydrocarbon. For example, Buchanan and coworkers have written several papers on hundreds of species that they have analyzed for hydrocarbon content. Unfortunately, there is not enough information on most of these plants in the literature to do a detailed analysis of their technical and economic feasibility. Further, these researchers analyzed from one to six plants for each species, and most values for hydrocarbon content were based on samples from two to three plants. Since hydrocarbon contents can vary tremendously in wild plants (rubber content of guayule in native stands is 5 to 20 percent of the plant weight), it would be difficult to make even a preliminary selection of promising plants from this data.

Rodriguez (personal and written communications) has investigated the potential of various plants from Baja, California and from the Chihuahuan desert. We did not assess this research because most of these plants have a limited range in the United States.

A detailed study on Russian dandelion (kok-saghzy) was reported by Whaley and Bowen (1947). This study indicated some potential in the commercial cultivation of this plant for rubber. However, we did not assess this plant because Whaley and Bowen's work indicated that kok-saghz requires fertile, highly organic soil, and an abundance of moisture during its growing season.

Part B

INSTITUTIONAL BARRIERS

It has been proposed in the literature (Johnson and Hinman, 1980) that 8 to 12 million hectares (20 to 30 million acres) of semi-arid or arid land, most of which has never been cultivated, is suitable for growing energy crops. Therefore, we have examined some of the major institutional barriers that may be encountered by developers of presently uncultivated land in the southwest.

From our assessment of available data of hydrocarbon and rubber producing plants (Part A), we are not convinced that the cultivation of any of these energy crops on arid lands will be possible without irrigation. In addition, it is our opinion that the problems arising from the lack of water and the rights to water supplies in the southwest will prevent any large-scale development of presently uncultivated lands.

The following sections discuss the availability of water and land in the southwest, as well as the implications of the Endangered Species Act of 1973 and state noxious weed laws on the development of hydrocarbon and rubber producing plants.

1.0 Recommendations

Our analysis of the water situation in the southwestern United States (which included consideration of three recent reports:[1] Arizona Water Commission, 1977;[2] U.S. Water Resources Council, 1978;[3] Congressional Research Service, 1980) indicates that the cultivation of large amounts of unfarmed arid land in the southwest would be unlikely. This conclusion is based on the following facts:

- All of the desert and semi-arid plants examined to date require some irrigation for large-scale cultivation, especially when initially establishing the plant (Part A).
- Dryland farming of these plants in the southwest is unproven; in any case, it is clear that yields from unirrigated crops in arid lands would be greatly reduced.
- Most hydrocarbon or rubber producing plants require 15 to 24 inches of rainfall per year; therefore, some irrigation will be necessary to grow them in the southwest.
- Water supplies are extremely limited in the southwest. For example, in Arizona, groundwater provides most of the water for irrigation, and these supplies are being depleted at the rate of 2.2 million acre-feet (maf) per year.
- As a result of scarce supplies, water use is highly restricted in the southwest (see appendix A at the end of Part B).

---

[1] abbreviated AWC in remainder of discussion
[2] abbreviated WRC in remainder of discussion
[3] abbreviated CRS in remainder of discussion

Therefore, given that the gross annual water requirements of native desert plants are lower than those of traditional crop plants*, and that water resources are extremely limited in the southwestern United States (see section 2.0, Part B), we conclude that arid-land crops will be grown primarily as replacement crops. That is, they will be grown on lands that otherwise would have gone out of production because they were no longer economic for traditional crops. There may be one exception to this conclusion. Some arid-land crops may be more tolerant of saline irrigation water and salinized soils than traditional crops, and therefore, grown on marginal lands with lower quality irrigation water.

Hydrocarbon and rubber are not the only products that can be derived from desert plants. For example, Karpiscak et al. (1980) have suggested that Salsola kali L. (Russian thistle or tumbleweed) be developed for arid lands as a source of burnable biomass. Other desert plants that have been investigated for their value as forage plants, such as Artemisia, Atriplex, Ceanothus, Ceratonia, Dalbergia, Eurotia, Lucaena, Lupinus, Morginga, Prosopis, Pureria, Quercus, Salix, Sesbania, Sutherlandia, and Opuntia (Goodin and McKell, 1971), may have some yet undiscovered value as an energy crop for either burnable biomass or bioconversion to alcohol.

In order to compare hydrocarbon producing plants with other plant sources of energy, we recommend that a net energy to water efficiency -- that is, the ratio of net Btu's produced to the amount of water consumed -- be experimentally determined for each potential arid crop species. This efficiency, together with the economic value of the energy product, would greatly aid in assessing the potential of all kinds of energy crops for arid lands. In some cases, the economic value of the product may be weighted more heavily than the net energy to water efficiency. For example, rubber is a strategic and critical resource and it has a premium economic value. Therefore, rubber-producing plants might be grown instead of plants that have a higher net energy to water efficiency, but produce less valuable products.

---

*In Pinal County, Arizona, cotton consumes 40 inches of water year and alfalfa, 70 inches (AWC, 1977).

2.0 Overall Water/Land Availability in the Southwest

The water supply situation in the southwest is questionable. Figure 2-1 and 2-2 show the critical groundwater and surface waters in the United States, as defined by the U.S. Water Resources Council (1980). As shown, critical supply problems exist with both of these sources of water in the southwest. Groundwater overdraft* in the Texas-Oklahoma High Plains area is 14 million acre-feet or more than 12,500 mgd (million gallons per day), which is an amount equal to the natural flow of the Colorado River (WRC, 1980). The overdraft in this area is the most severe in the country. In some areas, groundwater levels are declining from 7 to 10 feet per year (WRC, 1980). Table 2-1 indicates the groundwater situation in the southwest (refer to figure 2-3).

Table 2-1. Groundwater Overdraft in the Southwest

	Total Withdrawal (MGD)	Overdraft		Overdraft Range (%) Within Region
		Total	Percent	
Texas-Gulf	7,222	5,578	77.2	24 to 95
Rio Grande	2,335	657	28.1	22 to 43
Lower Colorado	5,008	2,415	48.2	7 to 53
California	19,160	2,197	11.5	7 to 31

(from WRC, 1980)

Percent overdraft for the conterminous United States is 25.4 percent. Irrigation accounted for 40 percent of the water withdrawn, and 83 percent of the water consumed. As discussed in the following sections, irrigation is a very large factor in the consumption of water and in the overdraft of groundwater.

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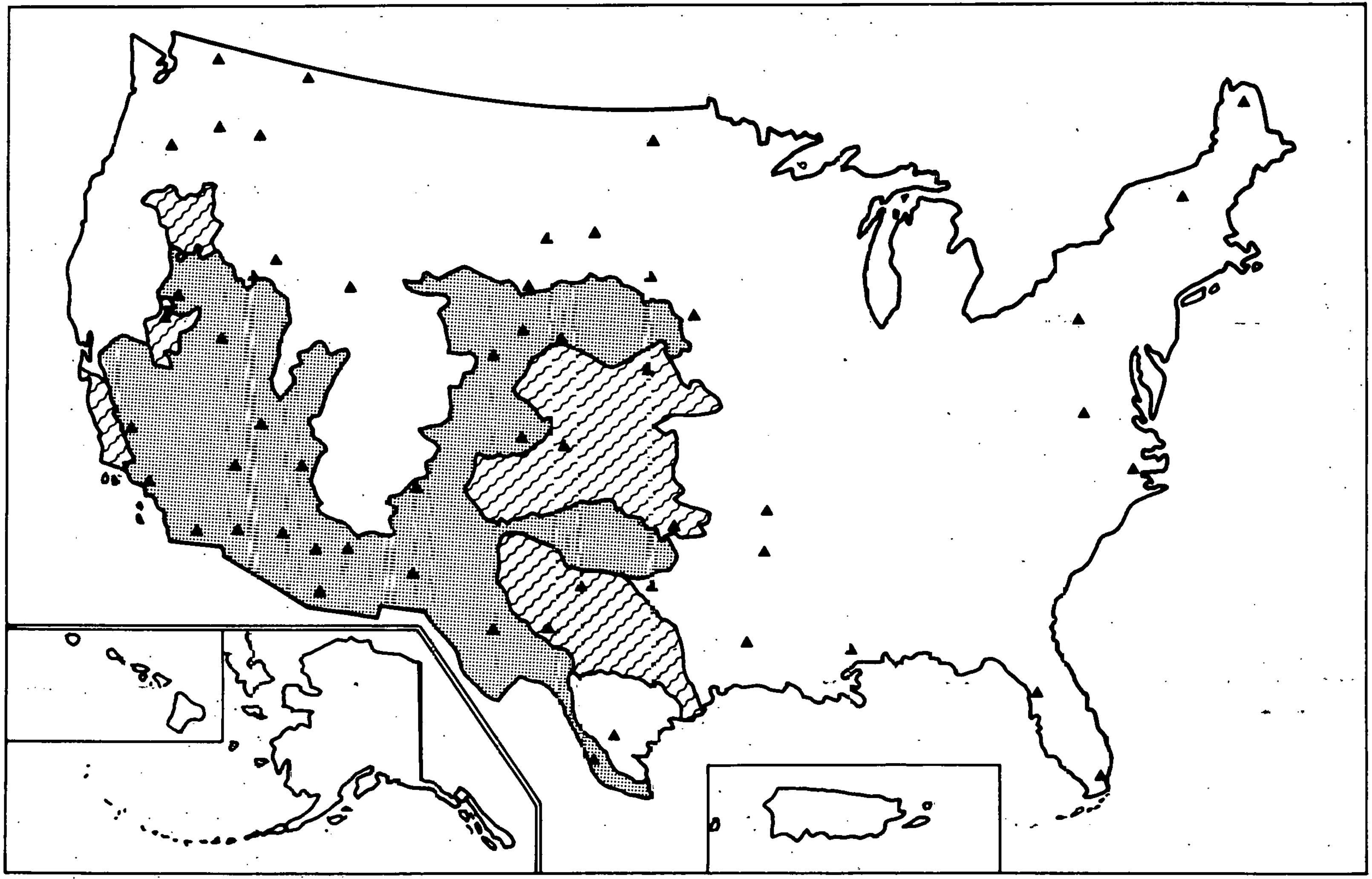
*An aquifer is said to be overdrawn when water is withdrawn from it at a rate greater than the long-term rate of recharge.



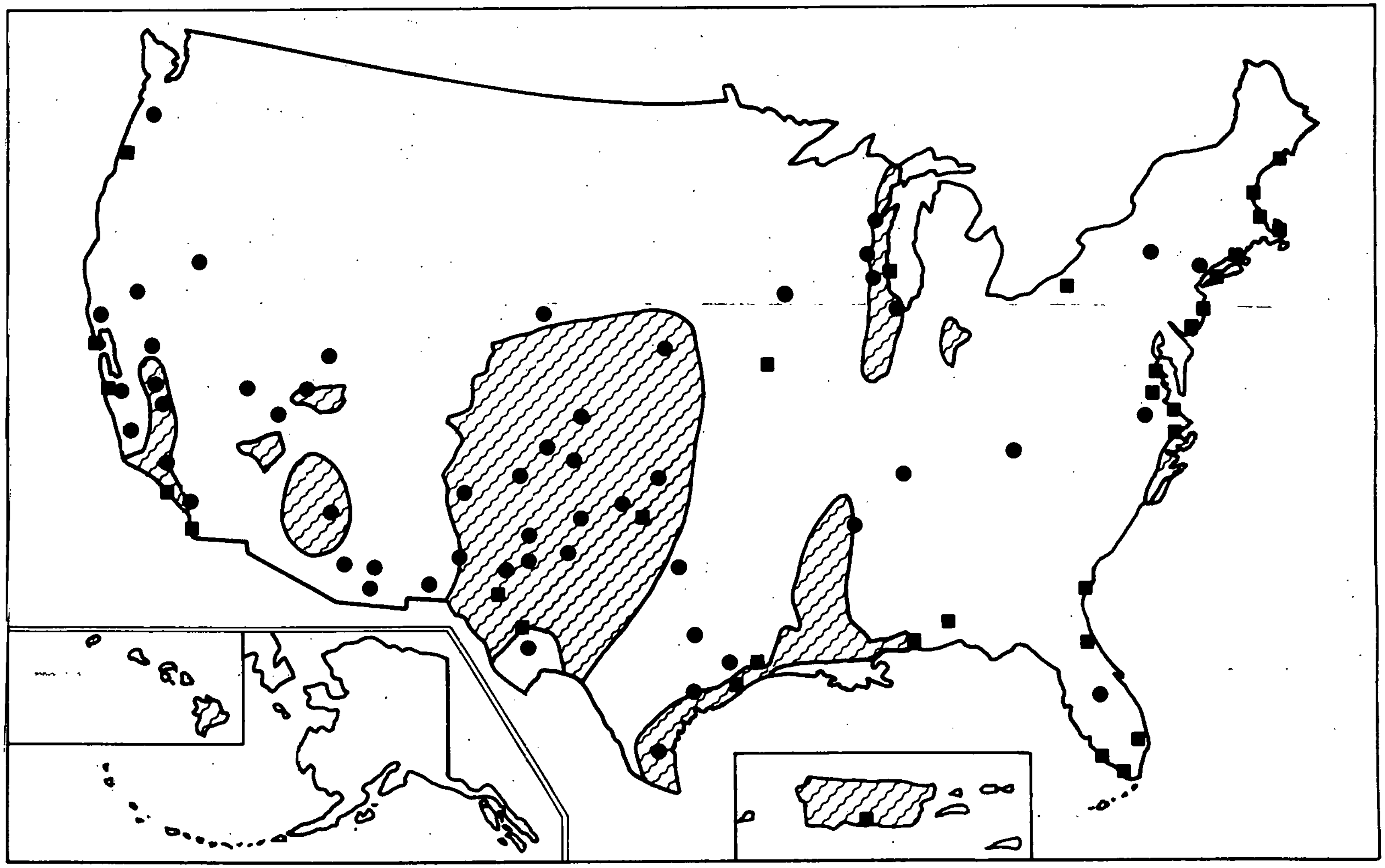
(from WRC, 1978)

Explanation

Subregion with inadequate streamflow ("1975"-2000)

- ▩ 70 percent depleted in average year
- ▨ 70 percent depleted in dry year
- ☐ Less than 70 percent depleted
- ▲ Crop irrigation

Figure 2-1. Inadequate Surface Water Supply and Related Problems



Explanation

(from WRC, 1978)

Area problem

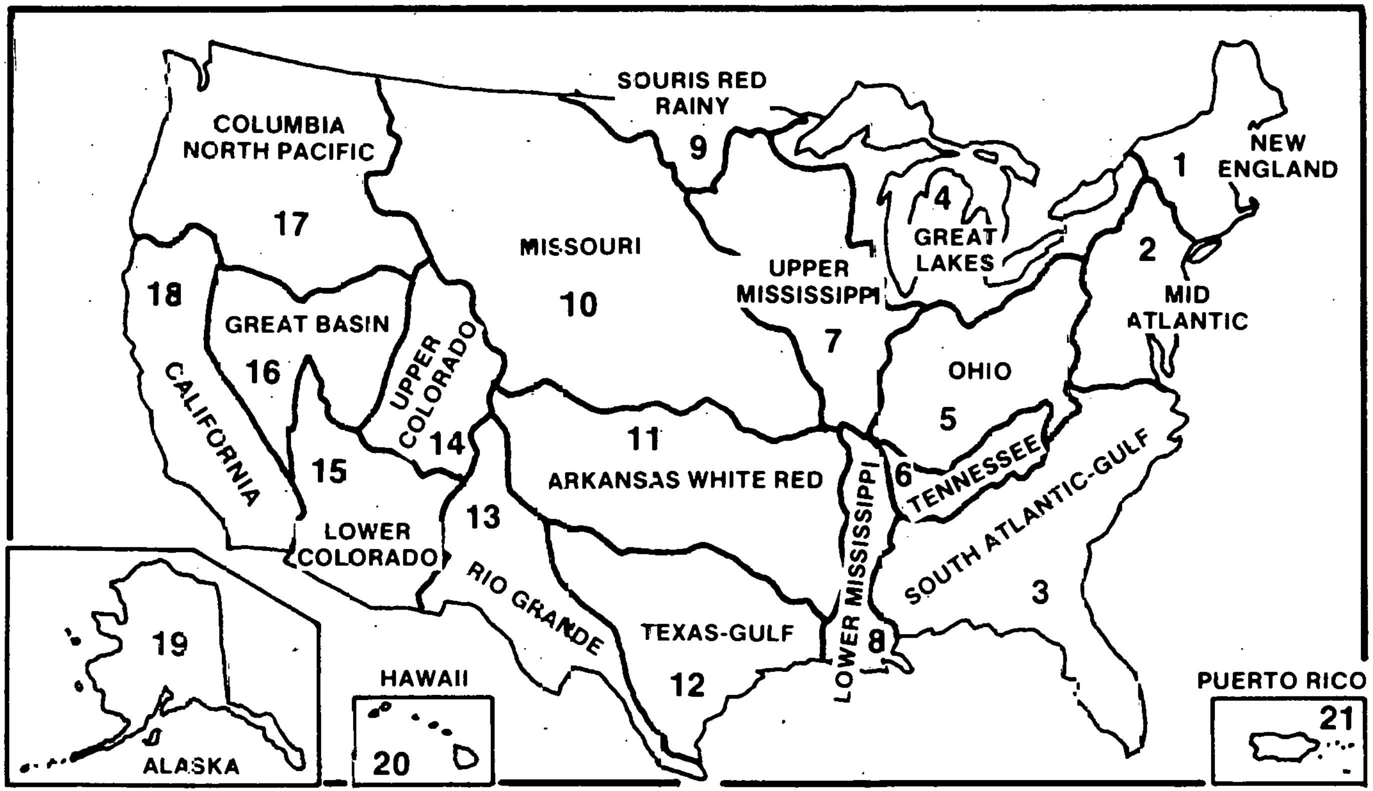
▨ Area in which significant ground-water overdraft is occurring

☐ Unshaded area may not be problem-free, but the problem was not considered major

● Declining ground-water levels

■ Saline-water intrusion into fresh-water aquifers

Figure 2-2. Groundwater Overdraft and Related Problems



(from WRC, 1978)

Figure 2-3. Water Resources Regions

2.1 Arizona

The Arizona Water Commission (1977) should be referred to for a more detailed review of the water situation in Arizona. According to this report, over 33 million acres of land in Arizona are suitable for crop production in Arizona, but crop land in 1970 accounted for only 1.2 million acres. The Commission cites the lack of a dependable and affordable supply of water as the most significant reason for the fact that this arable land is not farmed.

In addition to the scarcity of supply and to the expense of pumping water for irrigation, there are also legal barriers (see appendix A). Under the critical groundwater area law (Ariz. Rev. Stat. 27-667 et seq) the Arizona Water Commission, which has control and supervision of state waters, is prohibited from issuing permits for the development of new wells to bring new lands under irrigation in areas declared critical. Critical areas are defined as basins that do not have sufficient groundwater to provide a reasonably safe supply for irrigation of cultivated lands at the current rate of withdrawal (Ariz. Rev. Stat. 45-301). These areas include Pinal County, the Prescott region, the Tucson region, and the Phoenix region (figure 2-4). Further, when there are conflicting uses of a water supply, domestic and municipal uses have precedence over irrigation needs (Ariz. Rev. Stat. 45-147).

Figure 2-1 shows areas designated by the U.S. Water Resources Council to have significant groundwater overdraft problems. This area is much larger than the area identified by the Arizona Water Commission as being critical groundwater areas. Therefore, the former may provide an indication of areas in which the Commission will restrict the drilling of agricultural wells in the future.

Irrigation accounts for 89 percent of all the water consumed in the state of Arizona (AWC, 1977). Sixty percent of Arizona's annual withdrawals of water are from groundwater supplies (CRS, 1980). Since groundwater supplies are replenished by natural precipitation, which is less than 5 inches per year in the southwestern part of the state (figure 2-5), extensive use

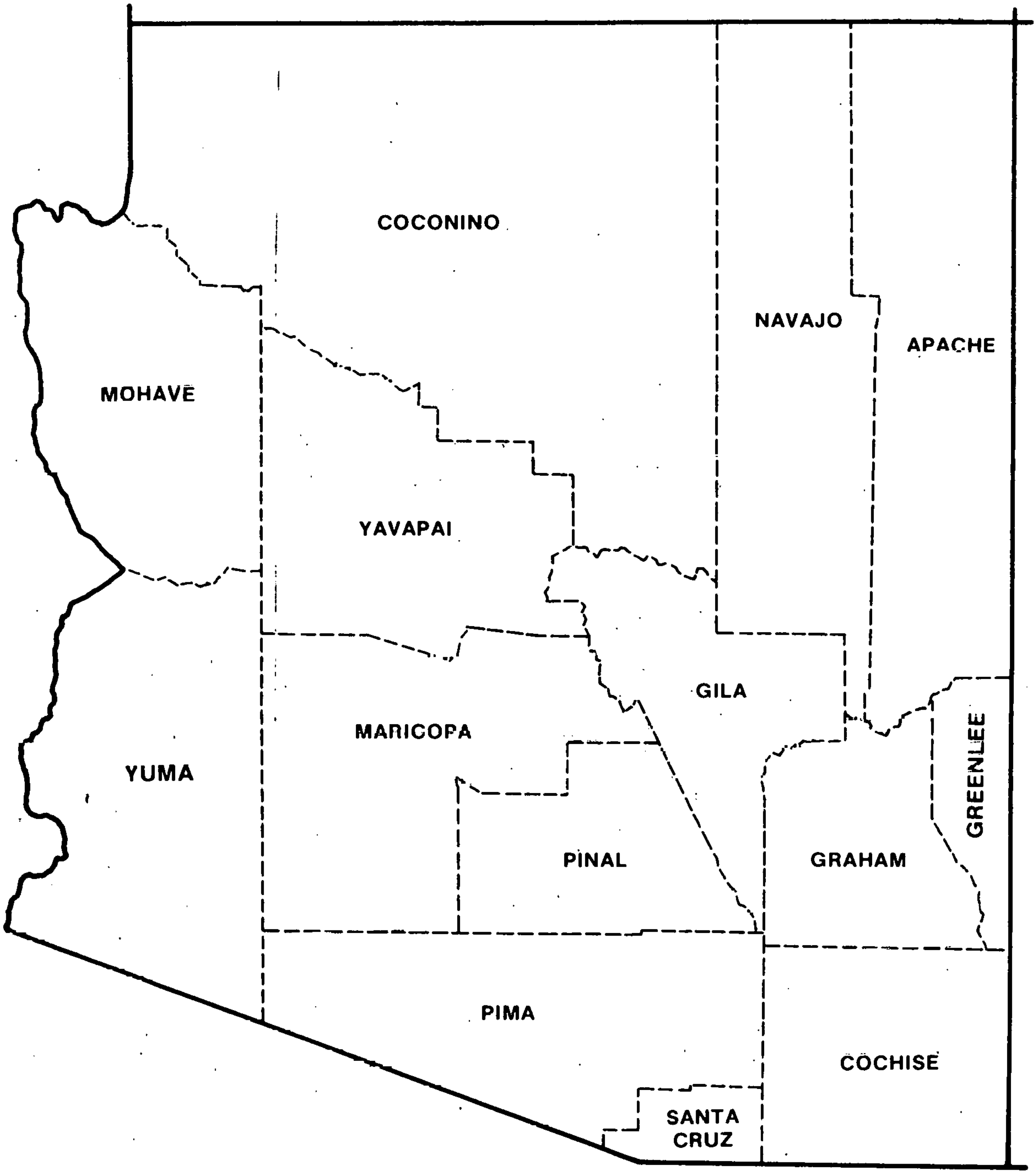
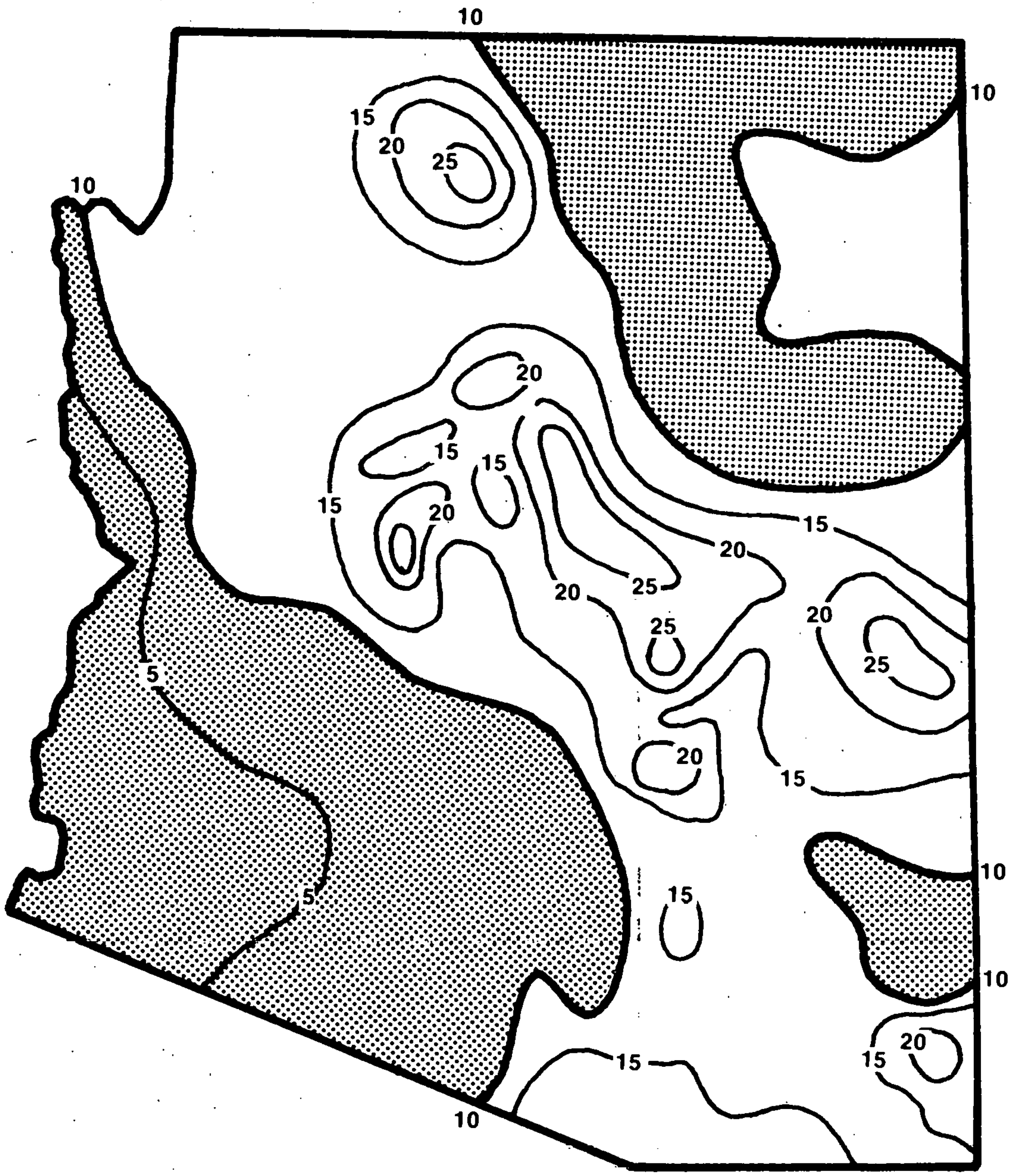


Figure 2-4. Counties of Arizona



Average annual precipitation shown in inchs per year.
Shaded area - less then 10 inches annually

Figure 2-5. Average Annual Precipitation of the groundwater in this region may cause overdrafting. The areas that are currently identified as critical groundwater regions receive about 15 inches of rainfall per year. Given the low precipitation, high evaporation rate, and high rate of withdrawals, it is not surprising that groundwaters in Arizona are being depleted at the rate of 2.2 maf per year (AWC, 1977).

2.2 California

A Congressional Research Service (1980) report concludes that the supply of water in California is favorable, but increases in irrigation could alter this conclusion. The base year used for the study was 1975. In that year, 91 percent of the water consumed in California was used for irrigation.

The most significant problems with water supply identified in this report were an inadequate supply of surface water and overdrafting of groundwater supplies. Of the 7.6 million acre feet (maf) of water removed annually in California, 2.2 maf were in overdraft. Two water projects (State Water Project and Central Valley Project) are expected to increase the water supply by 1990, but California's supply from the Colorado River will be cut by 750,000 maf because of a Supreme Court decision.

California's annual precipitation varies from 4 to 80 inches (see figure 2-6), however, most of the areas with rainfall greater than 30 inches per year are in the mountains. Most of the southern half of the state (the region usually suggested for growing hydrocarbon and rubber producing plants such as guayule) receives 4 to 16 inches per year, with mountainous regions receiving up to 40 inches. Most of the land in southern California that is not currently being farmed (figure 2-7) and is not in the mountains (see section 3.0, figure 3-2) is in areas, such as the southeastern part of the state, that receive 4 to 8 inches of rain. Therefore, it is extremely unlikely that hydrocarbon or rubber producing crops could be grown commercially without irrigation in this region. Further, land costs in most of California are extremely high.

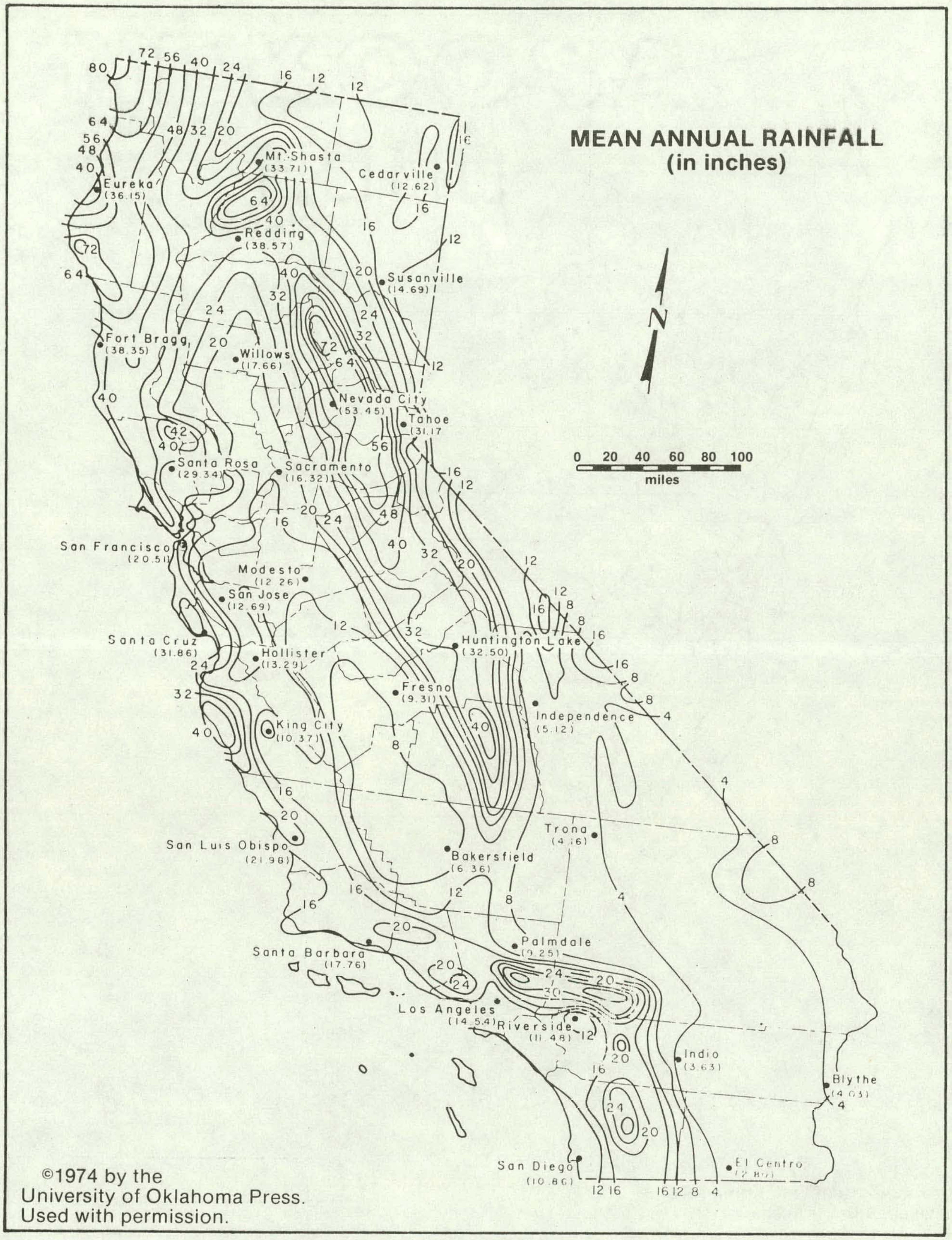


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Figure 2-6. California Rainfall

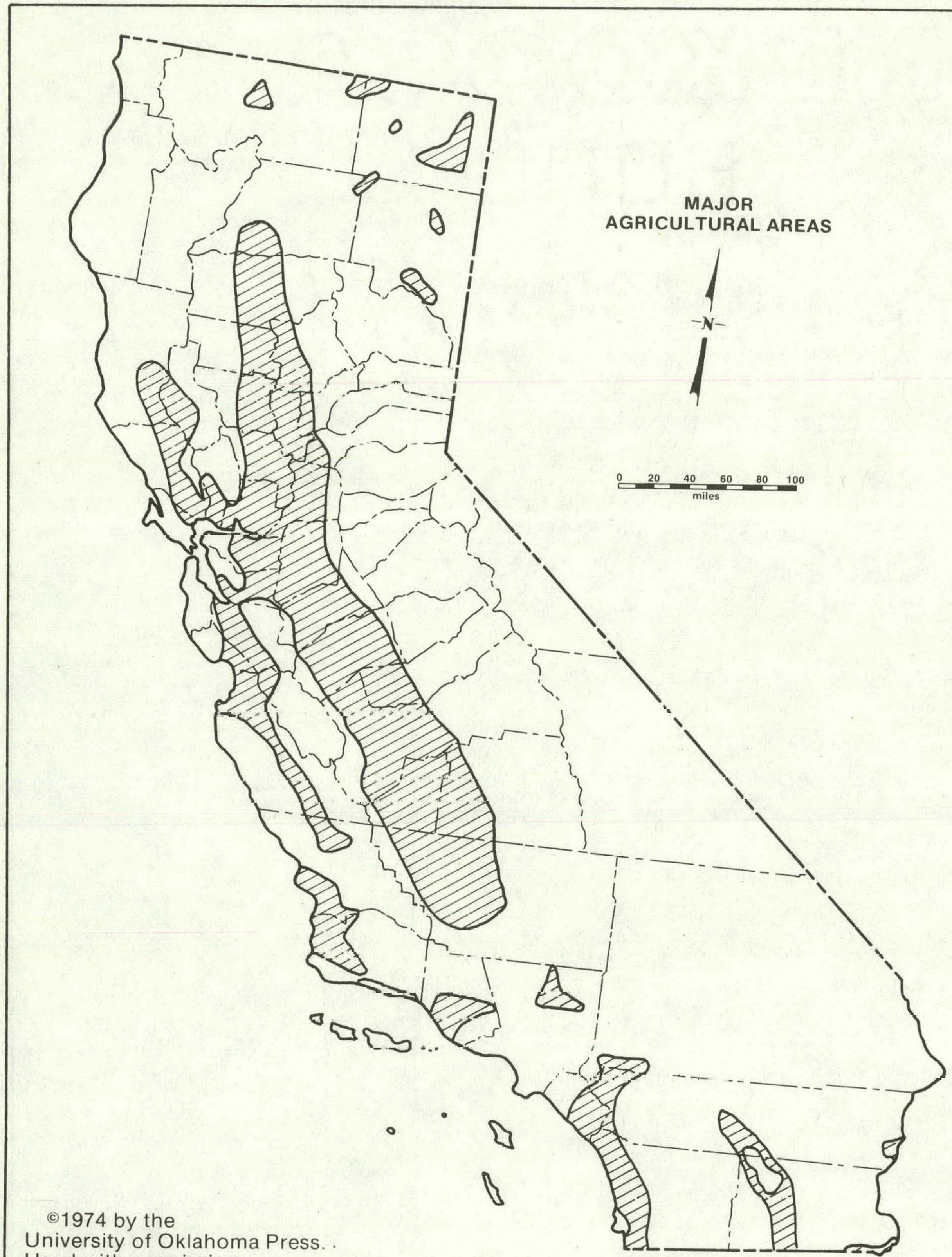

Figure 2-7. California Agricultural Areas

2.3 New Mexico

The Congressional Research Service report (1980) concludes that water supply is an overriding issue in New Mexico. The study states that even if conservative growth trends are realized, continued and increased overdrafting will occur by the year 2000.

Average precipitation in New Mexico is 15 inches per year. Precipitation ranges from 8 to 40 inches per year (see figure 2-8), but most of the areas that receive over 20 inches per year are located in the mountainous regions. During average years, there is an inadequate surface water supply -- depletions levels are in excess of 70 percent over most of the state. Groundwater overdraft is also extensive (CRS, 1980).

Areas currently being cultivated are shown in figure 2-9. Irrigation constituted 91 percent of the water withdrawn in 1975, and approximately 50 percent of this was used consumptively (CRS, 1980).

2.4 Texas

The Congressional Research Service report (1980) states that Texas has an inadequate surface supply of water, and that there are serious overdrafting problems in Houston-Galveston, Fort Worth-Dallas, El Paso, Winter Garden (south Texas) and High Plains (west Texas) areas of the state. According to this analysis, the level of water withdrawals in the year 2000 will be impacted chiefly by irrigation and steam electric cooling, and they project that water withdrawn for irrigation will increase by 40 percent during this time period.

Irrigation accounted for 75 percent of all the water used, and for 85 percent of the groundwater used in 1975 (CRS, 1980). Of the total water used consumptively, irrigation accounted for approximately 92 percent. Rainfall increases from 8 inches per year in the western part of the state to 56 inches per year in the extreme eastern part of the state (figure 2-10).

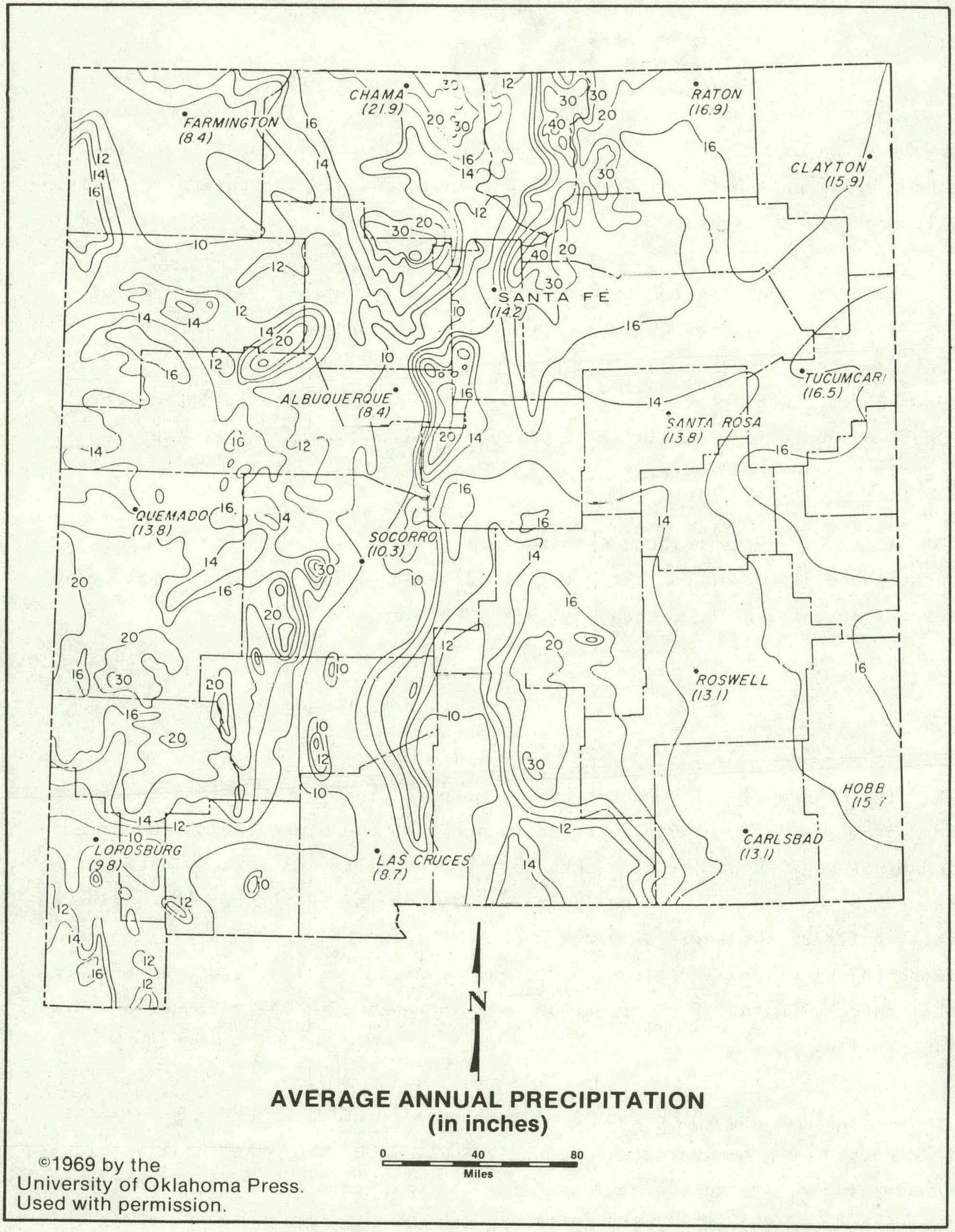

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Figure 2-8. New Mexico Rainfall

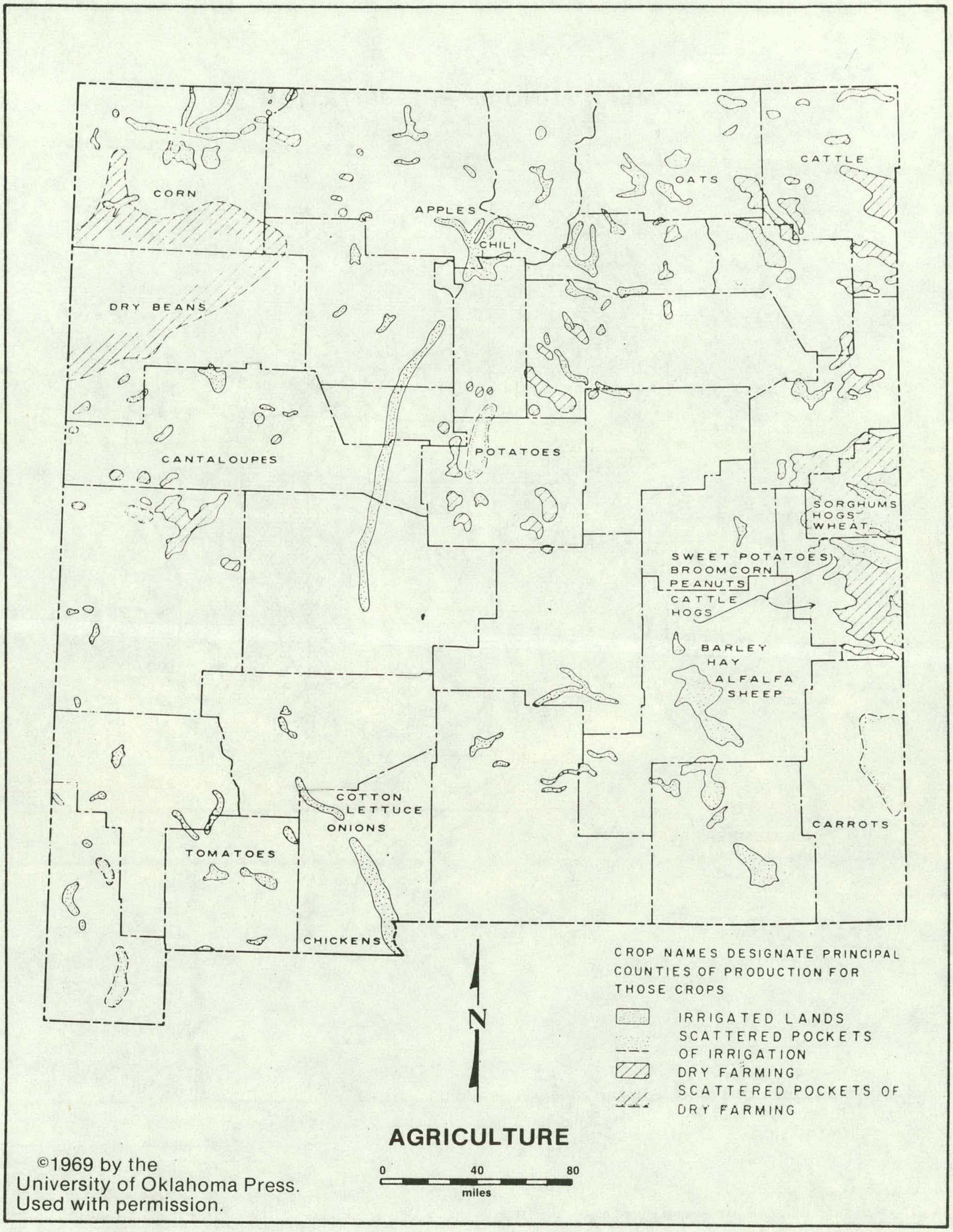

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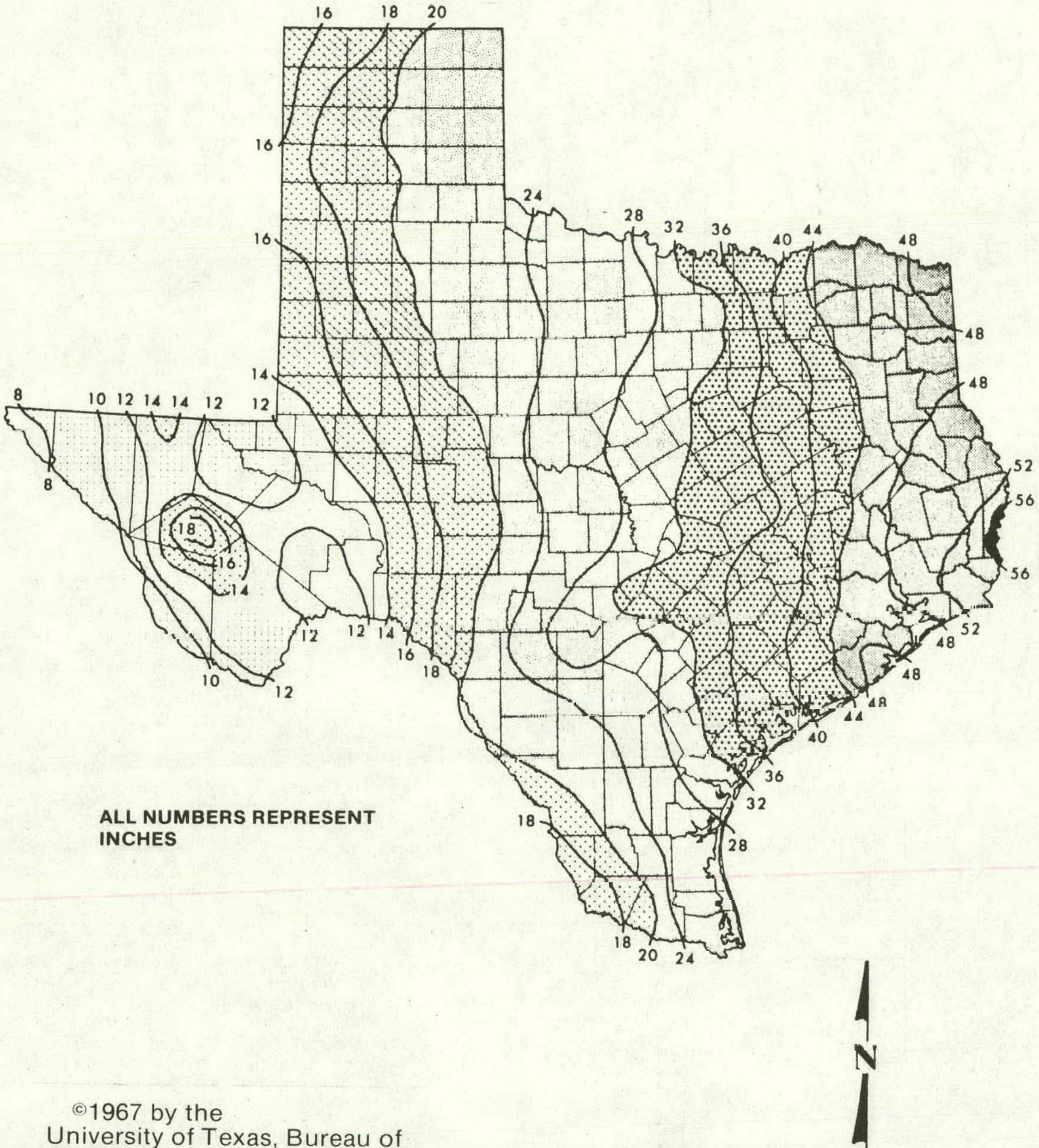
Figure 2-9. New Mexico Agricultural Areas

MEAN ANNUAL* PRECIPITATION



ALL NUMBERS REPRESENT INCHES

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*1931-1960

Source: Texas State Climatologist, U.S. Weather Bureau, Austin, Texas, 1966.

Figure 2-10. Texas Rainfall

Therefore, the severity of groundwater overdrafting will probably continue to be the greatest in the western half of the state.

Texas has approximately 8.6 million acres of land that are irrigated for agriculture and about 35 million acres that could be potentially irrigated and developed for cropland (CRS, 1980). The irrigated acreage in Texas is expected to decrease in the future, unless new sources of water are found (Texas Almanac, 1980/1981).

3.0 Land Availability in the Southwest

Much of the land in Arizona, California, New Mexico, and Texas is mountainous and could not be cultivated on a large scale (figures 3-1 to 3-4). Further, much of the remaining land is unavailable because of various institutional reasons. The following is a brief discussion of the availability of land in each of the four states.

3.1 Arizona

Only 1.96 percent of the land in Arizona is presently being cultivated (Walker and Bufkin, 1979). Much of the remainder of the state is unavailable for agricultural development by private concerns. For example, Indian reservations alone constitute 27 percent of the land in the state, and national forests, parks, and monuments constitute over 19 percent (also see table 3-1 and figure 3-5).

Table 3-1. Land Ownership in Arizona

Ownership or Jurisdiction	Percentage of Total Area of Arizona
Federal Lands	70.70
Indian reservations	27.00
U.S. forests	15.67
Bureau of Land Management (BLM)	17.54
National parks and monuments	3.42
Department of Defense	5.01
All other federal lands--misc, depts.	2.06
State Lands	13.26
Arizona Land Department	13.20
Arizona Fish and Game	0.03
Arizona state parks	0.03
Private Lands	16.04
Cropland (irrigated agriculture)	1.96
(from Walker and Bufkin, 1979)	

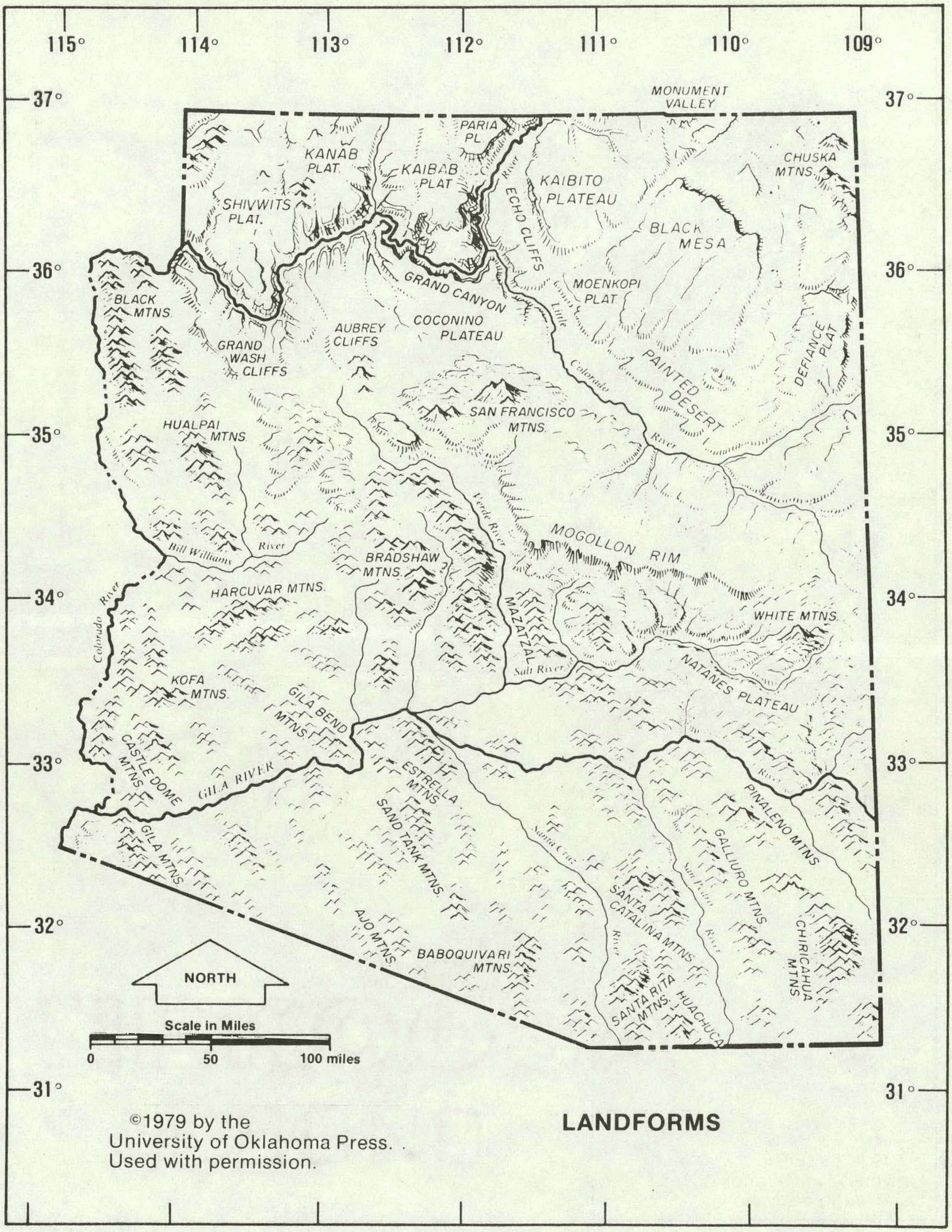

Figure 3-1. Arizona Landforms

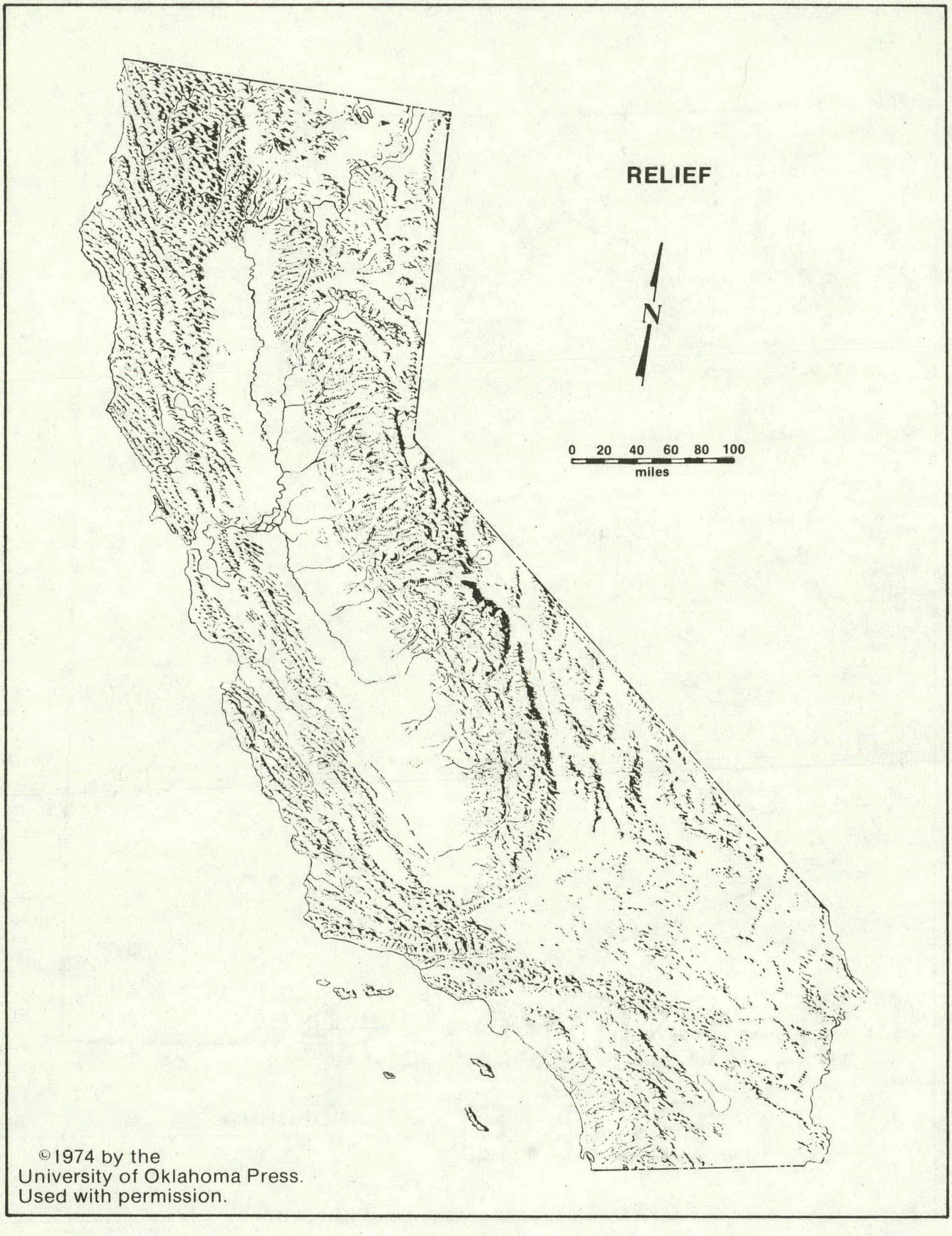

Figure 3-2. California Landforms

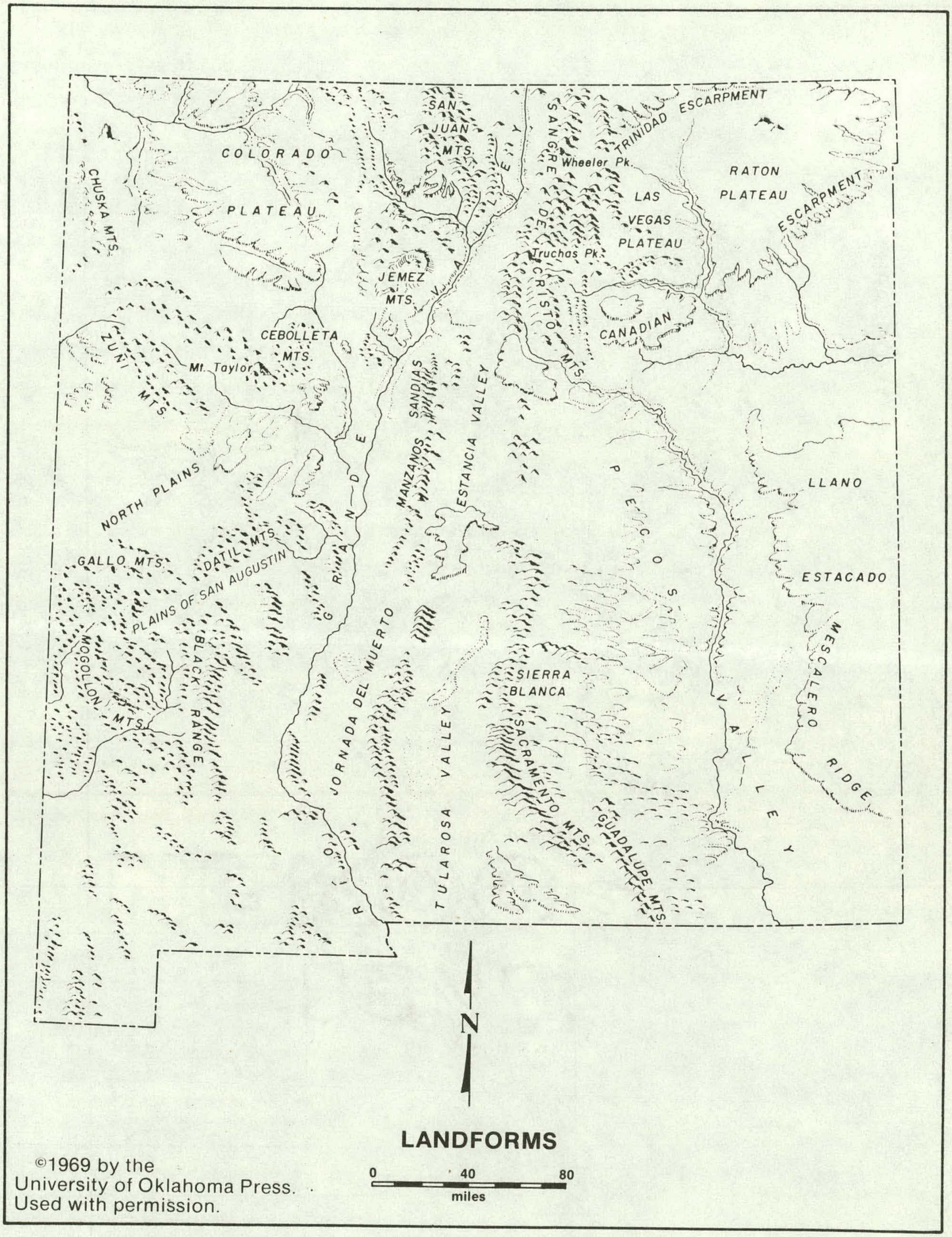

Figure 3-3. New Mexico Landforms

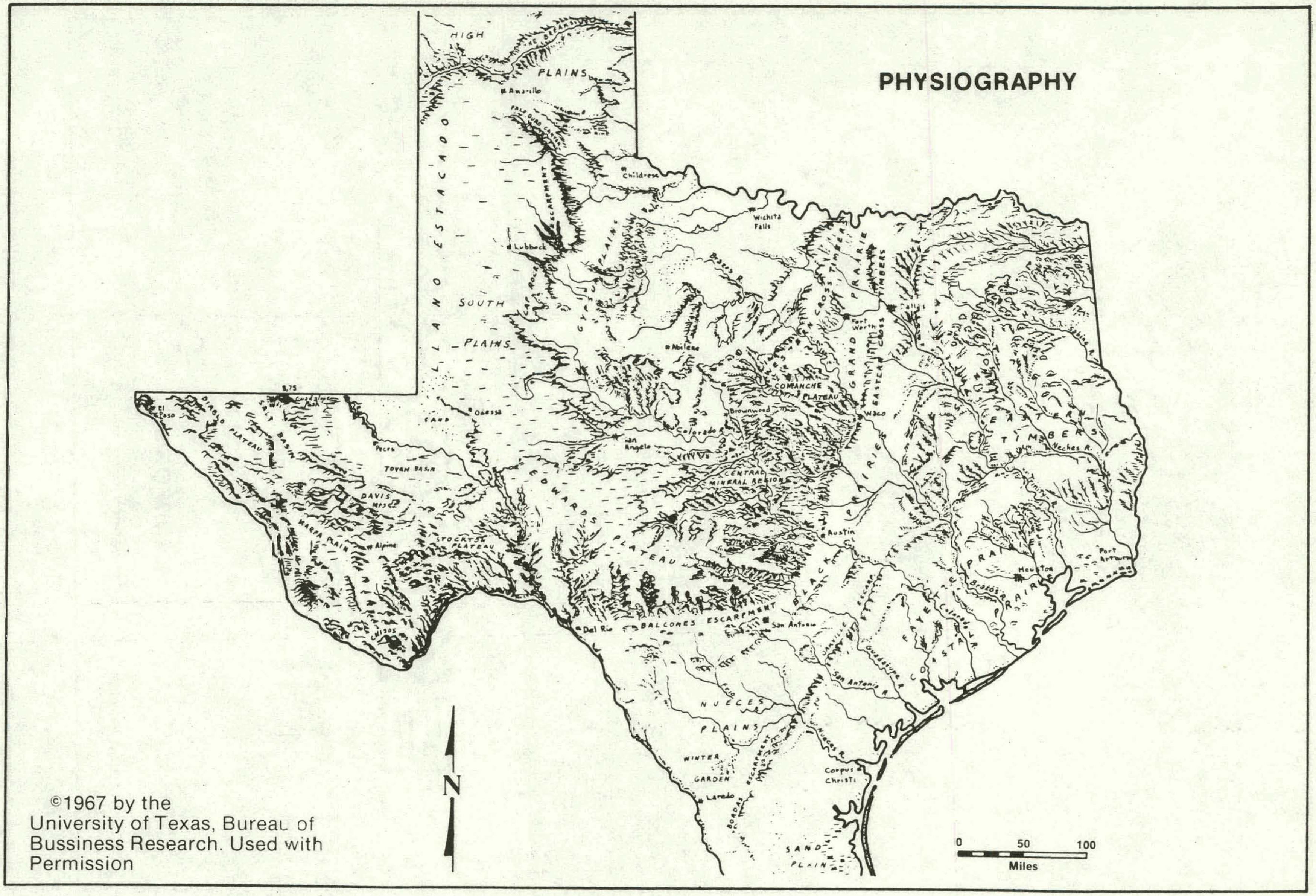
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Figure 3-4. Texas Landforms

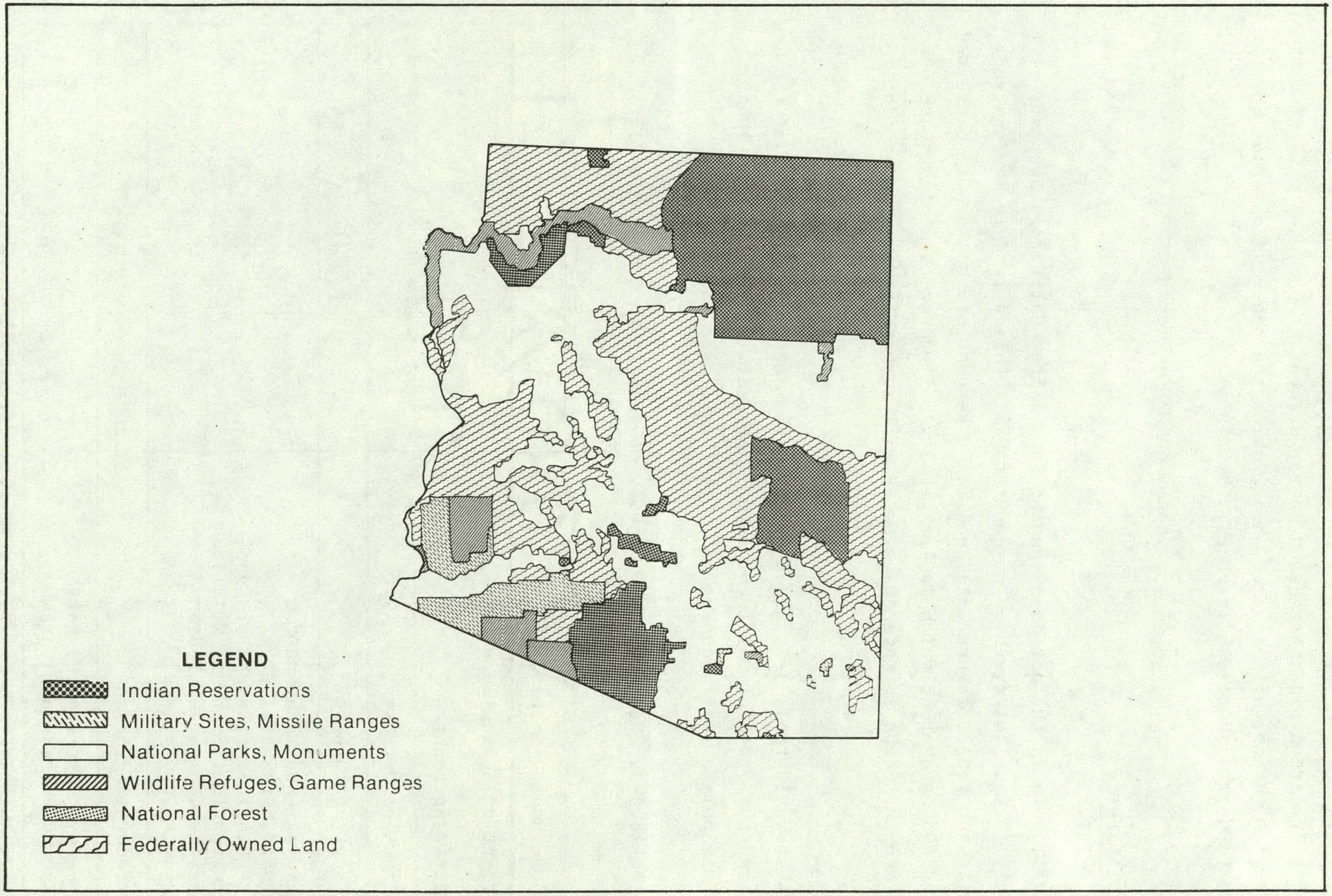


Figure 3-5. Ownership of Land in Arizona

If hydrocarbon plants are used as replacement crops, they will probably compete with cotton, alfalfa, and wheat, which are the leading crops of Arizona (AWC, 1977; Arizona Yearbook, 1979/1980).

3.2 California

California is the nation's leading farm state (California Statistical Abstract, 1979). Thirty-three percent of California's land is in farmland (refer to section 2, figure 2-1), and eight percent of the land is harvested cropland (93 percent of which is irrigated). If hydrocarbon plants are used as replacement crops in this state, they will compete strongly with food crops.

As shown in table 3-2, the federal government owns 45 percent of the state, and the State of California owns 1 percent. Indian reservations constitute only a small percentage of the state (see figure 3-6).

Table 3-2. Real Property of U.S. Government in California, 1975

	Percent of Area of State
U.S. Government -- Total	45
Department of Agriculture Forest Department	 20
Department of Defense	4
Department of Interior	21
Bureau of Land Management National Park Service Other (including Bureau of Land Reclamation, Fish and Wildlife Service, Bureau of Indian Affairs, and others)	15 4 2
Other federal agencies	negligible
State Parks, Reserves, Historic Parks and Recreational Areas	1

(compiled from data in California Statistical Abstract, 1979).

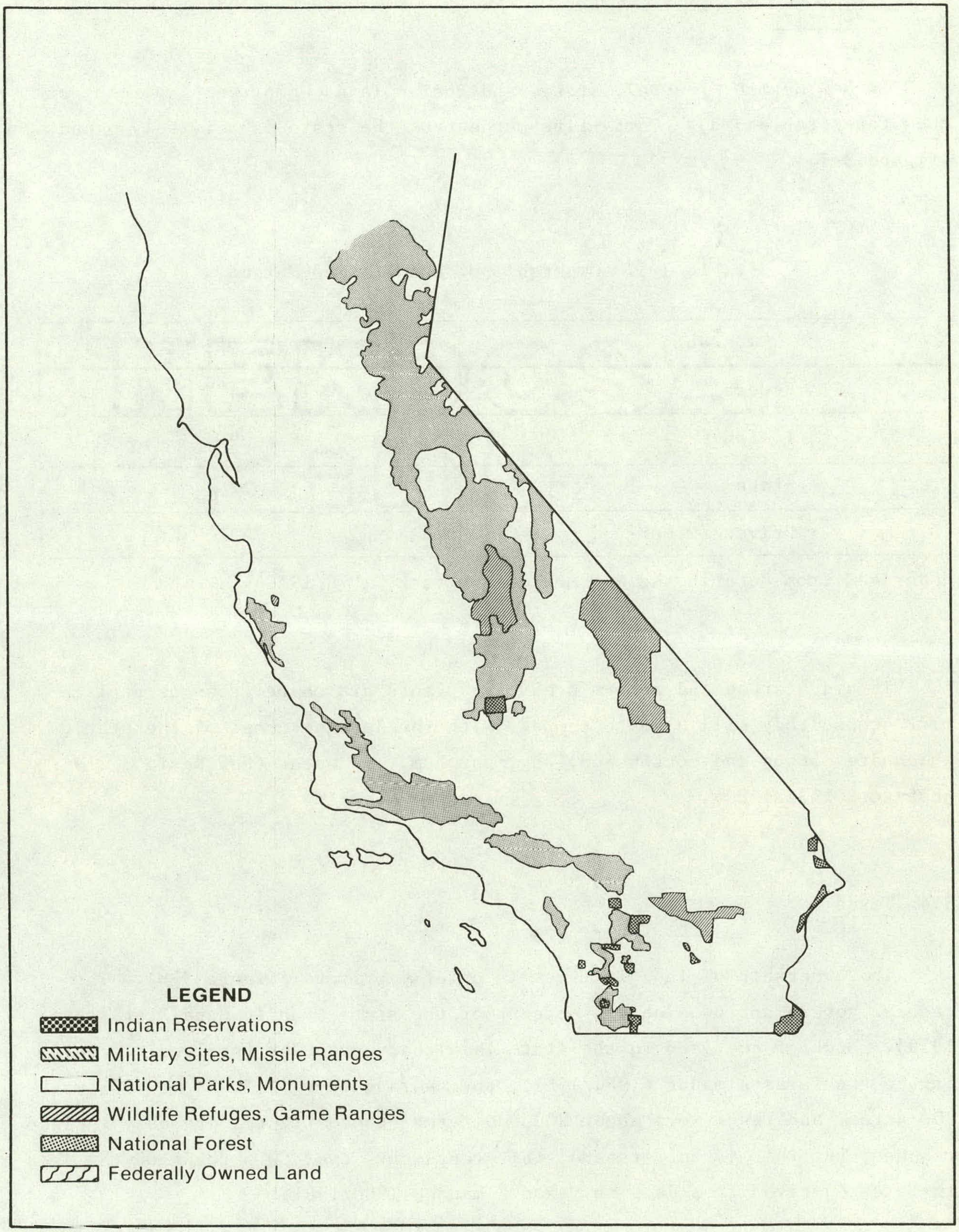


Figure 3-6. Ownership of Land in California

3.3 New Mexico

In New Mexico, federal, state, and Indian lands comprise 55 percent of the state (table 3-3). Forty-five percent of the state is privately owned (figure 3-7).

Table 3-3. Ownership of Land in New Mexico

Ownership	Percent of State
Federal	34
Indian	9
State	12
Private/Other	45

(derived from data in the New Mexico Abstract, 1979/1980).

If hydrocarbon and rubber producing plants are to be grown as replacement crops, they will have to compete with the leading crops of the state, which are cotton and cottonseed, hay, sorghum, and wheat (New Mexico Abstract, 1979/1980).

3.4 Texas

The ownership of land in Texas is chiefly private (figure 3-8). The federal government owns only 2 percent of the state (Public Land Statistics, 1979). Much of the land in the state is already used for farmland. According to the Texas Almanac (1980/1981), the average farm in Texas in 1978 was 700 acres, and there were about 200,000 farms (these figures probably include ranches, but this is not stated); this represents over 80 percent of the land in Texas (derived from data in Texas Almanac, 1980/1981).

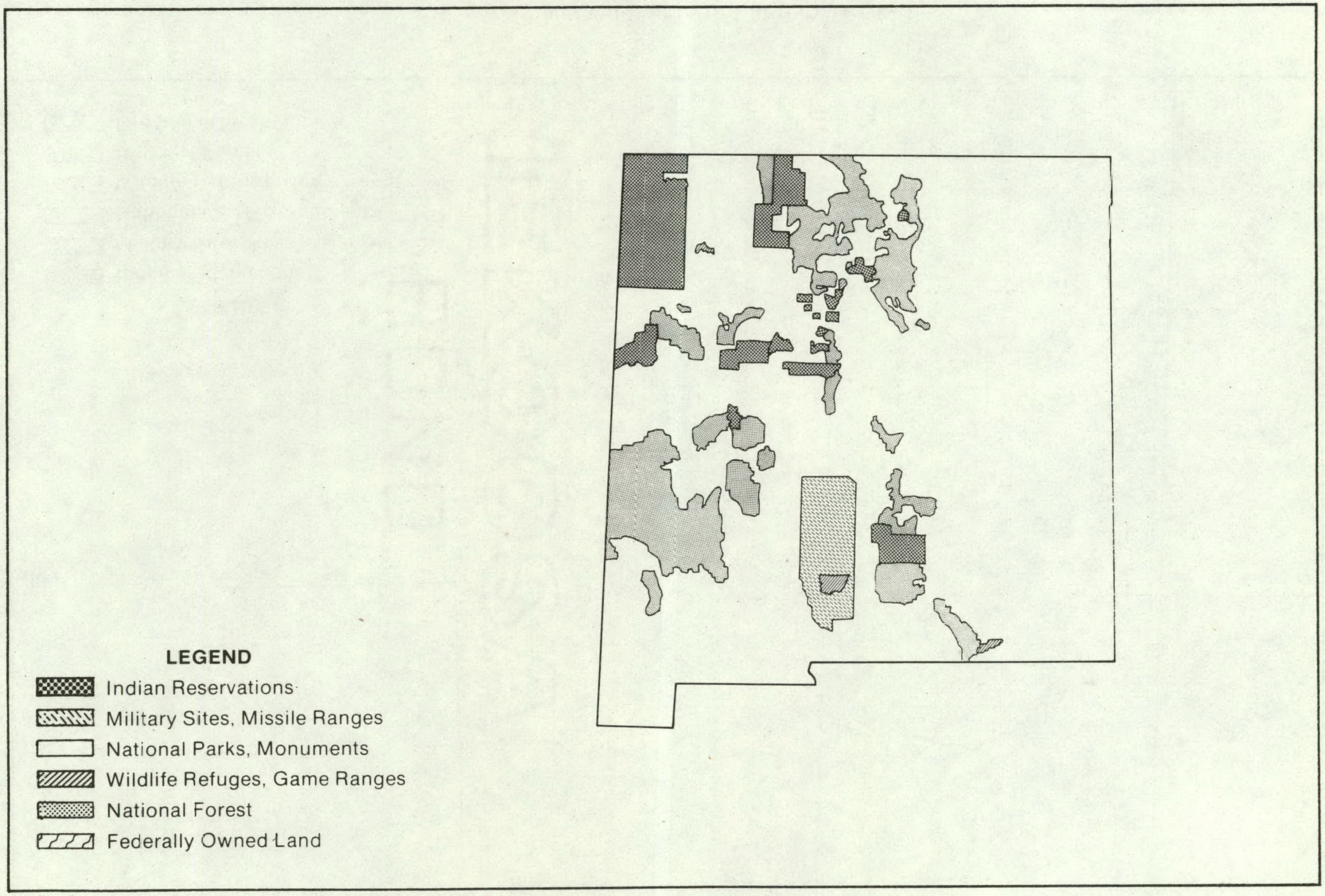


Figure 3-7. Ownership of Land in New Mexico

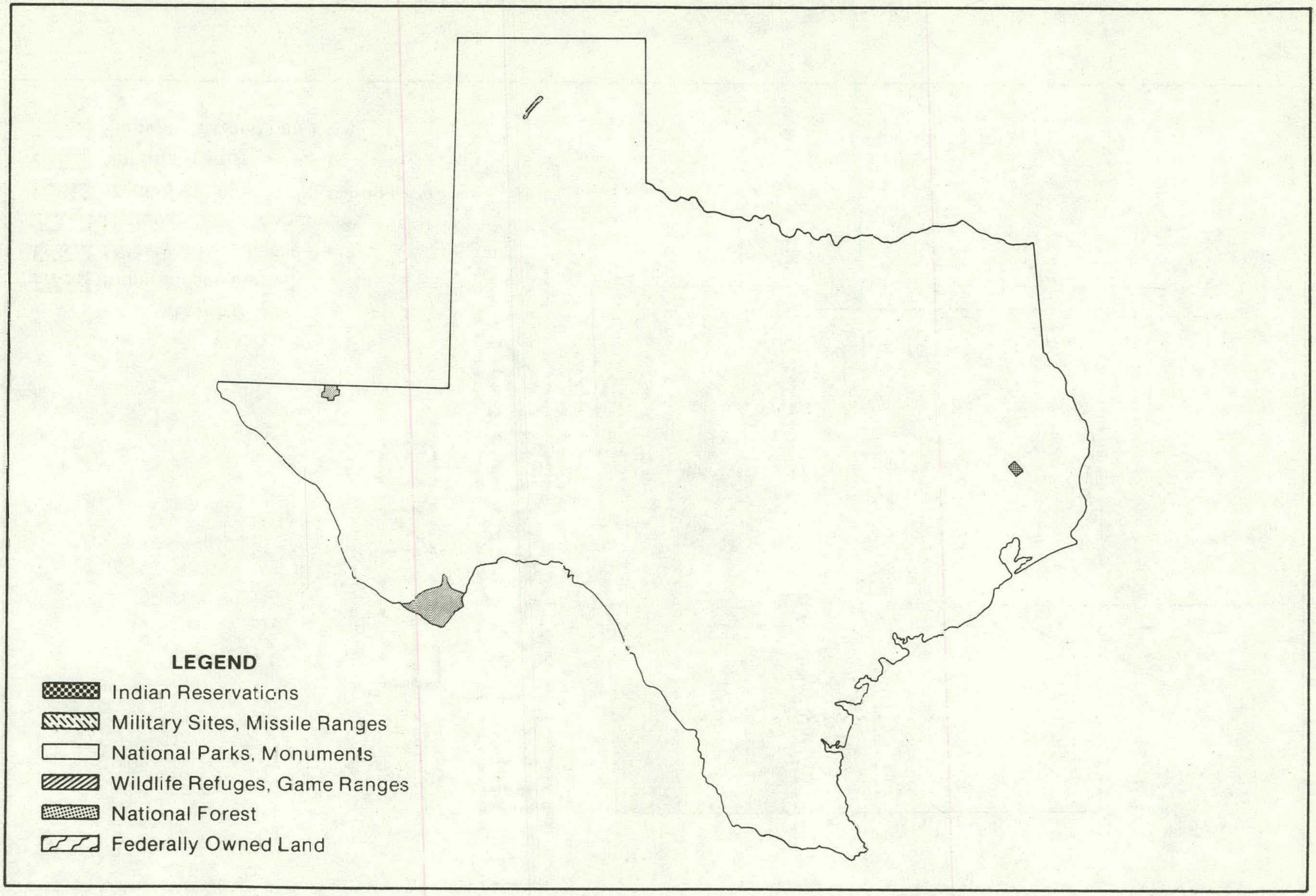


Figure 3-8. Ownership of Land in Texas

The chief crops in Texas are cotton (37 percent of total crop receipts) and grain sorghum (13 percent); other important cash crops are corn, wheat, rice, cottonseed, peanuts, and soybeans (Texas Almanac, 1980/1981). Therefore, hydrocarbon producing plants, if grown as replacement crops, may compete with food crops.

4.0 Endangered Species

The protection of certain plant species by both federal and state governments could be a significant barrier to the cultivation of large areas of land that presently are not being cultivated; however, this remains to be determined by the courts.

Under the Endangered Species Act of 1973, as amended by the Endangered Species Act Amendments of 1978 (16 U.S.C. 1536, 50 C.F.R. 402.01), federal agencies are required to:

1) Carry out conservation programs for endangered and threatened species,

2) Ensure that agency activities or programs do not jeopardize the continued existence of endangered or threatened species, and

3) Ensure that agency activities or programs do not destroy or adversely affect a critical habitat (a critical habitat is one that is essential for the survival of an endangered or threatened species).

Therefore, the cultivation of presently uncultivated land in the southwest, particularly by the federal government, would have to consider the effect on any critical habitats of endangered or threatened species. We have only investigated plant species, however, endangered or threatened animal species and their critical habitats would also have to be investigated before any large-scale cultivation by a federal agency could occur.

The names of plant species that are endangered or threatened were published in the Federal Register (45 Fed. Reg. 33,780-33,781). These species are given in appendices B, D, G, and I, and their critical habitats are shown on figures 4-1, 4-2, and 4-3. Many of these plants would probably

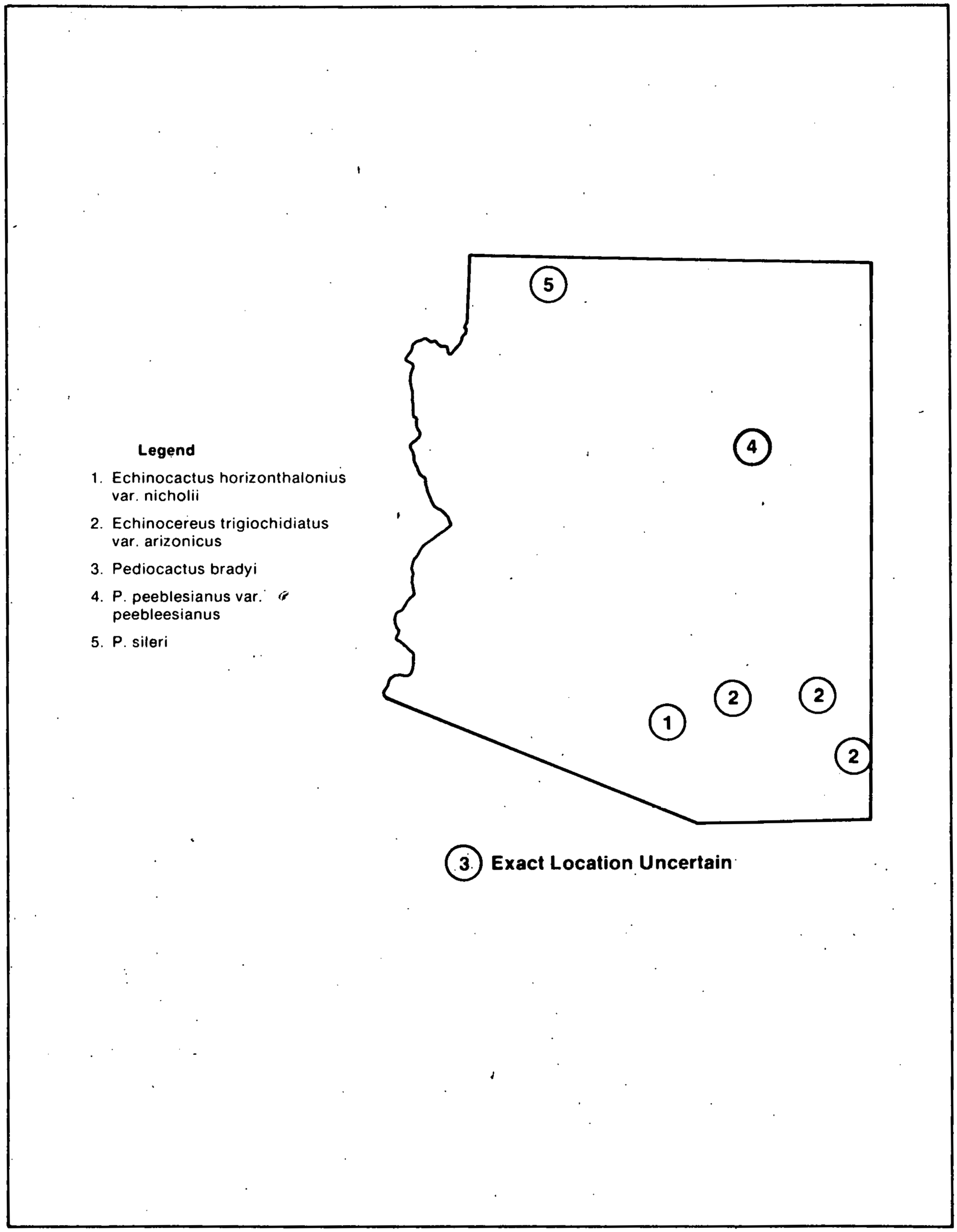


Figure 4-1. Arizona: Critical Habitats of Endangered Species

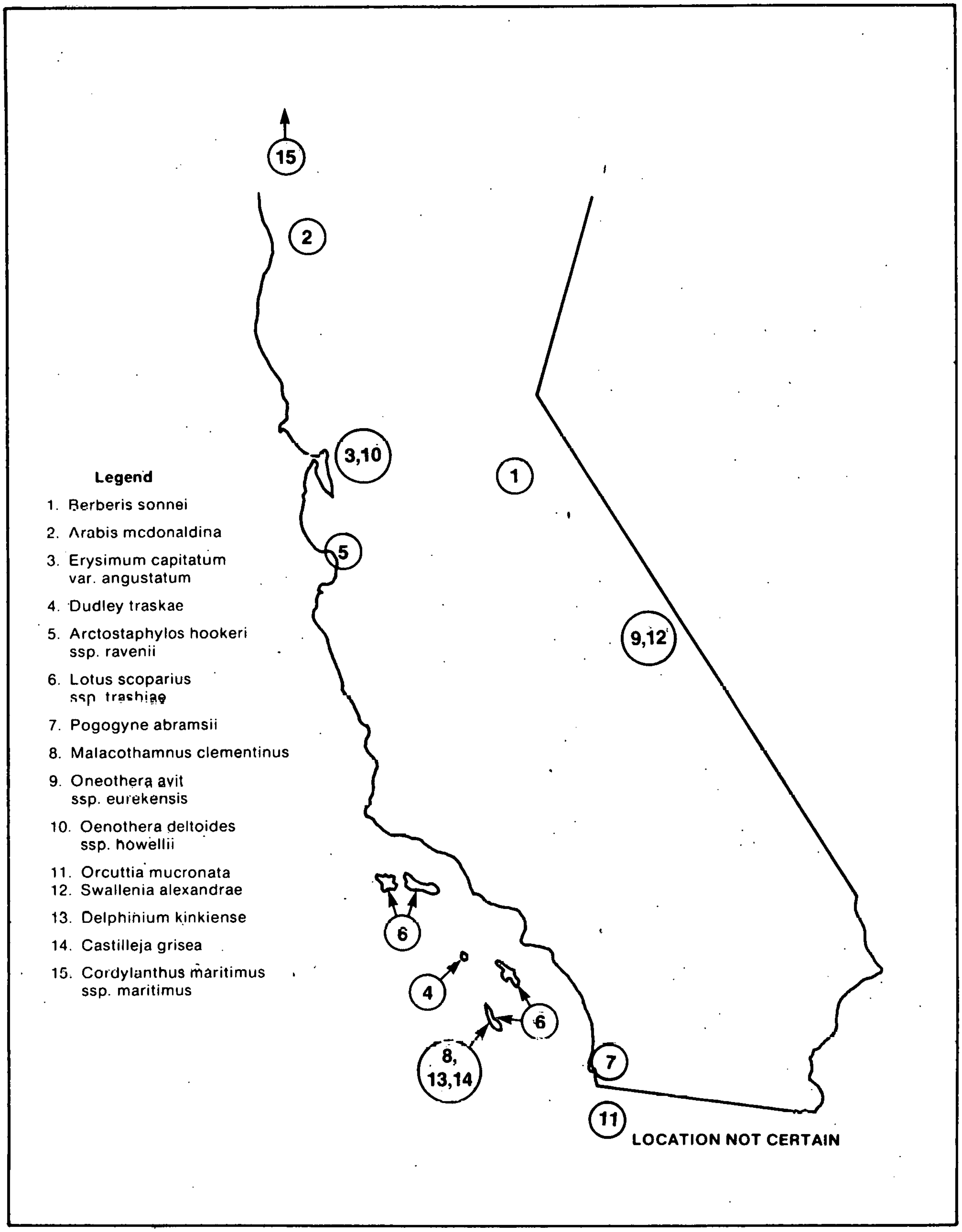


Figure 4-2. California: Critical Habitats of Endangered Species

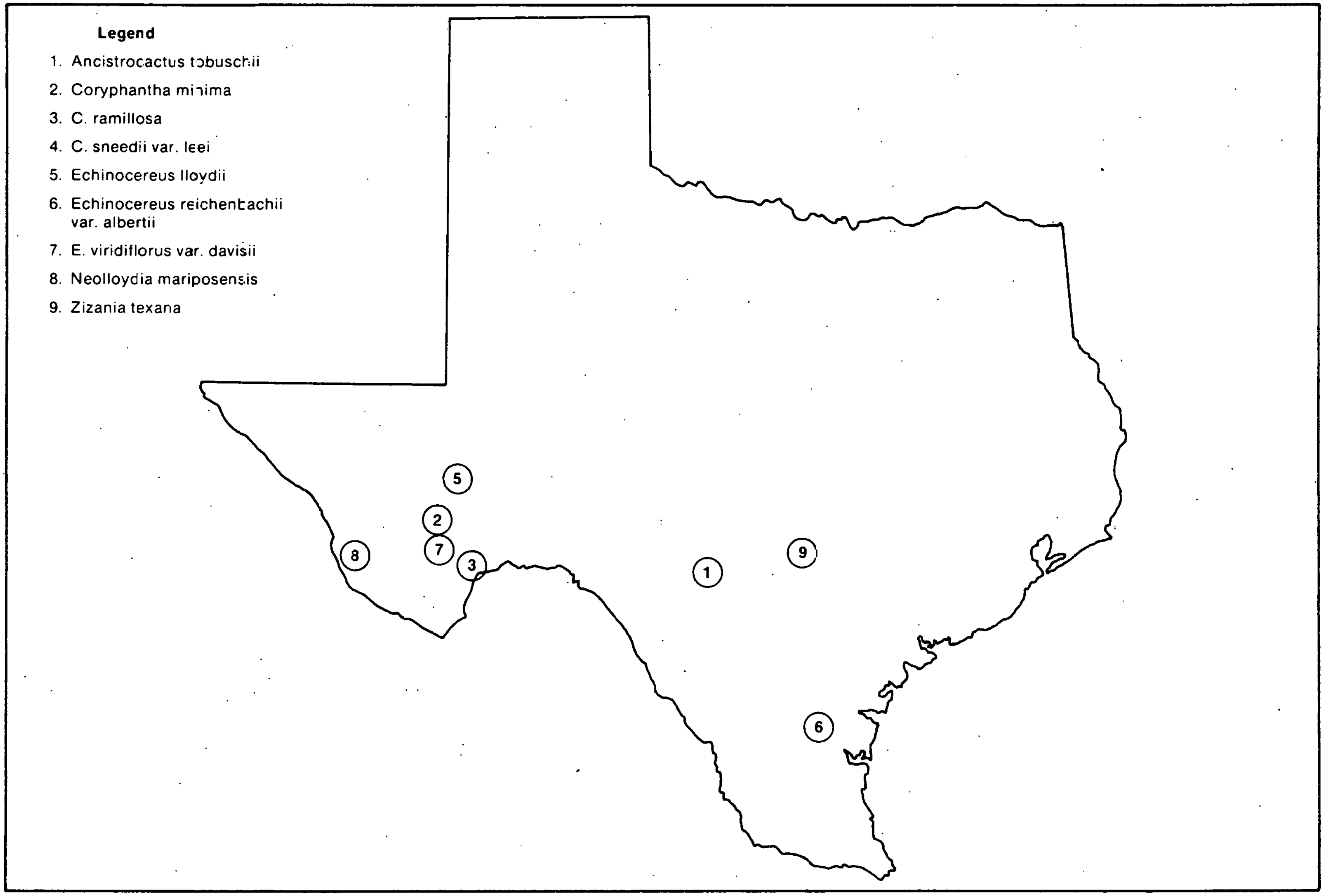


Figure 4-3. Texas: Critical Habitats of Endangered Species

not present a barrier to the cultivation of desert lands because many of them are not found in areas that could be cultivated for plants such as guayule and jojoba. For example, some of these plants grow in yellow pine forests, red fir forests, coastal salt marshes, on rocky canyon walls, or at high elevations. However, the critical habitats of some of these species, particularly those in the Cactaceae family, would undoubtedly overlap with some areas that could potentially be cultivated.

There are also several state laws that protect certain plant species. The protected plants of Arizona, California, and New Mexico are listed in appendices C, E, F, and H. The state laws do not appear to be as prohibitive as the federal law. Arizona state statutes (Ariz. Rev. Stat. 3-901 to 3-910) prohibit the collection of certain plants (about 221 species) without a permit from the commission of agriculture and horticulture. The collection must be for scientific or educational purposes or "where the protected native plant's existence is threatened by its location or a change in land usage." This would not appear to prevent the cultivation of land in which the protected species was found, particularly if the plant was transplanted to another site. New Mexico state statutes (N.M. Stat. Ann. 76-8-1 to 76-8-4) also require a permit before protected species (appendix H) can be destroyed or mutilated. About 60 species are protected. The California law (1979 Cal. Stats. Div. 23) appears to be the least prohibitive of the three states investigated (protected species listed in appendix F). It provides that "No provision of this division shall prevent: (a) The clearing of land for agricultural purposes..."

5.0 Noxious Weeds

Some of the plants that have been suggested as sources of hydrocarbon and/or rubber are considered noxious weeds in some states. Others may not be noxious weeds under law, but would probably meet strong opposition from farmers if cultivated on a large scale. In most of the state statutes that we examined, specific plants or species were not listed. Instead, a state official, frequently the director or commissioner of agriculture, is given the authority to publish regulations that prohibit certain species of plants. In most states, it is illegal to plant or transplant seeds of prohibited plants. Further, landowners are usually required to eradicate any of these plants found growing on their property before the plants reach maturity.

The United States Department of Agriculture, Agricultural Marketing Service, publishes a list of all species that are considered noxious weeds under state statutes and/or regulations. This list is updated annually.

The only plants that we have assessed that are considered noxious weeds are the milkweeds (Asclepias ssp.). This genus is only prohibited in Hawaii; however, its cultivation on a large scale may meet with strong opposition from farmers. According to Jeffrey and Robinson (1971), A. syriaca is resistant to commonly used herbicides. Further, Evetts and Burnside (1972 and 1973c) found that common milkweed reduced yields of sorghum by 720 kg/ha (640 lbs/acre).

The following two plants that are noxious weeds have been suggested by Buchanan and Otey (1979) as potential sources of rubber: Sonchus arvensis (sow thistle) is prohibited in Alaska, Arizona, California, Colorado, Connecticut, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Montana, Nevada, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Vermont, Washington, Wisconsin, Wyoming, West Virginia. Ambrosia trifida is considered noxious in California (B-rating, that is, eradication is at the discretion of the commissioner).

Appendix A

Water Rights in the Southwest

Agriculture in the southwest is undoubtedly more dependent on the supply of water than on any other single factor. Therefore, the allocation of water supplies is extremely important to the success of any agricultural projects.

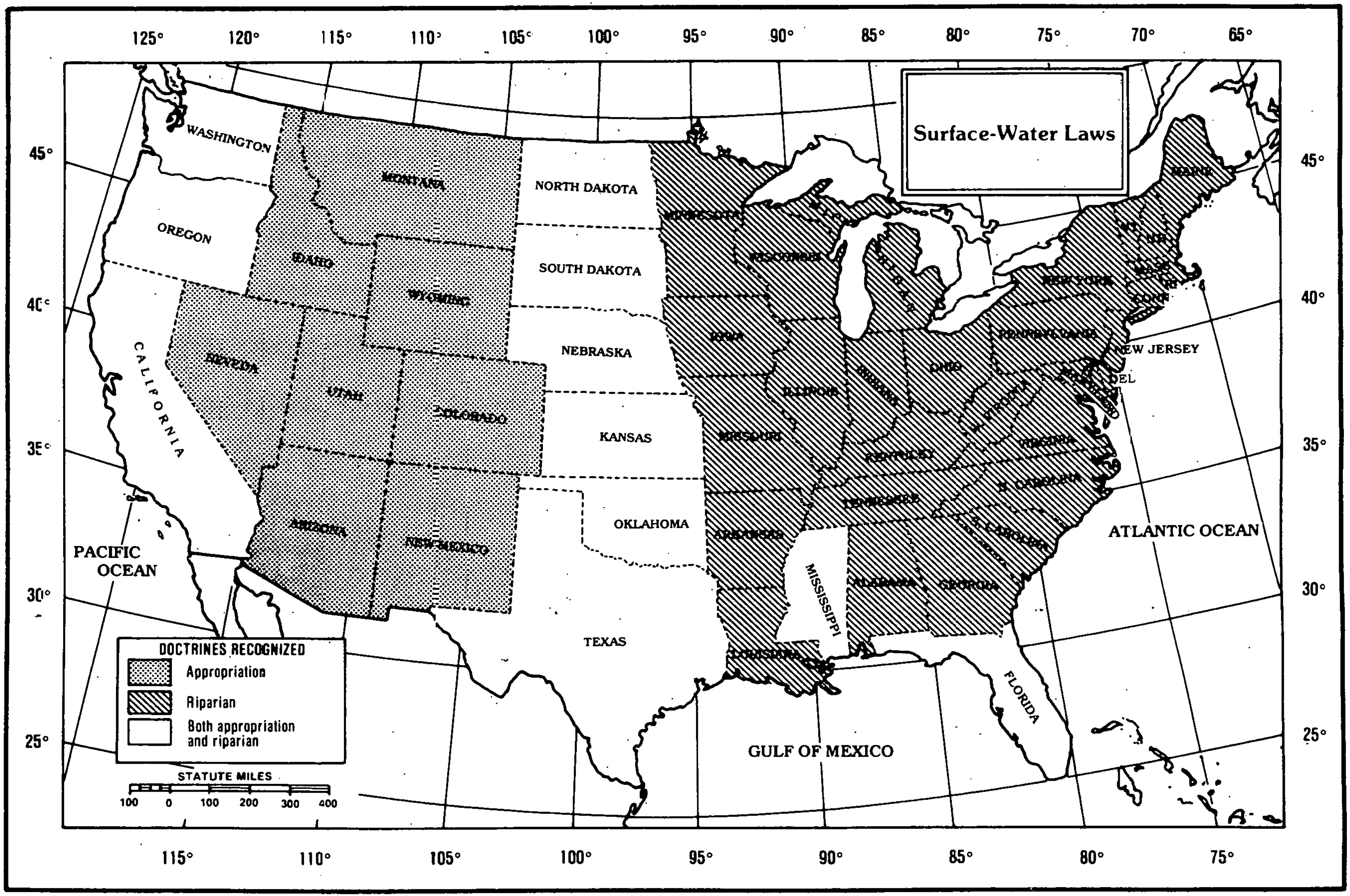
Since water availability is complicated by the regulatory system governing its use, this section briefly reviews how water rights are allocated in the southwest.

A.1 Surface Water Laws

Water rights in the United States are based on riparian rights, appropriation rights, or a combination of the two. The Common law based on the riparian doctrine (rights incident to and arising from the ownership of land adjoining a stream or watercourse) has generally proven to be inadequate in the western United States, given the high demand and scarce supply of water.

Therefore, the doctrine of prior appropriation, also know as "first-in-time, first-in-right" system, evolved. Basically, this system secured the rights of the earliest user of the water to use the water regardless of the demands of riparian owners. There are two version of this appropriation doctrine that are pertinent to the states of the southwest.

The first version is the Colorado Doctrine, which stems from the decision in the case of Coffin v. Left Hand Ditch Co. (6 Colo. 443, 1882). This Colorado case, decided in 1882, eliminated the riparian rights doctrine and established the prior appropriation doctrine as the sole means of determining water rights. Nine western states have adopted the Colorado Doctrine, including New Mexico and Arizona (figure A-1, plus Alaska).



(from Geraghty et al., 1973)

Figure A-1. Surface Water Laws

The second version of the doctrine is called the California Doctrine. It is based on riparian rights, however, the law of prior appropriation is recognized. The California Doctrine is recognized in California, Texas, and other states, as shown in figure A-1.

A.2 Groundwater Laws

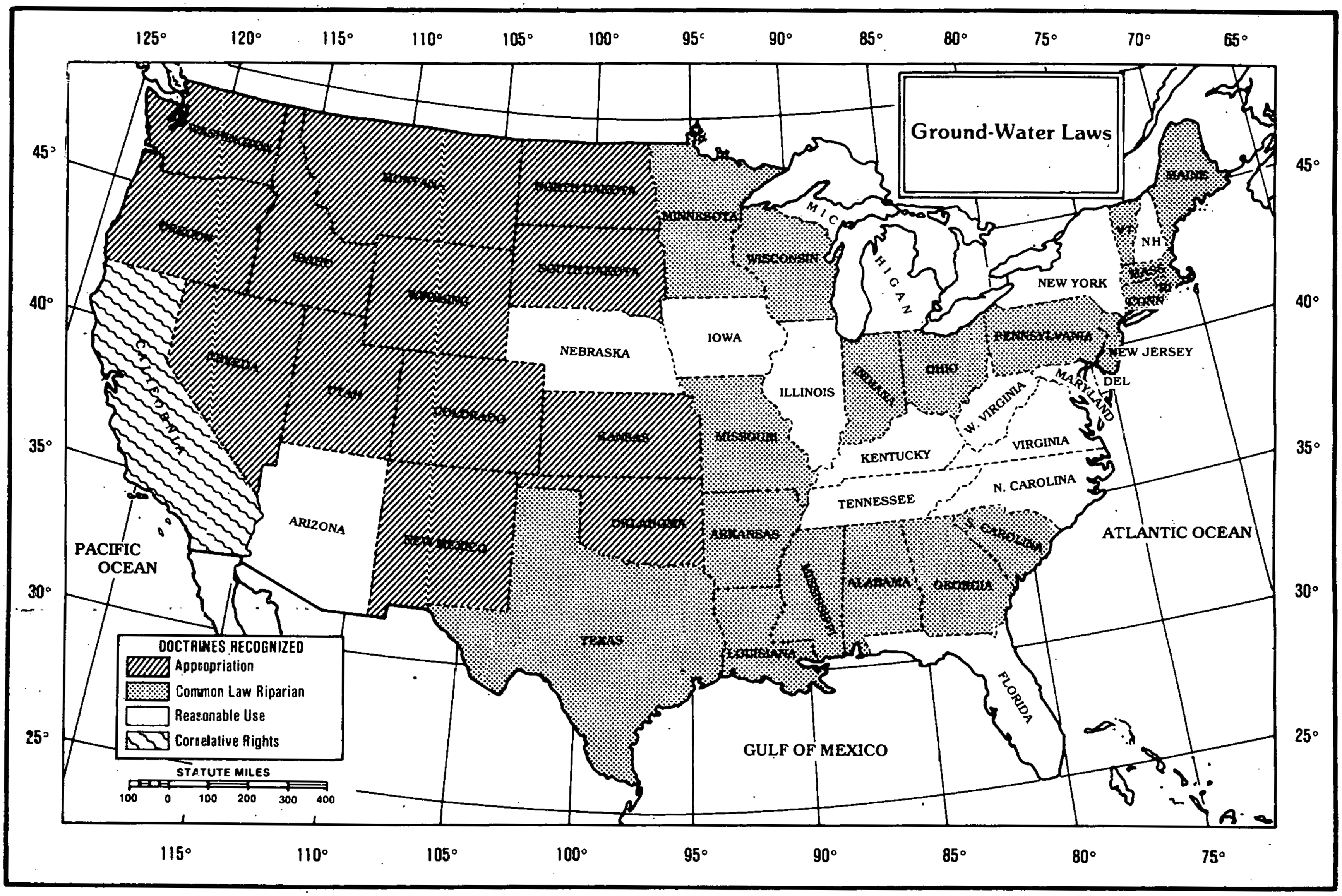
The groundwater law of the west is defined within four separate doctrines (figure A-2 shows which of these doctrines apply to the various states). The first is the common law, or riparian rights doctrine. Under this doctrine, the owner of the soil may use the percolating waters as he/she sees fit. This is an absolute right and may be exercised without regard to the effect on neighboring subsurface water supplies [Huber v. Merkel, 117 Wis. 355, 94 N.W. 354 (1903)].

In Texas, where the common law rule prevails, there is a limitation that "the owner may not maliciously take water for the sole purpose of injuring his neighbor." In fact, owners of land that has subsided because of such withdrawals may have legal grounds for charging appropriators with negligence [Friendswood Dev. Co. v. Smith-Southwest Indus. Inc., 576 S.W.2d. 21, Tex. (1978)].

The second and third doctrines are modifications of this common law rule and are called the reasonable use doctrine and the correlative rights doctrine.

The reasonable use doctrine requires that groundwater be used in a beneficial way on the land from which it was taken. In 1953, in the case of Bristor v. Cheatham, Arizona adopted this reasonable use doctrine [Bristor v. Cheatham, 75 Ariz. 227, 225 P.2d. 173, 180 (1953)].

The correlative rights doctrine is similar to the reasonable use doctrine, except that it requires that a user of groundwater be limited to a proportionate share, based upon previous use, during times of scarcity.



(from Geraghty et al., 1973)

Figure A-2. Ground Water Laws

Generally, the user must also consider the effect of groundwater withdrawals on lands adjoining or affected by the withdrawal.

The fourth doctrine applied to groundwater use is the prior appropriation doctrine (this doctrine is analagous to the Colorado Doctrine version of the appropriation doctrine discussed under surface water). This doctrine has been adopted by New Mexico, as well as thirteen other states.

A.3 Indian Reserved Rights*

In addition to the rights granted by the various doctrines, there is another significant set of rights that must be considered. These are the reserved water rights of Indians on reservation land. Reserved rights require that a sufficient quantity of water be reserved to accomplish the purposes of reserved lands, which includes both federal lands and Indian reservations (Devine et al., 1980). These rights are preemptive, however, they remain to be quantified in most cases. They exist by treaty and are "prior-in-time" to all existing appropriative user's rights. Moreover, these rights do not need to be exercised to be maintained (Du Mars and Ingram, 1980). How much water is needed (or will be available) to satisfy these rights is speculative and is a major area of potential controversy. In Arizona, where 29 percent of all land is in Indian reservations, the quantification of reserved Indian rights may conflict with existing commitments of water (U.S. Department of Interior Bureau of Land Management, Public Land Statistics 1976, U.S. Government Printing Office, Washington, D.C., 1977; U.S. Department of Commerce, Federal and State Indian Reservations and Indian Trust Areas, U.S. Government Printing Office, Washington, D.C., 1974). For example, the Colorado River has been totally appropriated by the Colorado River Compact agreement, but Indian reserved rights predating the compact, if exercised, would preempt the existing users.

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*For a more detailed discussion of Indian reserved rights, see Du Mars and Ingram, 1980; Back and Taylor, 1980; and Devine, Ballard, and White, 1980.

A.4 State Water Use Laws and Regulations

Each western state has established a permit system, which is required under an appropriative use allocation doctrine. It has been the position of the western states that, except for the prior reserved rights of Indians, all takers of water (federal, state, and local governmental or private) must comply with the pertinent state laws and regulations. This issue has been litigated by the states through the federal courts and the U.S. Supreme Court [United States v. New Mexico, 438 U.S. 696 (1978)].

Appendix B

Arizona Plants Protected Under the Endangered Species Act

Cactaceae - Cactus Family

1) *Echinocactus horizonthalonius* var. *nicholii* - Nichol's Turk's head cactus

   Silver Bell, Pima County, 2,500 feet; western Texas, southern New Mexico, Arizona and Mexico (Kearney and Peebles, 1951).

2) *Echinocereus trigiochidiatus* var. *arizonicus* (*E. arizonicus*) - Arizona hedgehog cactus

   Found in Graham, Pinal, Cochise, and Pima counties; mountains 3,000 to 6,000 feet; also in New Mexico and Mexico (Kearney and Peebles, 1951).

3) *Pediocactus bradyi* (*Toumeya bradyi*) - Brady pincushion cactus

   The exact location of this plant is uncertain. It can be seen only during the two or three days of the year when it flowers. For a short time before and after flowering, it can be located by prolonged searching of the rocky desert floor on hands and knees or stooping. During the rest of the year the stem, which is about two-thirds underground, shrivels, and the plant body retracts to ground level or below and the wind covers it with dust (Kearney and Peebles, 1951).

4) *Pediocactus peeblesianus* var. *peebleesianus* - Peebles Navajo cactus

   Known range - 5 to 7 miles in gravelly hills north and northwest (Navajo county) of Holbrook, Arizona. The special adaptations include going underground and adaptation to specialized soils requiring drastic physiological adaptation not possible for competitors (Prance, 1976). Other names include: *Echinocactus peeblesianus*, *Navajoa peeblesianus*, *Toumeya peeblesianus*, *Utahia peeblesianus*.

5) *Pediocactus sileri* (*Echinocactus sileri*, *Utahia sileri*) - Silver pincushion cactus

   Known with certainty only from northwestern Arizona (Kearney and Peebles, 1951).

Appendix C
Arizona Plants Protected Under State Law

a) Washintonia fillifera - Fan palm

The approximately 65 individuals growing in small lateral canyons or pockets in the walls of a larger canyon in the Kofa Mountains are the only plants of this species known in the wild in Arizona (Kearney and Peebles, 1951).

b) Lysiloma thornberi - Ornamental tree

Found in Pima County on rock ledges along Chimenia Creek in the foothills of the Ricon Mountains at about 3,500 feet (Kearney and Peebles, 1951).

c) Bursera fagaroides - Elephant tree

Known in Arizona only on dry limestone cliffs near Fresnal, western foothills of the Baboquivari Mountains, Pima County, at about 4,000 feet (Kearney and Peebles, 1951).

d) Cereus schottii - Senita or Old One

Found in western Pima County at about 1,000 to 2,000 feet (Kearney and Peebles, 1951.

e) Cereus thurberi - Organ pipe cactus

Southern Pinal, southern Maricopa, and western Pima counties, up to about 3,000 feet. A large area in the desert south of Ajo, Pima county, has been set aside as a national monument for the preservation of the organpipe cactus and the sinita (Kearney and Peebles, 1951).

f) Toumeya papyracantha -

Near Showlow, Navajoe County, 6,500 ft. (Kearney and Peebles, 1951).

g) Toumeya peeblesiana -

See Pedicactus peeblesianus var. peebleesianus table 3-1.

h) Neoevansia diquetii - Dahlia cactus

Near the Sonora boundary in southern Pima County (Kearney and Peebles, 1951).

All Sclerocactus species:

i) Sclerocactus parviflorus -

Navajo and Coconino counties, not uncommon, type from "Forbidding Canyon," Coconino County (Kearney and Peebles, 1951).

j) Sclerocactus whipplei -

Apache county, Ganado to Chinle, and Lithodendron Creek (Kearney and Peebles, 1951).

k) Sclerocactus polyancistrus -

Not definitely known to occur in Arizona (Kearney and Peebles, 1951).

l) Sclerocactus intermedius -

Sweetwater, Apache county, and 9 miles southwest of Pipe Springs, Mohave County (Kearney and Peebles, 1951).

In addition, all Pediocarpus species are protected, and Agave arizonica is protected.

The following categories of plants are also protected under the state law. The number of species for each group was obtained from Kearney and Peebles (1951).

I. All species of the following familes are protected:

Liliaceae (lily family) - 59 species

Amaryllidaceae (Amaryllis family) - 12 species

Orchidaceae (Orchid family) - 22 species

Crassulaceae (Orpine family) - 10 species

Cactaceae (Cactus family) - 72 species

II. All species of the following genera are protected:

Aquilegia (Columbine) - 7 species

Lobelia - 4 species; all species grow on moist soil.

Dodecatheon (Shooting star) 3 species; All species grow in the the mountains.

Primula (Primrose) - 4 species; All species found on mountains or canyon rims.

Fouquieria (Ocotillo)

III. All of the following species are protected

Atriplex hymenelytra (Desert holly); Western Maricopa, Mohave and Yuma counties, below 1000 feet in dry, sandy or stony soil.

Cercis occidentalis (Redbud); Near Kayenta (Navajo county), Grand Canyon and Havasu Canyon (Coconino County), Pagumpa Springs (Mohave county), Superstition Mountains (Pinal County); 4,000 to 4,500 feet.

Pinus aristata (Bristle-cone pine). San Francisco Peaks; 9,500 to 12,00 feet.

Rhus kearneyi (Kearney sumac). Southern Yuma county; 1,000 to 15,000 feet; dry cliffs.

Sapium biloculare (Mexican jumping bean). Near Gila Bend and from western Pima county to the Tinajas Atlas Mountains; 1,000 to 2,000 feet, locally abundant along sandy washes and on rocky slopes.

Sebastiana pavoniana (Mexican jumping bean).

IV. The following species of live or dead plants or parts are also protected.

Prosopis juliflora - Common or honey mesquite

Very common chiefly along streams and where water table is high.

Prosopis pubescens - Screwbean mesquite

400 feet or lower, flood plains, often in saline soil

Cercidium microphyllum - Little leaf palo verde

Northern Mohave County to Cochise, Pima, and Yuma counties, 4,000 feet or lower, dry rocky hillsides and mesas.

Cercidium floridum - Blue palo verde

Greenlei, Gila, Pinal, and Pima counties to Mohave and Yuma counties, 3,500 feet or lower, common along washes and on flood plains, less frequently on dry lower slopes.

Parkinsonia aculeatal - Jerusalem thorn

Castle Dome Mountains, foothills of the Coyote and Baboquevari Mountains, Pima County, occasional in sandy soil along washes, also south of Tucson.

Olneya tesota - Ironwood tree

Maricopa, Pinal, and Yuma counties, 2,500 feet or lower, common along washes in the foothills.

Appendix D
California Plants Protected Under the Endangered Species Act

Berberidaceae - Barberry family

1) *Berberis sonnei* - Truckee barberry

Rocky banks, 7,00 feet; Montane Coniferous Forest; central Sierra Nevada. [Yellow Pine Forest, Red Fir Forest]* (Munz, 1959).

Brassicaceae - Mustard family

2) *Arabis mcdonaldiana* - McDonald's rock-cress

Serpentine soil, at 4,000 feet. Red Mountain near Bell Spring, Mendocina County. [Yellow Pine Forest] (Munz, 1959).

3) *Erysimum capitatum* var. *angustatum* - Contra Costa wallflower

Sand dunes along San Joaquin River, just east of Antioch; Contra Costa County. For precise location, see 50 CFR 17.96. [Coastal Strand] (Munz, 1959).

Crassulaceae - Stonecrop family

4) *Dudley traskae* - Santa Barbara Island live-forever

Santa Barbara Island, (Munz, 1959).

Ericaceae - Heath family

5) *Arctostaphylos hookeri* ssp. *ravenii* - Raven's manzanita

Sand dunes and woods near the coast, Monterey County. [Closed-cone Pine Forest] (Munz, 1959).

Fabaceae - Pea family

6) *Lotus scoparius* ssp. *traskiae* - San Clemente broom

Chaparral; Santa Rosa, Santa Cruz, Santa Catalina, and San Clemente Islands. [Coastal Sage Scrub] (Munz, 1959).

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*Brackets indicate the name of the plant community in which species is found. See description in following key.

Laminaceae (presently called the Labiatae) family

7) *Pogogyne abramsii* - San Diego mesa mint

Beds of dried pools; Chaparral, mesas from San Diego to Miramer. [Coastal Sage Scrub] (Munz, 1959).

8) *Malacothamnus clementinus* - San Clemente island bush-mallow

Rocky canyon-walls; Lemon Tank, San Clemente Island. [Coastal Sage Scrub] (Munz, 1959).

Onagraceae - Evening-primrose family

9) *Oneothera avita* ssp. *eurekensis* - Eureka evening primrose

Sand dunes, south end of Eureka Valley, Inyo County. [**Creosote Bush Scrub] (Munz, 1959).

10) *Oenothera deltoides* ssp. *howellii* - Antioch Dunes evening-primrose

Sand dunes near Antioch, Contra Costa County. For precise location, see 50 CFR 17.96. (Munz, 1959).

Poaceae - Grass family

11) *Orcuttia mucronata* - Soland grass or Crampton's Orcutt

Location uncertain.

12) *Swallenia alexandrae* - Eureka Dune grass

South end of Eureka Valley and mouth of Marble Canyon, east side of Inyo Mountains, Inyo County. [**Creosote Bush Scrub] (Munz, 1974.

Ranunculaceae - Buttercup family

13) *Delphinium kinkiense* - San Clemente Island Indian paintbrush

Grassy places, San Clemente Island. (Munz, 1974.

Scrophulariaceae - Snapdragon family

14) *Castilleja grisea* - San Clemente Island Indian paintbrush

Bluffs, San Clemente Island. [**Coastal Sage Scrub] (Munz, 1974).

15) *Cordylanthus maritimus* ssp. *maritimus* - Salt marsh bird's beak

Southern Oregon to northern Lower California. [Coastal Salt Marsh] (Munz, 1959).

Appendix E
California Plant Community - Key

The following descriptions of plant communities were taken from Munz (1959) or Munz (1974). The latter are indicated by **.

Coastal Strand

Artemisia pycnocephala, Franseria Chamissonis, Lathyrus littoralis, Lupinus arboreus, L. Chamissonis, Abronia maritima, A. umbellata, Oenothera cheiranthifolia, Atriplex leucophylla, Fragaria chiloensis, Poa Douglasii, Haplopappus ericoides, Mesembryanthemum nodiflorum, M. crystallinum, Convolvulus Soldanella.

Sandy beaches and dunes scattered along the entire coast.

Annual rainfall 15 to 70 inches, with much fog and wind; growing season 12 months, with 350 to 365 frost-free days; small seasonal and diurnal fluctuations in temperature; mean summer maxima 61° to 70°, mean winter minima 39° to 47° F.

Vegetation low or prostrate, often succulent, late flowering. The constitution of this community varies considerably from north to south, some species reaching their southern limit at Cape Mendocino, some at Monterey Peninsula, and some at Point Conception. A number of others, however, exemplify the continuity of the community by extending the entire length of the state and beyond.

**Coastal Strand

Sandy beaches and dunes, with many succulent plants. Rainfall running from 10 to 25 inches; temperature rather even; little or no frost. Characteristic genera: Abronia, herbaceous species of Atriplex, Camissonia, Convolvulus.

Coastal Salt Marsh

Salicornia virginica, S. subterminalis, Suaeda californica and var. pubescens, Distichlis spicata, Spartina leiantha, Limonium californicum, Frankenia grandifolia, Triglochin maritima.

Salt marshes along the coast, from sea level to 10 feet.

Average rainfall 15 to 40 inches; growing season 12 months, with 330 to 365 frost-free days; small seasonal and diurnal fluctuations in temperature; temperature range about as in Coastal Strand.

Most extensive on tidelands.

**Creosote Bush Scrub

The great mass of the floor of the deserts and their lower slopes are covered by a scrub vegetation of Larrea or Creosote Bush. Rainfall 2 to 8 inches, partly in summer. Burr weed (*Ambrosia dumosa*), Ocotillo (*Fouquieria*), Incienso (*Encelia*), etc.

Coastal Sage Scrub

Artemisia californica, *Salvia apiana*, *S. mellifera*, *S. leucophylla*, *Eriogonum fasciculatum*, *Rhus integrifolia*, *Encelia californica*, *Horkelia cuneata*, *Haplopappus squarrosus*, *H. venetus*, *Eriophyllum confertiflorum*.

Usually dry rocky or gravelly slopes, South Coast Ranges to Baja California, mostly below 3000 feet and below the Chaparral.

Annual rainfall 10 to 20 inches; growing season 8 to 12 months, with 230 to 350 frost-free days; mean summer maximum temperatures 68° to 90°, mean winter minima 37° to 48° F.

Plants half-shrubs, 1 to 5 feet tall or somewhat woodier and larger forming a more open community than Chaparral.

Closed-cone Pine Forest

Pinus muricata, *P. contorta*, *P. radiata*, *P. remorata*, *Cupressus macrocarpa*, *C. pygmaea*, *C. Goveniana*.

Interrupted forest from Mendocino plains southward near the immediate coast to Santa Barbara County, from near sea level to 1200 feet. Northward it is on the seaward side of the redwoods in barren soils.

Average rainfall 20 to 60 inches, much fog; growing season 9 to 12 months, with 270 to 360 frost-free days; climate cool with temperatures comparable with those in the Redwood Forest.

Trees 30 to nearly 100 feet tall, in a relatively dense forest.

Yellow Pine Forest

Pinus ponderosa, *P. Lambertiana*, *Libocedrus decurrens*, *Abies concolor*, *Pseudotsuga Menziesii*, *Quercus Kelloggii*, *Ribes nevadense*, *R. Roezlii*, *Rubus parviflorus*, *Chamaebatia foliolosa*, *Arctostaphylos patula*, *A. Mariposa*, *Ceanothus integerrimus*.

North Coast Ranges, 3000 to 6000 feet; northern California, 1200 to 5500 feet; Sierra Nevada, 2000 to 6500 or 7000 feet; southern California, 5000 to 8000 feet.

Average precipitation 25 to 80 inches, partly as snow; growing season 4 to 7 months, with 90 to 210 frost-free days; mean summer maximum temperatures 80° to 93°, mean winter minima 22° to 34° F.

Trees 75 to 200 feet tall, in extensive continuous forests.

Red Fir Forest

Abies magnifica, *Pinus Murrayana*, *P. monticola*, *P. Jeffreyi*, *Castanopsis sempervirens*, *Ceanothus cordulatus*, *Ipomopsis aggregata*, *Populus tremuloides*.

Above 600 feet in North Coast Ranges; northern California, 5500 to 7500 feet; Sierra Nevada, 6000 to 9000 feet; southern California, 8000 to about 9500 feet.

Average precipitation 35 to 65 inches, with heavy winter snow; growing season 3 to 4.5 months, with 40 to 70 frost-free days; mean summer maximum temperatures 73° to 85° mean winter minima 16° to 26° F.

Trees to 100 feet tall or more, in dense forests.

Appendix F
California Plants Protected Under State Law*

I. Plants that may not be harvested except for scientific or educational purposes under a permit by the agricultural commission.

Burseraceae family (elephant tree) - all species

Carnegia gigantea (sahuaro cactus)

Castela emoryi (crucifixion thorn)

Dudleya saxosa (Panamint dudleya)

Pinus longaeva (bristlecone pine)

Washingtonia filifera (fan palm)

II. The following plants may be harvested under a permit issued by the agricultural commissioner or county sheriff.

Agavaceae family (century plants, nolinas, yuccas) - all species

Cactaceae family (cactus family) - all species exept *Carnegiea gigantea*

Fouquieriaceae family (ocotillo, candlewood) - all species

Prosopis genus (mesquites) - all species

Cercidium genus (palos verdes) - all species

Acacia greggii (catclaw)

Atriplex hymenelytra (desert holly)

Dalea spinosa (smoke tree)

Olneya tesota (desert ironwood) - includes both dead and live plants

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*See Division 23. California Desert National Plants (1979 Cal. Stats. Div. 23).

Appendix G
New Mexico Plants Protected Under the Endangered Species Act

Cactaceae - Cactus family

1) Coryphantha sneedii var. leei (Escobaria leei, Mammillaria leei) - Lee pincushion cactus.

A miniature species that grows on limestone rock ledges in Rattlesnake Canyon (Innes, 1977). Location of Rattlesnake Canyon unknown.

2) Coryphantha sneedii var. sneedii (Escobaria sneedii, Mammillaria sneedii) - Sneed pincushion cactus.

Location unknown.

3) Echinocereus engelmannii var. purpureus - Purple-spined hedgehog cactus

Location unknown.

4) Pediocactus knowltonii - Knowlton cactus

Near the San Juan River of northern New Mexico. Most of its range has been flooded by the San Juan Dam (Prance, 1976).

Appendix H
New Mexico Plants Protected Under State Law*

Polypodiaceae - Fern family

- *Gymnopteris hispida* - Gymnogramme
- *Adiantum capillus-veneris* - Common maidenhair fern
- *Woodwardia plummerae* - Chain fern
- *Asplenium septentrionalis* - Spleen wort
- *Asplenium resiliens* - Spleenwort
- *Asplenium trichomanes* - Spleenwort

Liliaceae - Lily family

- *Milla byflora* - Two-flowered milla
- *Fritillaria atropurpurea* - Purplish-brown fritillary
- *Uvularia amplexifolia* - Uvularia, twisted stalk
- *Leucocrinum montanum* - White mountain lily
- *Lilium montanum* - Wood lily
- *Calochortus* - all species - mariposa lily

Iridaceae - Iris family

- *Oreolirion arizonicum* - This is not the common blue iris of our mountains but is yellow in color.

Amaryllidaceae - Amaryllis family

- *Agave schottii* - Century plant
- *Agave lechuguilla* - Lechuguilla
- *Agave palmeri* - Century plant
- *Agave parryi* - Century plant
- *Agave neomexicana* - Century plant
- *Atamosco longifolia*- Atamosco lily

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*Article 8. Protection of Native New Mexico Plants (N.M. Stat. Ann. 76-1 to 76-8-4).

Ranunculaceae - Crowfoot family

Aguilegia - all species - red, yellow, and blue columbine

Aconitum - all species - Monkshood

Pulsatilla hersutissima - Pasque flower

Viorna - all species - Leather flower

Clematis pseudoalpina - Virgin's bower

Lobeliaceae - Lobelia family

Lobelia splendens - Cardinal flower o red lobelia

Lobelia gruina - Blue lobelia

Primulaceae - Primrose family

Dodecatheon - all species - Shooting star

Primula - all species - Primrose

Ericaceae - Heath family

Artostaphylos uva-urse - Bearberry, kinnickinick [kinnikinick]

Gentianaceae - Gentian family

Gentiana elegans - Fringed gentian

Gentiana barbellata - Fringed gentian

Gentian affinis - Closed gentian

Violaceae - Violet family

Viola adunca - Blue violet

Viola nephrophylla - Blue violet

Viola pedatifida - Blue violet

Viola pinetorum - Yellow violet

Viola missouriensis - Blue violet

Protulacaceae - Purslane family

Claytonia lanceolata - Spring beauty

Malaceae - Apple family

Sorbus scopulina - Mountain ash

Polemoniaceae - Phlox family

Gilia aggregata - Jilly flower

Orchidaceae - Orchid family

orchids - all species

Crassulaceae - Orpine family

sedum - all species (commonly known as stonecrop)

Saxifragaceae - Saxifrage family

all species

Epilobiaceae - Evening primrose family

Chamaenerion angustifolium - Firewood

Cornaceae - Dogwood family

Cornus instolonea - Cornel

Hederaceae - Ivy family

Aralia bicrenata - Aralia

Asclepias tuberosa - Butterfly weed

Scrophulariaceae - Figwort family

Castellejia integra - Indian paint brush, painted cup

Cactaceae - Cactus family

Peniocereus greggii - Night blooming cereus

Echinocereus - all species - Porcupine cactus

Ferocactus - all species - Barrel, bisnaga, or visnage cactus

Echinocactus - all species - Hedgehog cactus

Scherocactus - all species - Hedgehog cactus

Coryphantha or Mammillaria - all species - Pincushion cactus

Phellosperma or Mammillaria - all species - Fishook cactus

Neomammillaria or Mammillaria - all species - Fishhook cactus

Opuntia stanlyi - Stanly's cholla

all plants growing within four hundred yards of any highway, except noxious weeds.

Appendix I
Texas Plants Protected Under the Endangered Species Act

Cactaceae - Cactus family

1) *Ancistrocactus tobuschii* (*Echinocactus tobuschii*, *Mammillaria tobuschii*) - Tobusch fishhook cactus

   On limestone; amoung junipers, oaks and grasses at about 1500 feet elevation. Edwards Plateau of Texas in Bandera County near Vanderpool (Lundell, 1969)

2) *Coryphantha minima* (*C. nellieae*, *Escorbaria nellieae*, *Mammillaria nellieae*) Nellie cory cactus

   Grassy hills at 4,000 to 4,400 feet elevation. Northeastern Brewster county, Lundell 1969).

3) *Coryphantha ramillosa* - Bunched cory cactus

   Discovered in Reagan Canyon Big Bend country in Texas (Cutak, 1956). Near Rio Grande in Brewster and southern Terrell counties. On limestone in the desert at 2,500 to 3,500 feet (Lundell, 1969).

4) *Coryphantha sneedii* var. *leei* (*Escobaria leei*, *Mammillaria leei*) - Sneed pincushion cactus, Lee pincushion cactus

   Grows on limestone in the desert at 4,000 to 5,000 feet (Lundell, 1969).

5) *Echinocereus lloydii* (*E. rotteri* var. *lloydii*) - Lloyd's hedgehog cactus

   Found on sandy or gravelly soils in the desert at about 3,000 feet elevation. In Texas, found near Tunas Springs in Pecos County (Lundell, 1969).

6) *Echinocereus reichenbachii* var. *albertii* (*E. milanocentrus*) - Black lace cactus

   Found near Alice in Jim Wells County (Lundell, 1969).

7) *Echinocereus viridiflorus* var. *davisii* (E. *davisii*) - Davis' green pitaya

   Found in rocky crevices in grassland; stems mostly subterranean and often covered by low-growing plants such as *Selaginella*. Near Marathon, Texas (Lundell, 1969).

8) Neolloydia mariposensis (Echinocactus mariposensis, Echinomastus mariposensis) Lloyd's Mariposa cactus

Found near town of Mariposa, Texas (Innes, 1977). Found on limestone in the desert at 2,500 to 3,300 feet elevation; near Rio Grande in Presidio County (Lundell, 1969).

Poaceae - Grass family

9) Zizania texana - Texas wild-rice

Known only from the vicinity of San Marcos, Hays County, where it grows in the cool, fast flowing, spring-fed waters of San Marcos River near its source (Gould, 1975).

Part C

GOVERNMENT AGENCY SUPPORT

The following is a brief overview of some of the important areas of research and development of hydrocarbon and rubber producing plants in which the U.S. government is currently involved.

1.0 Federal Emergency Management Agency

The Defense Production Act of 1950 (64 Stat. 798) provided the legal basis for the federal government's authority to mobilize the nation's economy in time of war. As a result of this act, FEMA (Federal Emergency Management Agency) is given the authority to determine which materials are strategic and critical and to calculate the stockpile goals for those materials. The goals are estimates of the United States vulnerability to shortages of strategic and critical materials. The General Services Administration (GSA) is responsible for the purchase of critical and strategic materials.

The goals are based on the amount of that resource that would be required during a conventional three-year war. For every ton of material that is produced domestically, the stockpile requirement is reduced by three tons. Therefore, FEMA's policy is that it is more cost effective to encourage the domestic production of strategic and critical materials, where possible, rather than purchase additional resources for stockpiling (Hall, personal communication).

The agency has $100 million to purchase the 62 identified critical and strategic materials, most of which are metals (they purchased 1.2 million pounds of cobalt in 1981--Morozek, personal communication; Natural Rubber News, May 1981b).

1.1 Jojoba*

FEMA is considering the use of jojoba oil as a replacement for castor oil. Castor oil is on FEMA's critical and strategic materials list: It is used as a lubricant. Sperm oil is far superior to castor oil as a lubricant and can be substituted for all strategic and critical uses of castor oil

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*Chip Hines, FEMA, was the source of information in this section unless otherwise indicated.

(Hines, personal communication; Miwa, personal communication), but it is illegal to use sperm oil in the United States. Because jojoba oil is chemically very similar to sperm oil and can be substituted for sperm oil (NAS, 1977b), it is likely that any domestic production of jojoba oil could justify a reduction in the stockpiling of castor oil.

Castor oil was last produced in the United States in 1976, when USDA's price supports for castor oil ended. Our current supply comes from India and Brazil. If jojoba oil can in fact replace castor oil, then for every pound of jojoba produced domestically, 3 pounds of castor oil would be deleted from the stockpile requirement.

As shown in table 1-1, the equivalent of 9.5 million pounds of castor oil remains to be stockpiled. Since it costs about 45¢ per pound, this represents almost $4.3 million.

Table 1-1. Castor Oil: Stockpile Goals and Equivalent

Substance	million pounds	
	FEMA Stockpile Goal	Current Stockpile
Castor oil	22	none
Sebacic acid*	8.8	5
Castor oil* equivalent	22	12.5
*It requires 2.5 pounds of castor oil to make 1 pound of sebacic acid.		

1.2 Guayule**

Natural rubber is included on FEMA's list of strategic and critical resources (Morozek, personal communication). The current goal is to stockpile 850,000 long tons (952,000 short tons) of NR. After the sale of 500

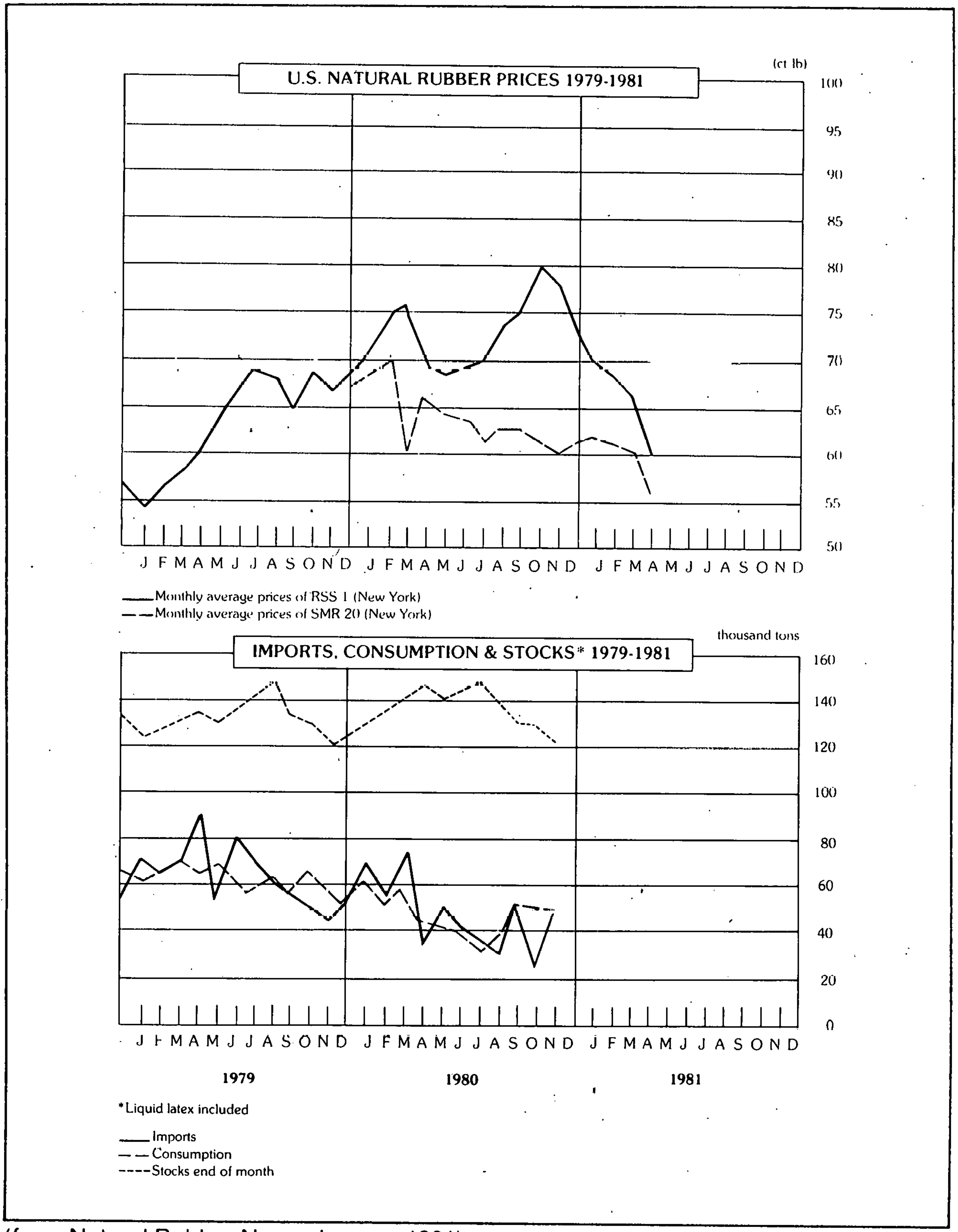
**Unless otherwise documented, the source for information in this section was Larry Hall, personal communication.

long tons in April (Malaysian Rubber Bureau, 1981b), FEMA has less than 119,000 long tons stockpiled. Therefore, to make up the deficit, FEMA must either purchase over 731,000 long tons of Hevea NR, or produce 250,000 long tons of domestic guayule NR.

Currently, FEMA's preference is to support domestic production of rubber, where possible, rather than to stockpile Hevea. FEMA's reasons for this policy are based on both the Hevea supply and price situation. All Hevea rubber produced is consumed; therefore, a surplus is unlikely. In addition, the price of Hevea rubber may be volatile, but it is consistently high. For example, the price in 1980 ranged from about 68¢ per pound to 80¢ per pound (see figure 1-1). The price in 1981 has been generally lower than in the previous year, but even at 58¢ per pound (Wall Street Journal, June 8, 1981) the cost to purchase 731,000 long tons of Hevea rubber for stockpile would be about $950 million for the rubber alone. At 65¢ per pound of rubber, this cost rises to over $1 billion.

To date, FEMA has not purchased any NR, although it is a very high priority item (Morozek, personal communication). Further, FEMA has been unsuccessful in convincing OMB (Office of Management and Budget) of the need to support guayule commercialization. In 1980, FEMA submitted a proposal for a 10-year $200 million project, which included building a processing plant. The proposal was not funded (Blundell, 1981), but it is being resubmitted this year.

FEMA is developing purchase specifications for guayule, although it has no budget to do so. If FEMA's budget for guayule is approved this year, they plan to examine the long term storage of guayule rubber as well as support research and development projects, and planting of guayule. FEMA will also investigate a guaranteed purchase program to ensure a market for guayule NR.



(from Natural Rubber News, January 1981)

Figure 1-1. Monthly Fact Chart on U.S. Natural Rubber Price/Supply Status

2.0 USDA*

The Joint Committee on Guayule Research and Commercialization (Joint Commission) was established by the Native Latex Commercialization and Economic Development Act of 1978 (P.L. 95-592 92 Stat. 2529). The Secretary of Agriculture is the chairman of the Joint Commission, which also includes representatives from USDA, the Department of Commerce, the Bureau of Indian Affairs (Department of Interior) and the National Science Foundation.

The bill authorized $30 million for appropriation by the Secretaries of Agriculture and Commerce during fiscal years 1980 to 1983. To date, no funds have been requested by the USDA under the Native Latex Act; however, USDA plans to request funds under the Act for FY 83. In 1981, USDA's own budget for guayule is $1.7 million. It is $2 million for 1982, and the 1983 budget has not been determined.

USDA is currently focusing on a seed program. The two goals of this program are to certify seed, that is, to establish the amount of rubber that can be expected from different varieties of guayule, and to increase the amount of seed available for planting.

2.1 USDA Certified Seed Increase Program

USDA has determined that 8 of the 26 known varieties of guayule are high rubber producers. These varieties are adapted to different environments, so the variety planted by a grower will depend upon where the plant is to be cultivated.

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*Information in this section obtained from personal communication with Wheaton, USDA.

Certified seed is guaranteed to be a true relative of foundation seed, which is the product of breeding by plant scientists at land-grant universities. The amount of foundation seed is increased by the agricultural experimental stations and by the state crop improvement associations.

2.2 Seed Increase Program

USDA began their seed increase program with three pounds of guayule seed (350,000 seeds per pound). USDA's plans for 1981 are to plant about 100 acres of guayule seedlings. Twenty-five acres have been or will be planted by Agricultural Experimental Stations in four states: Marana, Arizona; 50 miles south of Las Cruces, New Mexico; Pecos, Texas; and California. The seed from this planting will be used to plant more guayule seedlings in 1982.

Ultimately, the seed produced from this program will be available through the State Crop Improvement Program, which will sell the seed.

Once enough seed is available for 20,000 acres of guayule, which is sufficient to supply a pilot processing plant, USDA plans to cease their guayule operations.

2.3 Rubber Yields

USDA expects to obtain a rubber yield of 1,500 pounds per acre after four years of growth (375 pounds per acre per year). This is less than reported yields from the ERP (400 pounds per acre per year). However, USDA feels that reported ERP yields may have been overstated.

3.0 Department of Defense

The Department of Defense has been and perhaps still is involved in testing guayule rubber for critical and strategic uses, but their representative declined to comment.

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