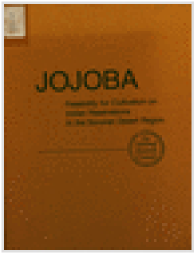

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JOJOBA

Feasibility for Cultivation on Indian Reservations in the Sonoran Desert Region

Committee on Jojoba Production Systems Potential
Board on Agriculture and Renewable Resources
Commission on Natural Resources
National Research Council

NATIONAL ACADEMY OF SCIENCES
1977

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In 1971, a project was initiated by the federal government to determine if the desert shrub jojoba (*Simmondsia chinensis*) could be utilized by Indians in California and Arizona. The plant grows wild, scattered over thousands of acres of reservation land belonging to San Carlos Apache, Papago, Pima, and several California tribes. Because the jojoba nut contains large quantities of a liquid wax whose chemical structure is unlike any other vegetable oil, it was thought to have potential as a raw material for industry.

The project was first supported in 1971 by the Office of Economic Opportunity and was later continued by the Office of Native American Programs (ONAP) of the U.S. Department of Health, Education, and Welfare and by the Bureau of Indian Affairs of the U.S. Department of the Interior.

In the summer of 1972, more than 87,000 pounds of jojoba nuts were harvested from the San Carlos Apache reservation in Arizona and from several small reservations in Southern California. The nuts were processed by the U.S. Department of Agriculture and the liquid wax was made available through the University of Arizona to over 200 industries worldwide for analysis, testing, and product development. At the request of ONAP, the Office of Chemistry and Chemical Technology of the National Academy of Sciences (NAS) undertook a study of the results. The conclusions were published in the NAS report *Products from Jojoba: A Promising New Crop for Arid Lands*, an updated version of which is reprinted as Part III of this report.

In that report, the Committee on Jojoba Utilization concluded that "jojoba oil and its hydrogenated product have marketable properties"; that "jojoba oil resembles sperm oil in chemical composition and physical behavior"; and that "jojoba could become the basis for viable Indian-owned and Indian-operated industries." Thus, the report suggests that an Indian jojoba agro-industry would be feasible.

However, that committee was not constituted to consider the market possibilities and how jojoba might be produced in the quantities needed to meet industry's demand. Accordingly, in 1975, ONAP requested the Board on Agriculture and Renewable Resources of the National

Research Council to analyze the production of jojoba nuts, including its commercial feasibility and relevance to Indian economic development.

This report was produced by the Committee on Jojoba Production Systems Potential made up of agronomists, chemists, ecologists, engineers, economists, and Indian tribal representatives, all familiar with jojoba or with related subjects relevant to the Committee's mandate. The Committee formulated the report at a meeting in Ensenada, Baja California, Mexico, February 13-14, 1976, held in conjunction with the Second International Conference on Jojoba and Its Uses.

Written for administrators making decisions on Indian economic development, for tribal leaders, and others interested in the potential of jojoba production, the report is not intended as a detailed technical treatise on jojoba production. Rather, it is a general analysis of the current knowledge, problems, and research relevant to the cultivation of jojoba on Indian lands.

Thanks are due Mr. William P. Miller of the Bureau of Indian Affairs, who shared his findings and opinions with the Committee and assisted in producing the report.

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SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR RESEARCH AND DEVELOPMENT

SUMMARY

The desert shrub jojoba (*Simmondsia chinensis* [Link] Schneider) grows naturally over an extensive area in the Sonoran Desert that covers parts of Arizona, California, and Mexico. Jojoba nuts contain a yellowish, odorless, oily liquid (about 50 percent by weight) with unusual properties, commonly referred to as "jojoba oil." Chemically, the oil is a liquid wax made up of nonglyceride esters having a narrow range of chemical composition; the esters are almost entirely composed of straight-chain acids and alcohols.

This unique liquid wax (hereafter referred to as oil) has a wide variety of industrial applications in lubricants, paper coatings, polishes, electrical insulation, carbon paper, textiles, leather, precision casting, cosmetics, and pharmaceuticals. Jojoba oil can be hydrogenated to a hard, colorless solid (wax) resembling spermaceti, carnauba wax, and beeswax in both chemical structure and properties. New industrial uses are being considered for this solid wax, including food coatings, polish, and candles.

With funding for agricultural improvement, all indications are that jojoba can be cultivated successfully and economically on Indian reservations in the Southwest. The Indians have expressed a strong interest in cultivating the plant and developing an industry to produce the oil. The harvest of natural jojoba nuts will help supply research and development materials, as well as low-volume, high-value commodities, until the plantations can supply the commercial demand for the oil. Research emphasis must be placed, however, on the establishment of plantations; the future of a jojoba industry lies in developing the natural shrub into a cultivated plant.

The following conclusions and recommendations for research and development have been drawn by the committee for the establishment of a jojoba production system.

CONCLUSIONS

Agricultural Development of Jojoba

1. The future of a jojoba industry lies in developing the natural shrub into a cultivated crop.

Establishing plantations is the key to jojoba's commercial development. However, the reservations where jojoba grows naturally lack their own capital and technical expertise; therefore, the committee strongly endorses federally financed programs aimed at establishing jojoba plantations on Indian lands. Because jojoba is a native desert shrub with low water requirements, it is better suited to the desert environment than conventional crops.

Nevertheless, plantations must be established cautiously. The sites should be chosen where the shrub has the best chances for survival--where frost is slight, and where soil conditions are favorable. Jojoba has almost miraculous abilities to withstand the high salinity and high boron content of the soils, drought, and other conditions of arid lands that are lethal to most plants. But until we better understand its ability to become domesticated under these conditions, commercial planting should only be attempted under the most favorable conditions. Test plots on widely different marginal soils and climates in reservations in California, Arizona, New Mexico, Nevada, and other states are, however, recommended.

A major disadvantage in the establishment of plantations is the time required for the shrub to bear nuts. When this time is reduced, jojoba will become an exceptionally attractive commercial proposition.

2. International scientific cooperation will greatly facilitate development of a successful jojoba agro-industry.

To domesticate a natural shrub into a crop plant suitable for agricultural production under man-made conditions is a scientific challenge. The talents and resources of all jojoba researchers will be required to achieve this goal. For the rapid development of jojoba as a successful commercial crop, researchers must cooperate and collaborate openly and frankly, sharing information on successes and failures, as was the case in two international conferences on jojoba and its utilization (June 1972 in Tucson, Arizona, and February 1976 in Ensenada, Baja California, Mexico). These meetings and others have brought together researchers from the countries that are spearheading jojoba development: Mexico, Israel, and the United States. In this regard, the committee endorses the efforts of the International Council for Jojoba Development and its sponsors: The CONACYT (Consejo Nacional de Ciencia y Tecnologia), the University of Arizona Office of Arid Lands Studies and the Department of Plant Sciences of the University of California in Riverside.

It is important that the government agencies that have sponsored research in the three countries, and the Indian tribes in the U.S., recognize that each has much to gain by sharing knowledge on jojoba plantation development. The eventual market demand for jojoba products appears great enough that all may benefit, and in the pioneering effort to develop jojoba agriculture inputs from different research fields, from industry and academia, and from different countries, will be needed for success.

3. <u>Jojoba has the characteristics and market potential needed to establish an agro-industry</u>.

Although more information is needed on jojoba's cultural requirements, there appear to be no fundamental technical barriers that will prevent domestications. Although the magnitude of yields cannot be accurately predicted at this time, no apparent difficulties exist with respect to past harvesting, and processing the nuts.

The physical and chemical properties of the jojoba oil from different plants and from year to year has sufficiently low variance that industry can expect a product with uniform and predictable properties. In many arid and semi-arid locations, jojoba, because of its drought tolerance, is likely to succeed economically where conventional crops fail.

The demand for oil and wax currently exceeds the supply and is large enough to support substantial jojoba plantations; the market price is high enough to make them profitable when the plant is successfully domesticated. Among the natural populations, there is ample genetic material to support the development of cultivars.

4. <u>As a plantation crop jojoba appears to be commercially attractive</u>.

Although some uncertainty clouds any estimate of the costs of producing jojoba products, on balance cultivation of the shrub seems to have a high probability of being an economically viable and attractive agricultural investment. This is especially true for Indian reservations because the land does not have to be purchased or leased.

In general terms the economic picture can be judged by comparing jojoba's costs to those of other plantation crops:

• The costs for establishing and maintaining jojoba plantations should be of similar magnitude to the equivalent costs for other plantations crops (almonds, pistachios, fruit trees, macadamia, etc.).

• The 3-5 year period between planting and first harvest applies to many tree crops (e.g., apples and oranges).

• Jojoba's harvesting costs are not expected to differ markedly from those of comparable crops such as almonds.

• Jojoba nuts have soft skins; no shelling is required. The dried hulls that sometimes cling to the nut are thin, brittle, and easily separated.

Thus at no point in the production of jojoba nuts are any exceptional expenses expected.

On the other hand the expected market value of jojoba oil and of the projected per-acre yields strongly suggest that jojoba can at least equal the profitability of other crops. This is because established 10-13 year old plantations with uniform, good-yielding shrubs (i.e., annually producing at least 2.3 kilograms per shrub) should produce about 0.75 metric tons of jojoba oil per acre. At a selling price of $.40/lb a gross income of $800 per acre is projected. This considerably exceeds the expected gross income from other crops. Furthermore, both the yield and the selling price used in this estimate seem to be conservative figures. That such income might be obtained in semi-arid regions where few crops can be grown successfully makes jojoba attractive for the southwestern states.

5. The development of a jojoba industry has important national implications.

The jojoba plant provides a method for harnessing solar energy to produce raw materials for the nation's industries. It is a renewable natural resource, which from all indications can be produced in a sun-rich corner of the U.S. on marginal, arid land, where little or no conventional agriculture can be practiced economically.

Jojoba could become an important crop in the southwestern U.S., where large areas are not well adapted to conventional dryland or irrigated agriculture. The shrub's low requirement for water and high tolerance of salt (which is frequently found in arid zone irrigation water and which adversely affects the growth of many crop plants) may allow marginal arid lands to be cultivated productively. Furthermore, if in some areas irrigation is required, it will be needed during winter months--when jojoba begins to set its fruit--and not during the summer when water is most scarce and most in demand for conventional agriculture. Unlike other crop plants, jojoba is adapted to the summer desert heat and to summer aridity, which have little adverse effect on its production of nuts.

The oil from jojoba nuts shows great promise as a base for high performance lubricants used in mechanisms that develop extreme pressures, temperatures, and wear. There are now indications that it makes a lubricant base superior to that derived from sperm oil. In the recent past, sperm-oil-based lubricants were designated as strategically important to the U.S., and sperm oil was stockpiled against national emergency. With the current ban on sperm oil imports, jojoba may prove a strategically important national resource. Furthermore, as a renewable natural resource and as a possible source of alcohols and esters, it could eventually provide substitutes for some petroleum-based products.

Jojoba Production on American Indian Reservations

6. The first step in establishing an Indian agro-industry based on the jojoba plant is to develop a master plan.

To develop a profitable jojoba based agro-industry is a complex, intricate and lengthy process and to specifically detail this process is beyond the scope of this study. Therefore, the committee suggests that this study, which outlines the production and market potential, be immediately followed with the development of a government financed agro-industry jojoba production system master plan and a socioeconomic and technological impact study to determine the consequences of developing large-scale jojoba agro-industries on Indian reservations.

The master plan must be objectively developed and be based on an economic analysis of the financial feasibility of jojoba agro-industries, emphasizing financial risk and projected return on the grant and loan investments.

The general objective of the socioeconomic and technological impact study should be to evaluate the growth and consequences of an Indian reservation-based jojoba agro-industry. Specifically, the study should identify and evaluate the consequences of the projected commercial potential and impact in the economic, social and environmental areas, and identify strategies to alleviate problems that may hinder the development of this industry or to neutralize its impacts.

7. Strong interest exists on American Indian reservations and in industry for the development of a jojoba production system.

The name jojoba derives from an Indian word, ho-ho-wi. Indians in the Sonoran Desert have long used the plant in many ways: for example, as a source of food (roasted, the nuts taste very much like coffee beans) and as a medicinal oil for skin problems. Today jojoba grows naturally on a number of reservations in Arizona and California, where the Indian people have been receptive to the idea of jojoba development; it is not alien to their culture as are some industrial projects.

Several tribal governments in the jojoba region have resolved to endorse the development of the shrub on their lands and have earmarked thousands of acres for jojoba plantations; some tribes are already committing their own scarce funds to the task. During the last 4 summers over 1,000 Indians participated in harvesting jojoba bushes growing wild on their reservations.

8. Jojoba can be cultivated successfully and economically on Indian reservations in the Southwest.

Jojoba is a shrub that is native to the Southwest and is therefore suited to the harsh, arid, marginal conditions on the reservations. It is a crop that can be cultivated either on a small scale with labor intensive techniques or *en masse* with mechanization. As evolution from small-scale production to full mechanization will require several years, Indian tribes can develop the necessary expertise and organizational infrastructure to participate in all aspects of the development process.

All indications are that jojoba can be produced by current agricultural techniques and that these can be applied on reservations. Furthermore, nut processing can be carried out and products manufactured on reservations. The committee feels that a cultivated jojoba system has potential for providing jobs, income, and economic development for many now-impoverished reservations.

9. American Indian reservations must be given financial support in order to utilize the extensive, natural jojoba populations now existing on Arizona and California reservations.

Jojoba will become important on a commercial scale only when plantations are established to maximize growth and production. Jojoba, like tree crops, apples, oranges, olives, and avocados, requires several years before bearing commercial quantities of nuts. During the interim, the only source of jojoba nuts will be from the natural populations. Harvesting nuts from the natural plants that mostly grow on hilly reservation land is costly because it must be done by hand and is very inefficient and time-consuming. Consequently, the harvest of nuts from natural shrubs has to be sold at a high price. Nonetheless, there is a market demand for substantial quantities of the high-priced oil for a few specialty items such as candles and cosmetic ingredients. These can be marketed at close to cost and, in some cases, at a small profit.

The committee suggests that the federal government extend financial support that will allow Indian tribes to harvest, process, and sell the natural population product at prices more attractive to consumers. It also suggests that considerable effort and support be directed towards the improvement and exploitation of the natural shrubs available and the development of harvesting and management methods to maximize yields and reduce costs.

Jojoba cultivation is a sound investment of federal funds earmarked for improving the welfare and monetary income of tribes in the Southwest and consistent with the intent of the Indian Self-Determination and Education Assistance Act (P.L. 93-638). The chances are high that a viable long-term agro-industry can be established within 10-13 years that would provide jobs and income for the unemployed.

Restrictive regulations should be modified to permit Indians to harvest jojoba now growing on federal lands (Bureau of Land Management, Forest Service, and National Parks Service) in Arizona and California.

RECOMMENDATIONS FOR RESEARCH AND DEVELOPMENT

The committee in arriving at its conclusion that a commercial jojoba production system is feasible on Indian land in the Sonoran Desert expressed its concerns that new knowledge and techniques must be sought and on-going research strengthened in order to develop an economical jojoba agro-industry. The following research and development areas are considered the most important.

1. Research should be undertaken on the ecology of the jojoba plant.

- The natural stands should be quantified as to location, number of plants and annual variation of nut production and oil composition.
- Studies should be made of the response of the shrub to environmental factors in order to improve natural stands, such as pruning, supplemental irrigation, water harvesting, temperature, soil types, nutrient addition, weed control, animal protection, etc.

2. Techniques should be developed for breeding and propagation of jojoba and for better cultivation in plantations.

- Studies should be made of genetic improvement of jojoba through selection and cross breeding to produce plants with homogeneous high yield, predictability in plant and oil production, adaptation to plantation cultivation, salt tolerance, and cold resistance. Other areas for breeding include hermaphroditism (both sexes on the same shrub), multiple yields and early maturation. Research should be carried out to identify sex-linked characteristics that would allow early sex identification of a seed or seedling.
- Better propagation techniques are needed to reduce cropping time. Techniques should be developed for repetitive propagation for

rapid production of desirable, uniform, high yield varieties which would improve the production capacity for large plantations.

- Studies should be made of the optimum population density including the optimum male-to-female ratio of plants.
- Studies should be made of flowering and nut set. Pollen transport and viability should also be studied.
- Cultivation techniques should be developed for both natural stands and plantations. These techniques should apply to dryland agriculture, irrigation and fertilization.
- Cultivation methods should be developed to improve uniformity of maturity (unison of male and female flowering) and should include pruning and chemical treatment.
- Techniques should be developed for intercropping of other commercial crops with the developing jojoba plants.

3. Techniques should be developed for harvesting and handling of the nuts.

- Methods and equipment should be adopted from present technology for harvesting both natural and plantation grown nuts.
- Methods should be developed or adopted from present technology for cleaning, handling and storage of nuts.

4. Research and development studies should be undertaken in relation to an Indian jojoba agro-industry.

- An institutional model should be developed.
- Studies should be undertaken on the technological impact of an agro-industry on the Indians of the Sonoran Desert.
- Studies should be undertaken on Indian manpower development such as scholarships, scientific and technical training, and management training.

PART I

AGRICULTURAL DEVELOPMENT OF JOJOBA

INTRODUCTION

A natural desert plant, jojoba (*Simmondsia chinensis [Link] Schneider*, also known as *Simmondsia californica*) is native to the Sonoran Desert of northwestern Mexico and to neighboring regions in Arizona and Southern California. Nowhere else in the world does it grow as a native plant, but within this region it exists, often in dense stands, scattered over 100,000 square miles of arid lands, where soils are usually infertile and rainfall varies 10-50 cm (4-20 inches) annually (Figure 1).

It is an unspectacular looking shrub that may reach 4.5 m (15 feet) in height. Its flat, gray-green, leathery leaves appear well adapted to withstand desert heat and aridity and this, together with a deep and extensive root system for tapping all available soil moisture, allows jojoba plants to survive and grow where most plants wither and die.

The soft-skinned nuts produced by jojoba have long been used by Sonoran Desert Indians as food (roasted, they smell and taste like roasted coffee beans) and as medicine (Figure 2). Like the seeds of many plants, the nuts contain a vegetable oil that is yellowish and odorless but feels less oily than traditional, edible oils. In jojoba the oil comprises a good portion of the nut: half the weight of an average nut is oil, and in some cases the oil content may be as high as 60 percent. The oil has a radically different chemical structure from any other known vegetable oil. Chemically it is a liquid wax free from the glyceride esters that make up peanut oil, soybean oil, olive oil, and other common vegetable oils. Instead, jojoba esters are entirely composed of straight-chain alcohols. Both the acid and the alcohol portions have 20 or 22 carbon atoms and each has one unsaturated bond. Thus, jojoba oil is a polyunsaturated liquid wax that is readily obtainable from a renewable resource. Waxes of this

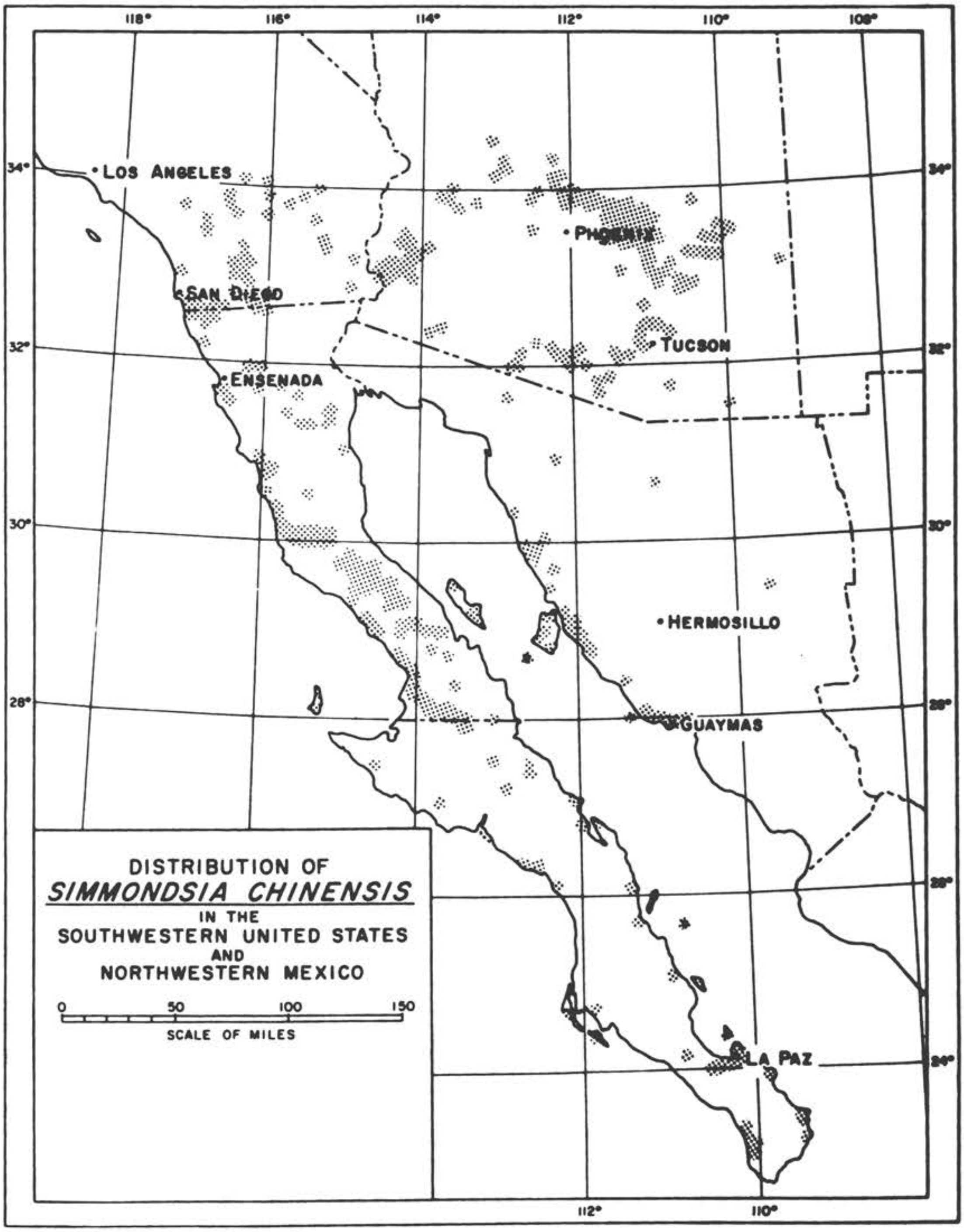

FIGURE 1. Distribution of Simmondsia chinensis. (Courtesy of the Office of Arid Lands Studies, University of Arizona.)

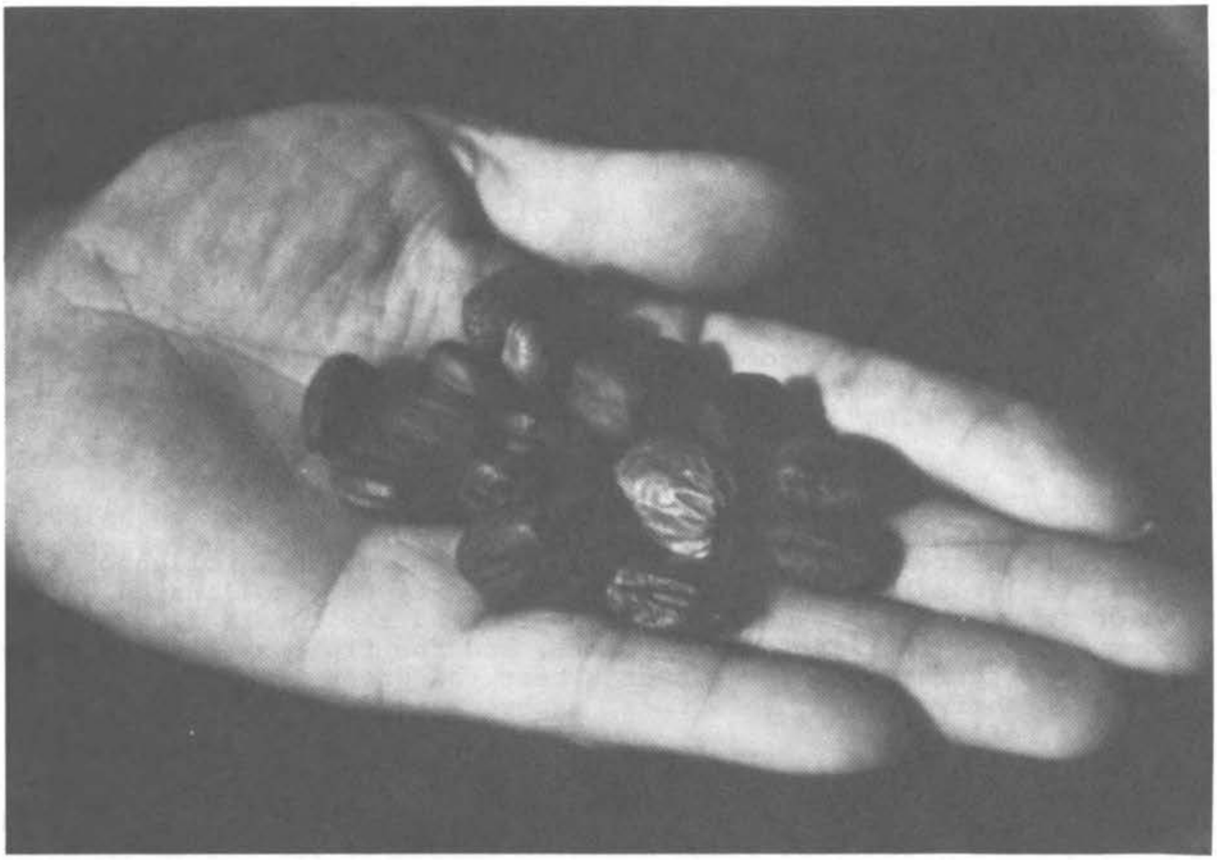

FIGURE 2. Jojoba nuts.
(Courtesy of N. D. Vietmeyer.)

type are difficult to synthesize commercially*; for decades the only source has been the sperm whale. However, despite this single source, liquid waxes have become industrially important and in 1975 about 20,000 sperm whales were killed to supply the demand from industry, the military, and space programs. Sperm whales have become the most hunted species of whale.

The liquid wax from the sperm whale is called sperm oil. Its chemical structure is so like that of jojoba oil that the two were termed "virtual duplicates" by the NAS Committee on Jojoba Utilization (NRC 1975).

Oils and waxes are used in many industries and in a wide variety

*This synthesis has been researched for five years by the U.S. Department of Agriculture. The starting materials are normal glyceride esters from crambe (Crambe abyssinica) and meadow-foam (Limnanthes douglasii). These esters must be partially hydrogenated and then hydrolyzed. Half the resulting fatty acids are reduced to fatty alcohols, which are then esterified with the remaining half of the acids to form a wax ester. (Technical difficulties encountered in these steps have so far kept the process from becoming practical.) Jojoba stands alone as a plant that itself produces wax esters that need no chemical modification.

of applications, but the major sperm oil use has been in lubricants for extreme pressure situations, such as in automobile transmissions. Jojoba oil has been shown to duplicate sperm oil's lubricating properties and a growing body of extensive test data indicates that it has major potential in other industries: the cosmetics industry, the textile industry, the leather industry, and the production of penicillin and other antibiotics.

Like other vegetable oils, jojoba oil is a liquid; but when hardened by hydrogenation (the process that produces margarine from liquid oils), it forms a dense solid of sparkling, white crystals. This solid is generally called "jojoba wax." It resembles spermaceti (which also comes from the sperm whale), carnauba wax, and beeswax in chemical structure and properties. It has a high melting point of 158°F (70°C) and a hardness that approaches that of carnauba, which has become the "king" of waxes because of this property.

THE PLANT

Jojoba shrubs are either staminate ("male") and produce pollen or pistillate ("female") and produce flowers that, when pollinated, develop into fruit. Generally, the pollen and the female flowers are produced during the late summer months, and the fruit swells and grows through the spring. In the summer's heat the green fruit dries, its outer skin shrivels and peels back, exposing a wrinkled brown nut the size of a small olive.

In areas of low rainfall, 2-3 inches (50-75 mm) and low soil fertility, jojoba plants range from 2-4 feet (0.60-1.20 meters) in height; in areas of higher rainfall, 16 inches (40 cm) and medium soil fertility, the height may reach and even exceed 10 feet (3 meters); in coastal areas jojoba acquires a prostrate growth habit following the soil contours practically to the waterline. Although jojoba of inland populations are, in general, bushy and hemispherical in shape, it is not difficult to distinguish several types of growth habit in relation to number of branches, as well as length and diameter of branches. Variability is also obvious in terms of leaf size and shape, leaf color, number of flowers per infloresence, sequence of flowering nodes, shape and size of nuts, date of flowering, and maturity of nuts.

Jojoba floral buds start to appear in the winter or spring or even in the fall following summer rains. Flower bud inhibition, due to unknown factors, may persist through several to many months. These buds remain in a dormant condition until the weather starts warming at the end of the following cold season; then, male flowers start to enlarge, turn yellowish and finally release their pollen; female flowers develop at a somewhat slower pace; they swell and in a few weeks acquire a diameter of about 3-5 mm. If pollen is available when the female flowers become receptive, and they are fertilized, nuts develop which continue to grow in size until they reach maturity sometime during the summer.

Jojoba flowers have no petals or odors to attract pollinating insects. Although bees are often observed feeding on the male flowers, they are rarely seen to visit female flowers. Thus, jojoba depends almost entirely on wind pollination.

The nut yield of individual shrubs fluctuates greatly from shrub to shrub and from year to year. Yields of up to 12 pounds (5 kg) of clean, dry nuts per shrub have been recorded. Oil content of the nut ranges from 42-60 percent. Both nut yield and oil content seem to be strongly influenced by environmental factors. No technique is yet available to determine the age of jojoba plants. The large number of factors that contribute to yield of nut and oil per plant makes it difficult to identify with certainty superior jojoba genotypes to be used as sources of parental material for propagation.

The jojoba nut does not go through a period of dormancy and it can be germinated soon after harvesting. At about 77°F (25°C) germination occurs in less than a week. Stem and apical softwood cuttings of jojoba treated with a fungicide and a rooting hormone produce roots within 8 weeks in mist propagation chambers kept at about 72°F (22°C). Tissue culture techniques have also been developed, and are suitable for commercial propagation of jojoba.

ECOLOGY OF NATURAL JOJOBA STANDS

Studies of the environmental parameters in the natural range of jojoba can assist us in gauging where jojoba may be successfully cultivated. Among the many environmental factors that determine the distribution of the natural jojoba populations are several that are direct or primary.

1. In the north and east of its range, jojoba is confined within a geographical zone where winter low temperatures rarely drop below 19°F (-7°C). Like many other organisms, jojoba is most vulnerable during certain stages in its reproductive cycle. Light frosts of a few degrees below freezing are frequently lethal to young seedlings although the older woody plants are not seriously injured. Flowers are also damaged by frost and this curtails the production of nuts. The establishment of new jojoba plants in the colder margins of the jojoba populations appears limited to those climatic cycles when benign winters are synchronized with adequate moisture for seedling establishment.
2. Within the desert jojoba is not found in areas having less than 5-6 inches (12-15 cm) of annual average rainfall, except in special sites where runoff from higher slopes and regular maritime fogs increase moisture to the jojoba subsistence level.
3. In other peripheral areas, where jojoba is not limited by low winter temperatures and low rainfall, the controlling or confining factor appears to be competition with other plants. Northeast of its range it is excluded by the denser growth of California chaparral, south of its range by the taller thorn forest with summer rainfall and dry winters.

Jojoba shows its best development in areas with 10-18 inches (25-45 cm) of annual rainfall, where temperatures seldom fall below 25°F (-4°C) for more than a few hours at night. Within this area it grows in diverse types of soil, from porous rocks to clays, in slightly acid to alkaline soils, on mountain slopes and in valleys. But it is always found on well-aerated soils, never on wet lowland or marshy sites. It is also not found on vast open plains within its natural area. Therefore, while jojoba is broadly preadapted to many types of soils, there are certain types, not yet well defined, where it may not be successfully cultivated without excessive soil amendment.

The animal and plant associates of jojoba are secondary control factors. Some of these are significant for plantation planning. Most are deleterious to jojoba and some of them in the geologic past may have constituted a survival threat (Gentry 1958) just as cattle grazing does today. Deer and rabbits are known to browse on jojoba, eating tender foliage and fruits; javelinas, rodents, and large birds eat the nuts. Jojoba plays host to an unknown number of insects: a bostrychid beetle chips off branchlets; a moth chews out the young ovules in fruits and, in certain years, destroys a great percentage of nut yield in the Pinal Mountain area of Arizona. This moth is the only known potential pest. Others, such as aphids, are a minor nuisance and easily controlled.

Among the few associates that may be of some benefit to the dispersal of jojoba are squirrels that disseminate and bury seeds and small thorny shrubbery that protect tender seedlings (Turner et al. 1966). The jojoba shrub itself is not suitable as nurse plant, as its foliage is too dense to allow sufficient light to penetrate.

The conditions prevailing in the natural jojoba stands provide guidance for establishing jojoba plantations:

1. Jojoba fields should be fenced to protect them from the ravages of both wild and domesticated animals.
2. Plantings should be kept clear of weeds, especially since jojoba is not a good competitor in its young stages.
3. Jojoba should be grown where rainfall is optimal (25-45 cm), preferably with a winter-spring distribution.
4. Plantations should be started only on soils that are determined as suitable to jojoba growth. We know little about soil requirements; therefore, soil investigations should be conducted for further guidance.
5. The layout of jojoba plantations should allow sufficient spacing between plants. Furthermore, young jojoba seedlings should not be interplanted with tall crops that may shade them.

In general, plantations should not be attempted in regions beyond the presently known limits of jojoba adaptation. Attempts to grow jojoba outside this region should be made only where agricultural methods can supply the proper environment. Natural stands of jojoba have a limited range of adaptation at present. It is reasonable to expect, however, that as it has been accomplished with many other crops, improved strains will be developed through breeding which could be grown profitably in a greater range of environments in response to agricultural and commercial needs. Jojoba is already being successfully cultivated beyond its geographical limits, as in central California, in Mexico, and as far away as Israel. As jojoba is improved by genetic selection and its cultivation improved by special knowledge, we can expect its tolerance to cold and to other soils to be greatly extended.

USE OF NATURAL STANDS

The potential clean-dry nut annual harvest from natural stands on Arizona Indian reservations alone is estimated as in excess of 100 metric tons; Mexico appears to have more than the U.S., California has significant stands on public and private lands, and Arizona has significant stands on Indian land. Conservatively, and without any attempt at yield improvement, the natural stands in Arizona, California, and Mexico will surely yield a clean-dry nut crop of 300-500 metric tons. The jojoba industry will almost entirely depend on this natural stand yield for 5-7 years after cultivated plantations are established. With improved yields, improved harvest techniques, and an increasing demand for the raw material, natural stands may potentially maintain their economic value indefinitely.

To use the natural stands effectively, two avenues of development must be explored: (1) increasing their yield and (2) decreasing the costs of harvesting them.

Improvements in plant development and substantial increases in nut yield following clearing of competitive vegetation, water, water harvesting, and pruning have been reported by Mexico. Similar observations have been made in the U.S. Additional research work should be done to evaluate the reported increases in yield. Studies are needed to indicate the true yield response to environmental factors--such as pruning, supplemental irrigation, temperature, nutrient addition, weed control, plant bruising during harvest, protection from browsing and burrowing animals, and to determine what factors can be manipulated to increase the natural crop yield.

It is currently possible to use the natural shrubs of jojoba, but the production of nuts from those stands, because of high harvesting costs, will go to small-scale manufacturers of low volume, high value products or to high volume products which use only a small portion of liquid wax. The natural stands should also be utilized as propagation material for plantations and the oil for additional industrial tests and new product development.

Prices of oil now are being established at $5.00 a pound in the U.S. and $38.00 a gallon in Mexico. The cost of harvesting nuts from natural stands in Mexico is $1.13-1.50 a kilogram plus the cost of handling and transportation. In the U.S., harvesters have been paid $1.10 per pound of green nuts. Besides the expense, there are other difficulties involved in using nuts from stands: (1) manpower at time of harvest; (2) accessibility to the place where jojoba grows; and (3) lack of basic services for the harvesters--water, food, and storage.

All of these situations increase the cost and pose personnel management problems. These extra costs have to be paid by funds from the federal government or have to be paid by the industrial user of the oil and by the consumer. If the fact that natural stands of jojoba do not assure a predictable supply due to environmental factors and other considerations are added, the commercial harvest of jojoba from natural shrubs becomes, over the long term, uncertain.

Decrease of harvest costs is the most critical factor in jojoba production. The harvesters must be paid a fair wage and cost reduction must come through increased efficiency not reduced income. An adaptation of simple mechanical aids such as the blueberry rake or vacuum cleaner to jojoba harvesting, might double or triple the harvest rate with obvious advantages.

<u>The committee believes that it is essential, even if large financial assistance is required, that as much as possible of the natural resource be harvested annually</u>. The nuts and wax should be stockpiled with only portions of it going to established users to ensure dependability of supply and sufficient material for continuing new product research. After 5-7 years, plantation output will increase the amount of material that can be released into the marketplace, and in 7-10 years the plantations should be providing the basic commercial product with natural stands of lesser importance.

PLANTATION ESTABLISHMENT

Successful establishment of plantations depends on the availability of superior genetic strains for plantings, on the development of suitable cultural practices, and on the design of efficient low-cost harvesting systems.

Genetics, Propagation, and Plant Breeding

The only source of seed available to jojoba breeders at present is the natural populations of California, Arizona, and Mexico. A survey of these populations shows great variability among plants within each population as well as among populations.

Although jojoba can be seeded directly to commercial fields a number of advantages can be derived from growing jojoba seedlings in containers in semi-protected areas until the seedlings reach a height of almost 30 cm, usually within 4-6 months. These seedlings may then be transplanted in the field preferably in the spring or fall. In hot and dry areas some irrigation will be necessary until the seedlings establish their root-system. Jojoba stems and roots are very brittle and may be easily damaged with careless handling. With proper care, success in transplanting of 6-24 month old seedlings exceeds 95 percent. If plants were derived from cuttings, plantations can be laid out with predetermined male to female ratios. If plants were derived from seed, there is no technique available yet for determining their sex prior to blooming. This difficulty can be circumvented, however, by planting 4-5 seeds per container and by removing unwanted plants after they bloom.

Land Preparation

Although continued research with jojoba may raise its productivity to the point that it could compete with some of our traditional crops on developed farm land, the first attempts to start plantations will be made on less productive, marginal lands where little else may grow. Such lands may require considerable preparation, such as removal of existing unwanted vegetation and rocks, levelling, level contour cultivation, ditches for water harvest and erosion control and leaching where soil salinity is high.

An irrigation system must be installed well ahead of transplanting. Favored systems appear to be furrow irrigation or drip irrigation. Optimum growth has been observed in areas with about 16 inches (40 cm) of annual precipitation. In view of the higher efficiency of drip irrigation systems, it would seem that 4-8 inches (10-20 cm) of irrigation water annually would be adequate in areas of negligible rainfall. There are indications that lower quality, brackish water could be utilized for irrigation under suitable cultivation conditions. Greenhouse experiments have shown that jojoba responds very favorably to nitrogen and phosphorus fertilization. Greenhouse experiments have also indicated that Dacthal and Chlorpropham (CIPC) can be used safely as herbicides on fields of extremely low organic matter content. With 30 percent or higher organic matter content, propazine and simazine may also be used.

Tall, upright, cone, or tree shaped jojoba plants are easier to harvest regardless of the harvesting system used. The growth habit of jojoba can easily and drastically be modified by pruning to satisfy the needs of a particular harvesting system (Figure 3).

With adequate soil moisture, jojoba shrubs have a 2 meter diameter when they are 6-7 years old. It appears that a 2 meter shrub-to-shrub spacing on the row would be advisable. Yield data from plantation experiments will tell in time whether this spacing will be maintained indefinitely or whether a number of shrubs will have to be removed around the 10th year to alleviate undesirable effects from excessive competition. Spacing between rows will probably range from 3-8 meters depending on shrub development and yield, equipment used, and system of management in each location.

Information on pollen dispersion is not available and, therefore, it is difficult to decide what the minimum number of male plants per acre should be. Since poor pollination would have disastrous effects, the early tendency will be to allow a high number of male plants such as a 1 male to 4 female ratio. To minimize the reduction in yield per acre because of the high number of males, a male plant should be planted along with every fourth female as shown in Figure 4.

Field plantings of jojoba respond very favorably to irrigation. New growth may be observed shortly after water is applied to the field. In view of the fact that new floral buds appear during the summer, bud formation is greatly enhanced by a light irrigation at that time. In areas with winter rainfall, poor rainfall seems to affect yields. In such cases, irrigation at the end of the cold season could prove useful.

Vegetative growth continues through the winter months provided temperatures do not dip much below freezing. At -5°C jojoba begins to suffer some damage due to freezing. The terminal 3-5 cm of branches wilt and gradually die; large numbers of flowers drop off, too. Occasions have been observed where a new flush of flowers appeared after an early killing frost. Late frosts, however, appear to lower seed yields drastically. Older plants (10 years or over) appear to survive temperatures lower than -5°C. Young seedlings, however, of less than 2 years appear to have very low tolerance to such

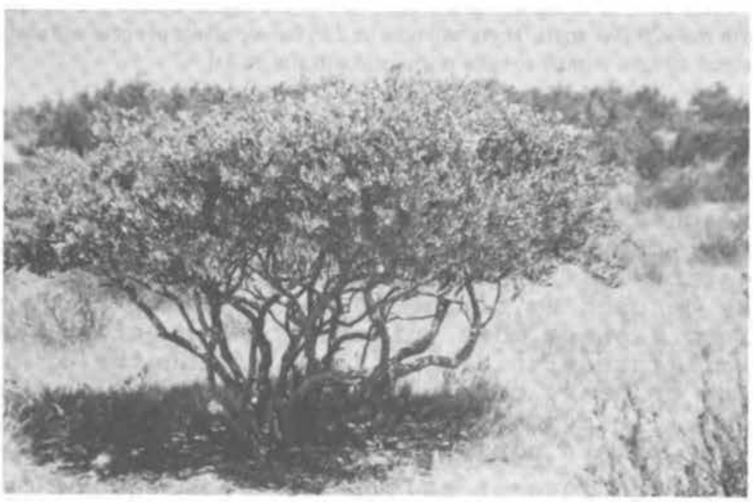

FIGURE 3. Jojoba shrub pruned for easy harvest. (Courtesy of D. M. Yermanos.)

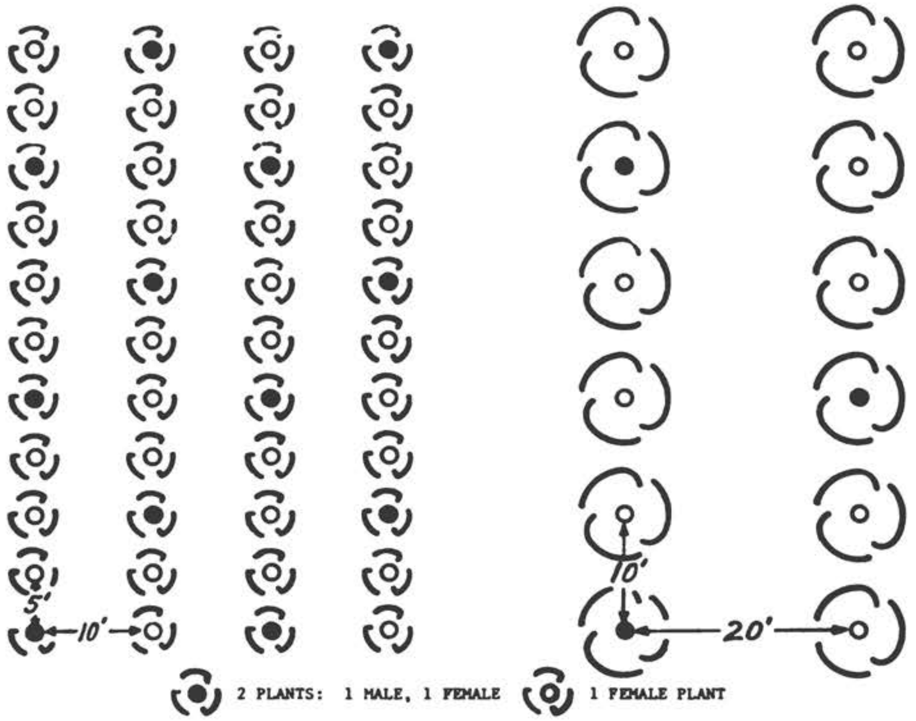

FIGURE 4 Potted seedlings will be transplanted to their permanent location in a plantation when they are about 6 months old, on rows spaced 10 feet apart. Spacing of seedlings on the row will be 5 feet. Every hill on the row will have one female plant, giving a total of about 900 female plants per acre. Every fourth hill on the row will have a male plant growing side by side with the female plant there, giving an over-all ratio of 4:1 female to male plants. With this layout, every female plant will have a male pollinator within at least 10 feet, as shown on the left half of the figure.

After about 10 years, shrubs will have developed to the point of crowding each other. Each row will now be a continuous wall of jojoba resembling a hedge. If this high plant density is not desirable for maximum yields, every other shrub may be removed. At the same time, every other row of jojoba may have to be removed. The layout would then be as shown on the right half of the figure. Shrubs will be spaced 10 feet apart on the row with rows 20 feet apart. There will now be 225 female plants per acre and each will have a pollinator within at least 20 feet. Female to male plant ratio will still be 4:1.

temperatures. By contrast, jojoba appears to suffer no ill effects from temperatures at the 40 to 42°C range. When temperature occasionally reaches 50°C, burning on the terminal parts of branches was observed but, otherwise, growth was not affected in a major way, provided irrigation was supplied.

Pruning may be used to remove low branches to force the plants to grow upright into a shape more suitable to harvest and cultural practices. Similar results are obtained if sheaths of plastic mosquito netting or heavy construction paper are placed over the lower portion of stems. In addition to modifying growth habit, these sheaths offer the plants considerable protection from rodents and other desert animals.

In well equipped and organized farming operations, companion crops may be planted with jojoba to generate income during the 2nd to 5th year period. Space between rows could be utilized for production of annual crops as well as for readily marketable landscape and garden plants.

Intercropping Jojoba with Sesame and Other Cash Crops

With the exception of the first year when jojoba plantations are being established, employment on plantations will be seasonal. Further, the prospects for newly established plantations to produce any significant income is anticipated only after the fifth year and profits after the tenth. With those considerations in mind, the committee recommends that investigations be conducted to determine what cash crops could be intercropped with jojoba on a profitable basis. One such crop that appears to have such potential is sesame (*Sesamum indicum* L.) an ancient oilseed which is now being grown as a garden plant under the name of "benne."

Research conducted by the University of California at Riverside, Department of Plant Sciences, indicates that sesame grows well on the Cabazon and Barona Indian reservations and could grow on a number of others in California and Arizona. A test plot of 10 acres, for example, at Cabazon demonstrated that intercropping with the existing jojoba plants was horticulturally feasible and the results very promising.

There is a large commercial market for sesame and today sesame demand on a world basis is frequently greater than the world production. Except where sesame is deliberately grown as a cash crop for export there is seldom any large amount available for world trade. There is none presently grown in the United States.

The average cost of planting this crop is approximately $170/acre. Each acre is estimated to yield approximately 1,500 pounds. The 1976 price of sesame seed, wholesale, is between $.31 and $.40 per pound. The sesame seed can be planted in May and harvested in September or October, approximately five months later. Two crops per year also appears to be a possibility. Depending on markets, it could be possible, providing there was only the one sesame crop per year, that the balance of the year (seven months) could be used to plant other crops such as lettuce, alfalfa, or tomatoes, etc. In this way, the reservations could have more of a continuous income during the first five years when jojoba plants are not yielding commercially.

Harvesting

Jojoba nuts are now harvested by hand. It is tedious and hard work. The harvest takes place during July and August--the hottest period of the year. There are no shade trees growing in the same area with jojoba under which the pickers can rest. Under these conditions it is difficult to concentrate and keep up a fast pace of work throughout the day. The nuts are small--1,000-1,500 per pound--and they are hard to spot on the plant.

Studies have shown that a worker can pick by hand 3-8 pounds of nuts averaging about 4 pounds per hour if consideration is given to the time spent walking from plant to plant looking for plants with greater nut load. The minimum U.S. hourly pay rates for agricultural workers is $2.20 effective January 1, 1977, and it will increase to $2.30 effective January 1, 1978 (P.L. 93-259). Thus, if workers are to be paid fair wages for their work in accordance with these rates $0.60/lb of nuts harvested must be paid. Experience has shown that it is difficult to find hand pickers for the natural stands of jojoba at the above rate. Thus, picking rates of $1.00-1.43/lb have had to be paid in California and Arizona to obtain the desired amounts of jojoba nuts. Although pay rates are lower in Mexico, $0.80/lb of seed harvested have had to be paid to attract sufficient numbers of pickers.

The small quantities of jojoba oil that became available in the last two years were sold at $5.00-6.00/lb in the U.S. and at $38.00 a gallon in Mexico. Although presently, the annual world market demand is approximately 40-100 thousand pounds, a number of economic studies have shown that substantially lower prices will have to be asked for the oil if the interest of domestic and foreign buyers of jojoba oil is to be maintained. Thus, picking costs of $0.60/lb or higher for most product use above 100,000 pounds are prohibitive and can only be sustained if a major proportion of these costs is covered by funds from the federal government. Even so, the production of wax from the natural stands will have to be sold to small scale manufacturers of low volume, high value products such as cosmetics and specialized lubricating oils.

Other difficulties, in addition to the high cost of hand harvest, should not be overlooked in relation to the harvest of the natural stands. These include: (a) the availability of manpower at the 4-6 week period of the harvest, (b) the accessibility to the places where jojoba grows, and (c) the lack of basic services for the pickers, in terms of water, food, lodging, and nut storage. All of these difficulties increase the cost of nuts and pose personnel management problems. If added to the above situations is the fact that natural stands of jojoba do not assure a constant and predictable supply level of nuts annually because of climatic and other uncontrollable considerations, the exploitation of the natural populations of jojoba becomes a limited commercial enterprise. The above considerations have led to the conclusion that the long-term success of the jojoba project will have to depend on the establishment of large scale commercial, cultivated, and properly managed plantations. The general consensus of opinion, however, is that until producing plantations become a reality, the harvest of the natural populations must continue in spite of the costs and other difficulties.

Harvesting aids or portable or hand carried equipment similar to that used with other crops could possibly be developed for jojoba, doubling a worker's productivity. This would only result in a cost saving of 15-20 percent, or $.10-.15/lb because some of the savings would have to go to the worker and some to pay for the equipment. The research and development costs would be high (possibly $100,000 or more). If such equipment were used in harvesting 50 tons per year of natural jojoba, it would take 10 years to recover the research investment--a poor cost/benefit ratio. Therefore, it is questionable whether such research should be undertaken.

On plantations, however, a reduction in harvesting costs is feasible. Because of higher yield per shrub, the high density of shrubs per acre, and level terrain making movement easy, workers should be able to more than double their picking rates.

The real promise is in complete mechanization of the harvest. When plants are somewhat uniform, planted in straight lines, and on terrain suitable for machine movement, equipment for performing specific functions can be developed or adapted from existing technology. Machines and techniques have been developed for harvesting fruit and nut crops. For example, machines are in use that harvest over an acre of blueberries each hour (2000-8000 lb/acre)--and for harvesting each hour almost an acre of grapes yielding 3-10 tons/acre.

It is believed that these or similar high efficiency machines and techniques, e.g. such as the almond harvester, could be adapted for harvesting cultivated jojoba. They could reduce the harvesting costs to \$.05 to \$.10/lb (including depreciation, taxes, interest, and insurance on the machines). This figure is based on a machine that could harvest one acre per hour. Even with yields of only one ton of nuts per acre, there would be a saving of at least \$1,000/ton over hand harvesting. Higher yields would give higher savings.

Methods for removing the nuts from the plant, such as stripping, shaking, high vibration, impact, air or vacuum need to be evaluated as well as the social impact of such mechanization. Methods for separating the nuts from hulls and plant debris need to be improved. It seems desirable to incorporate the best methods of picking, cleaning, and handling into a single machine. The shape and size of the plant and type of pruning will affect the harvesting techniques or machines. It is therefore necessary that the horticulturist and engineer cooperate closely.

Growth-regulating chemicals, which might result in uniform maturity of nuts for once-over harvest, and chemicals that cause abscission (loosening) or tightening the attachment of the nut to the plant, need to be explored.

Until enough plantation acreage is available to justify the use of continuous harvesters, other harvesting methods will be needed. Harvesting aids, such as hand-held vibrators, and techniques, such as letting mature nuts fall onto the ground and later picking them up with sweepers, vacuum, or other equipment, could be utilized. Other possibilities, such as nets or sheets of plastic on the ground to collect mature nuts, need to be investigated. Up to five years of research would be required to explore various systems of harvesting jojoba.

Raw Material Processing

Experience accumulated at Riverside, California; Tucson, Arizona; and Israel, has demonstrated that oil can be extracted from the nuts using standard equipment particularly that used commercially for isolating vegetable oils from cottonseeds, soybeans, coconuts, and corn. No special difficulties have been experienced in obtaining a satisfactory yield from either crushing or solvent rendering. Because of the unusually high oil content in the nuts, minor adjustments in the equipment are necessary.

A small capacity mechanical prepress oil expeller facility could be constructed with new equipment for under \$50,000. The efficiency of the mechanical oil expeller is less than that of the solvent extraction; however, the latter requires greater expense, expertise, and production scale.

The extracted oil has a low acidity (<2 percent); neutralizing may therefore prove to be unnecessary. It is light colored, and bleaching can be performed using normal commercial techniques.

The meal left after extraction; which is about 50 percent of the nut, contains about 30 percent protein, as well as carbohydrate and fiber, and in the future it may prove useful as livestock feed. (Further information is given on page 60.) Any commercial operation will have to consider the handling of large amounts of meal and its potential uses. This is an area that so far has not received enough attention; its solution would improve the economic attractiveness of the industry.

PART II

INDIAN RESERVATION JOJOBA PRODUCTION SYSTEM

INTRODUCTION

The concept of a jojoba production system on Indian reservations is based on the creation of Indian owned and managed cooperatives organized for the production of nuts from natural and cultivated jojoba shrubs and for the processing, utilization and marketing of jojoba products. Within the tribes, agricultural organizations, unincorporated private farmers and individual farm workers could become associated with the Indian jojoba production and product effort. Using modern methods such as intensive cultivation, crop yield improvement techniques and production schedules designed to meet specific market demands, the system could initially (from natural jojoba populations) provide a volume of jojoba oil great enough to keep the marketing segment of the Indian production system at a break-even or near break-even point. For the specialty, expensive cosmetic market it should be possible to sell the products at a profit, thus the production system should be viable from the beginning. Within 10-13 years, when the plantations begin to yield commercial quantities of nuts, chances are high for the success of a jojoba agro-industry on Indian reservations.

Pre-harvest contracts with large quantity purchasers should be the general basis of each reservation's production and marketing activity. Agricultural pursuits would be more attractive and remunerative to the tribes by such a system of a scheduled production, an assured market, and an equitable price structure negotiated collectively among all the reservation producers.

There is strong interest on Indian reservations in development of a jojoba agro-industry. Most tribal governments have decided to endorse the development of the shrub in areas suited to its cultivation. Some tribes have already committed their own scarce funds to this task and thousands of acres have been earmarked for possible jojoba plantations. Cultivation of jojoba is not alien to tribal culture as are some industrial projects.

The potential jojoba production system on Indian lands in the Sonoran Desert region consists of the following major elements: (1) the cash crop as derived from the harvests from the natural habitat and cultivated plantations, (2) the processing of jojoba nuts to extract oil, produce hydrogenated wax, hulls, and meal, (3) the identification and utilization of existing and new products and (4) the marketing of products.

Technical assistance (scientific, technological, administrative and managerial) is vital to the successful development and implementation of an Indian jojoba production system. Both existing and future Indian jojoba development organizations will require full time assistance in identifying, preparing and implementing jojoba development policies and projects. Technical assistance should be provided both before and after production activities begin. When the Indian organizations believe that outside assistance is required, proper technical services should be obtained from educational institutions, from private consulting specialists, or other appropriate sources. The tasks for which consultants may be needed will vary from reservation to reservation. Since the tribes lack modern agricultural development experience and expertise in developing jojoba as a new commercial crop, they will need the following types of assistance: Development of high yielding, early, large-seeded high-wax content varieties of jojoba; existing and new product feasibility studies; management and organizational studies; special agro-economic and environmental studies; preliminary engineering and detailed design of plantations; processing facilities, harvest equipment, marketing analysis studies; preparation of specifications, bidding and contract awards; inspection of equipment and facilities ordered and/or constructed and installed; design and implementation of education and training programs; identification of technical problems; and initially, control and operation of the completed plantation and processing facilities.

The first phase consists of natural nut harvesting during the 5-8 year interim period before new plantations yield commercially harvestable nuts. During this period, the economic viability of implementing an Indian jojoba production system will depend on maximum use of nuts from existing natural populations, appropriate agricultural manipulation of these jojoba shrubs to increase their yields and development of efficient techniques for harvesting and processing the nuts. The second phase, concurrent with the first, consists of the establishment of cultivated plantations from existing and improved cultivars producing high yields of nuts which can be harvested efficiently by mechanical means.

JOJOBA PRODUCTS, USES AND POTENTIAL MARKET DEMAND

Jojoba oil, hydrogenated-wax and sulfurized liquid-wax are currently used or will probably be used in the near future in such products as: hair oils, shampoos, lubricants, stabilizing agents for penicillin, cosmetics, saturated waxes, coatings, and candles. Research now being conducted should be expanded to determine additional uses and related secondary products which could be produced and marketed profitably.

Some of these potential uses are listed in Table 1:

TABLE 1

POTENTIAL USES OF JOJOBA NUTS

JOJOBA	USE
Liquid Wax-Oil	LUBRICATION - requires little or no refining for use with high-speed machinery or machinery operating at high temperatures and pressures; serves well as cutting or grinding oil or additive to other lubricants; may be suitable as a transformer oil or an oil for delicate mechanisms.
	COSMETICS - present use as component of hair oil, shampoo, and soap; potential use in face creams, sunscreen compounds.
	PHARMACEUTICALS - suitable carrier or coating for some medicinal preparations; stabilizer of penicillin products; inhibitor to growth of tubercle bacilli; potential treatment for acne/ historical use as hair restorer.
	FOOD-RELATED - cooking oil; low calorie additive for salad oil, vegetable oil, oil, and shortening.
Liquid Wax-Oil (Sulfurized)	LUBRICATION - substitute for sperm whale oil; see above.
	FACTICE - potential in linoleum manufacture; printing ink composition; use in varnishes and chewing gum.
Alcohol and Acid Derivatives	PREPARATION OF - disinfectants, surfactants, detergents, lubricants, driers, emulsifiers, resins, plasticizers, protective coatings, fibers, corrosion inhibitors, and bases for creams and ointments.
Hydrogenated Wax (Solid)	POLISHING WAX - for floors, furniture and automobiles.
	PROTECTIVE COATINGS - on fruit, food preparations, and paper containers.
	COSMETICS - for lipsticks.
	EMULSION - good stability and excellent hardness suggest a variety of applications.

	CANDLES -combined with other waxes it burns with bright, essentially smokeless flame; high melting point; may increase burning time of candle.
	TEXTILES - sizing for yard goods.
	CARNAUBA WAX SUBSTITUTE - as hard as candelilla wax and almost as hard as carnauba; should eventually be very competitive on the basis of price.
Oil Extracted Meal	ANIMAL FEED SUPPLEMENT - potential use if possible toxin is denatured: 20-30 percent protein.
	FERTILIZER - potential use if high nitrogen content can be utilized.
Seed Hulls (capsules)	MULCH-SOIL AMENDMENT - protective ground cover to reduce evaporation, erosion, weed growth, or enrich soil which is low in organic matter.
Jojoba Shrubs	ANIMAL FOOD - excellent browse for deer, cattle, sheep and goats.
	ORNAMENTAL - already used throughout the southwestern United States as an ornamental shrub and good potential for use as ground cover.

Estimated Short Term Market Demand (1976 to 1982)

Conservative estimates, as of September 1976, of the market demand for high priced, low volume jojoba oil from natural stands is approximately 6 million pounds (2,700 million metric tons) ranging in price from $3.00-$6.00 per pound. The market demand for hydrogenated wax at $1.00-$2.30 per pound is estimated to be 13 million pounds (6,000 million metric tons).

These market estimates are based on industry requests to the Apache Cooperative Marketing Association and to the University of Sonora, Mexico from industrial users in California (lubricants) and Japan (cosmetics). Estimated total annual production potential for the natural stands areas presently surveyed in Arizona and California is 53 metric tons. Details are listed in Table 2.

Estimates indicate that the present annual harvest from only a small portion of the potential harvestable populations have yielded approximately 13.3 metric tons of oil in 1973 and 15.0 metric tons in 1976 in the U.S.

Estimated Long Term Market Demand (1982 to 1993)

Analysis by the Bureau of Indian Affairs indicates an estimated market demand in the long term, 1982-1993, for low priced ($.40-$.75 per pound) jojoba oil to be approximately 121,500 metric tons. The market

TABLE 2

ESTIMATED JOJOBA OIL PRODUCTION POTENTIAL FROM NATURAL STANDS AREAS PRESENTLY SURVEYED IN ARIZONA AND CALIFORNIA

Geographical Area	Metric Tons
	Arizona
San Carlos, Superior & Ray District	20
Papago and Tucson Mountains	25
Saguaro/Roosevelt Lake/ Camp Creek and Circle Ranch	3
Subtotal	48
	California
Aguanga	3
Jacumba and Otay Ranch	2
Total	53

demand for the solid hydrogenated wax is estimated to be 6,000 metric tons with a price range of $1.00-$2.20 per pound. Thus a total market demand of more than 127,000 metric tons per year is anticipated. To produce enough jojoba oil and crop to meet this market demand would require the establishment of approximately 75,000-150,000 acres of cultivated jojoba depending upon the actual per acre yield.

NATURAL SHRUB HARVEST SITES IN ARIZONA AND CALIFORNIA

Continued development of the jojoba agro-industry is entirely dependent upon the use of natural shrubs for at least the next 5-7 years and partially dependent for 10-13 years. It is therefore essential that the natural populations of jojoba be harvested and utilized to their fullest potential. These natural populations grow in an area comprised of approximately 100,000 square miles of the Sonoran Desert of Mexico and the United States between latitudes 25° and 31° north. It is estimated that the natural shrubs of this area produce approximately 10,000-16,000 metric tons of nuts each year, which, as previously indicated, should provide a clean-dry harvest of 300-500 metric tons without depletion of the natural stand ecology.

Throughout the entire natural range of the shrub, there are many separate populations varying from a few individual shrubs to 200 or more per acre. There are some extensive populations with millions of individual shrubs occurring, for example, along the slopes of the Pinal Mountains of Arizona and upon the high desert plain of San Matias Pass in Baja California. Many of these natural populations have been mapped by Hastings, Turner, McKetterick, Webber and Gentry; and under the University of Arizona's remote sensing program. Areas in Arizona have been photographed and mapped by Lepley and Sherbrooke. To date, however, no <u>extensive</u> scientific or photographic ground survey expeditions have been made throughout the area to specifically identify those dense populations which could be harvested economically.

The committee suggests that extensive surveys of natural jojoba populations be given the highest priority as a first step forward fully utilizing natural jojoba populations for oil sales and genetic material. Figures 1 and 2 show those actual and potential harvesting sites where nuts have been collected for scientific evaluation. There are approximately 11 sites in California and 27 sites in Arizona. However, only about 4 or 5 sites are harvested by Indians in California and just 2 in Arizona. The fact that a 50 mile area around Globe, Arizona could probably yield more than 60,000 pounds (27 metric tons) of nuts per year, provided that most or all of the densest populations were harvested, is indicative of the potential magnitude of the natural shrub productive capacity.

JOJOBA PLANTATIONS

In order to meet the market demand for jojoba oil and wax, the establishment of cultivated jojcba shrubs in plantations on Indian reservations should be undertaken immediately. The committee suggests that even though 75,000-150,000 acres may be necessary to meet the demand, an Indian reservation jojoba production system should be limited to 50,000 acres of plantations developed over 12 years. This area would be feasible for the Indian tribes to manage and finance.

Initially, it was suggested that 1,000 acres per year be planted during the first three years and that they be established on retired Class I irrigated agricultural lands in order to keep costs as low as possible. The committee recommends that the first 1,000 acres be established on the following Indian reservations: San Carlos, Papago, Ak Chin, Gila River, Salt River, Ft. McDowell, and Colorado River in Arizona and Quichon, Cabazon, Chemehuevi, and Morongo in California.

Estimates of the first year costs for establishing jojoba plantations, using the direct seed method, are estimated to be from $184 for retired Class I irrigated agricultural land on Arizona reservations to $900 for uncleared reservation lands in California which require fairly extensive water systems. These costs are shown in Table 3. Preharvest costs are estimated at $68-$188 per acre per year. Harvesting costs are estimated to be $150-$196 per acre per year using a mechanical harvester especially designed for jojoba nut harvesting. Tables 4 to 6 show the estimated plantation development costs and returns for jojoba plantations established on Class I irrigated agricultural lands in Arizona, on 250 acre plantation and natural stands on the San Carlos Indian reservation, and on Indian lands in California.

The dollar costs and returns on investment are based on nominal yield expectations. These include the shrubs yielding 10 pcunds (45 kg) of dry nuts per plant in the 12th year (see Table 4), an estimated price of $.50 per pound of clean dry nuts sold in the marketplace and accumulated costs increasing through the first five years.

Based on these considerations, the estimated year when profits would be greater than the year's costs would be the tenth, as well as a profit above costs incurred during the previous years. The net return would level off at approximately $2,716 an acre during the twelfth year (see Table 4).

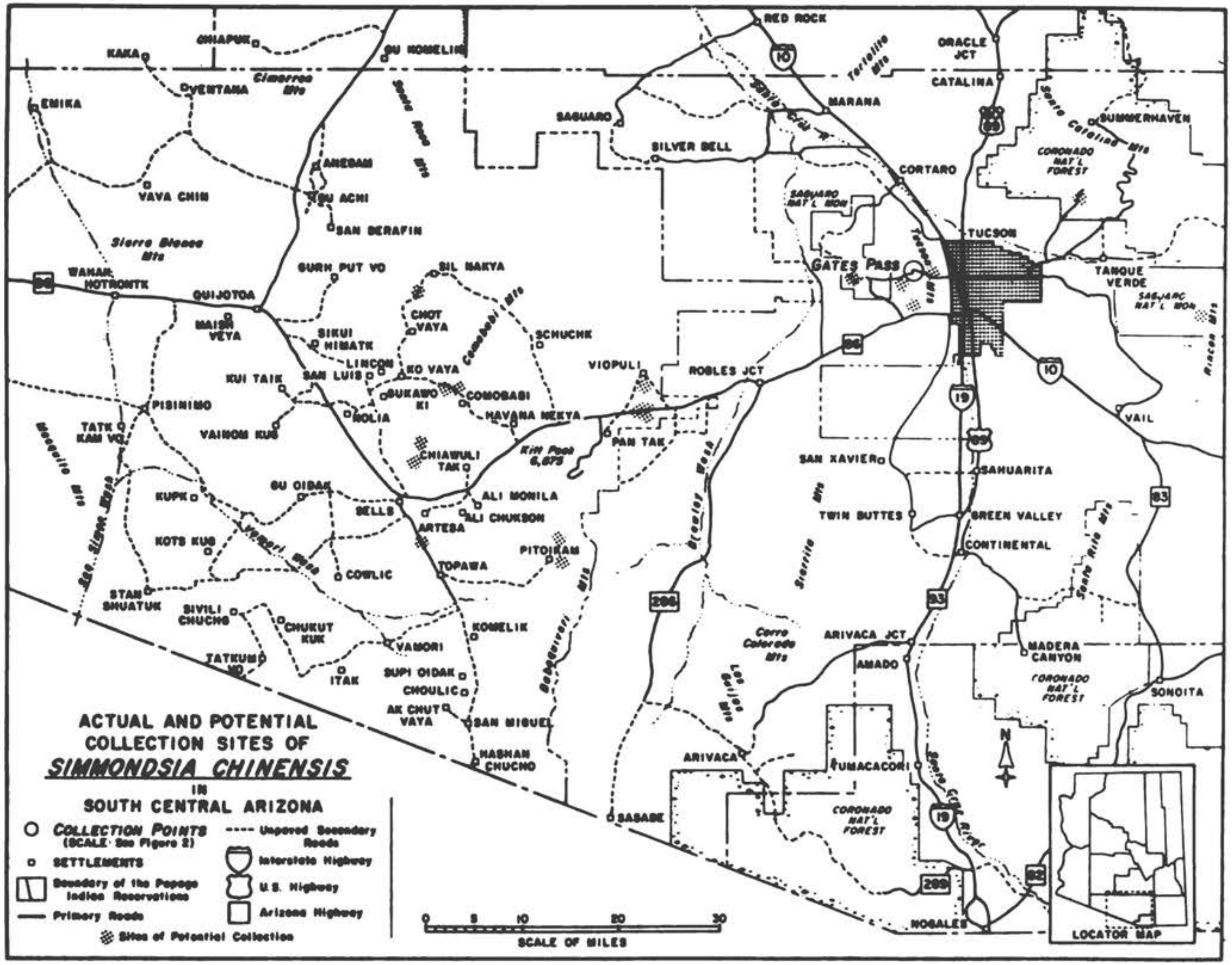

FIGURE 1. Actual and Potential Collection Sites of
Simmondsia chinensis.
(Courtesy of the Office of Arid Lands Studies,
University of Arizona.)

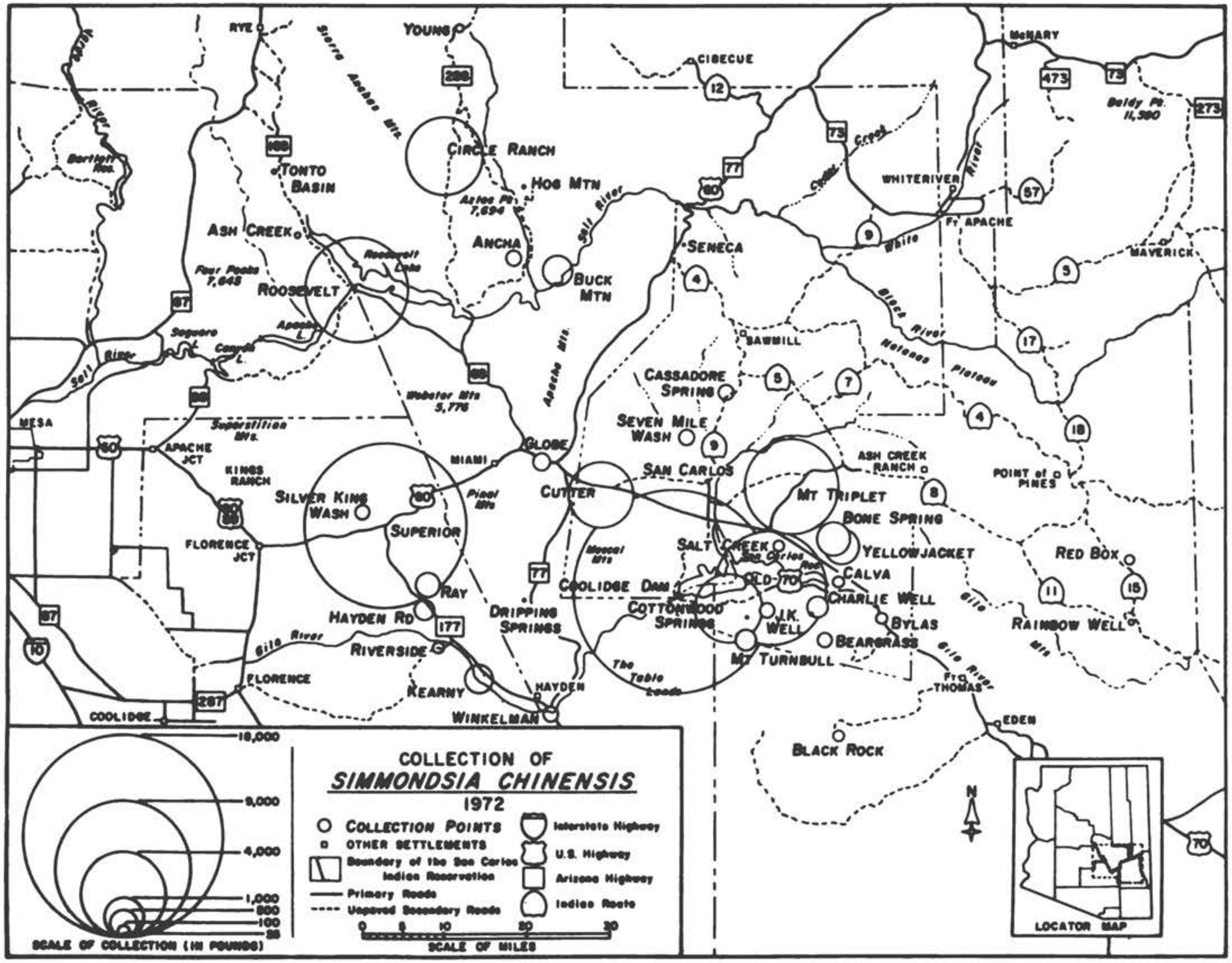

FIGURE 2. Collection of Simmondsia chinensis, 1972. (Courtesy of the Office of Arid Lands Studies, University of Arizona.)

TABLE 3

ESTIMATED AVERAGE COSTS PER ACRE FOR ESTABLISHING JOJOBA PLANTATIONS IN ARIZONA AND CALIFORNIA

(Estimates are extrapolations based on actual costs to establish 60 acres in California and 20 acres in Arizona)

DIRECT SEED METHOD (1)

A. Establishment Costs for Uncleared Land

Arizona (2)		California (3)	
.Low	$500	.Low	$700
.Medium	$600	.Medium	$800
.High	$700	.High	$900

B. Establishment Costs for Idle Class I Retired Irrigated Tribal Land

Arizona		California
.Low	$200	(No idle Class I land available
.Medium	$300	in California)
.High	$400	

Source: Bureau of Indian Affairs, U.S. Department of Interior, 1976.

(1) The direct seed method reduces plantation establishment costs by approximately $600 to $700 over the greenhouse potted plant method.

(2) Actual cost to establish 33 acres at San Carlos, Arizona was $661.00.

(3) Actual cost to establish 60 acres at Cabazon was $1,342.50 which includes a cost of approximately $700.00 for greenhouse grown potted plants.

TABLE 4

ESTIMATE PER ACRE DEVELOPMENT COSTS AND RETURNS FOR JOJOBA PLANTATIONS,
CLASS I IRRIGATED LAND, ARIZONA, 1976
(U.S. dollars)

Operation	Year 1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th
Land Preparation	30												
Layout and Plant @ $.30/plant	262												
Plants, 875 @ $1.25 each	1094												
Water, $35/AF	70	70	70	70	70	70	70	70	70	70	70	70	70
Irrigation and ditch labor @ $6/AF	12	12	12	12	12	12	12	12	12	12	12	12	12
Chemical weed control ($6 per app.)	12	12	12	12	12	12	12	12	12	12	12	12	12
Cultivation (@ $5 per cultivation)	15	10	10	10	10	10	10	10	5	5	5	5	5
Fertilization and application @ $.45 per unit of N	20	20	20	20	20	20	20	20	20	20	20	20	20
Plant replacement (@ $2.50 per plant)	45	45	45	45	45	45	45	45	45	45	45	45	45
Pruning and disposal	110	110	110	165	165	165	165	165	218	218	218	218	218
Supervision and Management	12	12	12	12	12	12	12	12	12	12	12	12	12
Variable Farm Overhead	15	15	15	15	15	15	15	15	15	15	15	15	15
Rent Value of Land	20	20	20	20	20	20	20	20	20	20	20	20	20
Sub Total	1717	326	326	381	381	381	381	381	429	429	429	429	429
Accumulative Sub Total	1717	2180	2680	3275	3934	4286	4261	3829	3005	1710	429	429	429
Interest @ 8%	137	174	214	262	315	343	341	306	240	137	34	34	34
Total Production Costs	1854	2354	2894	3537	4249	4629	4602	4135	3245	1847	463	463	463
Harvest Costs @ $98/hour	0	0	0	196	196	196	196	196	196	196	196	196	196
Clean and Handle Seed @ $.025/lb	0	0	0	20	60	105	150	195	240	285	330	375	375
Total Costs	1854	2354	2894	3753	4505	4930	4948	4526	3681	2328	989	1034	1034
Revenue @ $.50 per pound	0	0	0	200	600	1050	1500	1950	2400	2850	3300	3750	3750
Costs to be Carried Forward	1854	2354	2894	3553	3905	3880	3448	2576	1281	522*	2311*	2716*	2716*
Profit*													

Source: Wright and Stubblefield, (1976)

TABLE 5

ESTIMATED COSTS AND RETURNS FOR NATURAL STAND PRODUCTION SYSTEM AND 250 ACRE PLANTATION SYSTEM

	NATURAL STAND HARVEST							PLANTATION													
											COST OF MAINTENANCE		COST OF HARVEST			PRODUCTION		OIL		
	lbs. of seed (1000)	seed price $/lb	cost of seed (1000)	lbs. of oil (1000)	oil price $/lb	value of oil (1000)	PROFIT (1000)	acres in	acres estab. year	cost of estab. $600/A (1000)	$/A	$/yr (1000)	$375/A (1000)	¢/lb	TOTAL COST (1000)	lbs. seed (1000)	lbs. oil (1000)	price $/lb	value of (1000)	PROFIT (1000)
Spring*																				
1976				2.0	5.00	10.0	10.0													
Fall																				
1976	26,3	1.10	28.9	10.0**	5.00	50.0	21.1													
1977	39.5	1.12	44.2	15.0	5.00	75.0	30.8	50	50	30.0					30.0					-30.0
1978	52.6	1.14	60.0	20.0	4.75	95.0	35.0	100	50	30.0	75	3.8			33.8					-33.8
1979	78.9	1.16	91.5	30.0	4.50	135.0	43.5	150	50	30.0	80	8.0			38.0					-38.0
1980	78.9	1.18	93.1	30.0	4.25	127.5	34.4	200	50	30.0	85	12.8			42.8					-42.8
1981	72.0	1.20	86.4	27.4	4.00	109.6	23.2	250	50	30.0	90	18.0	18.8	.94	66.8	20.0	7.6	4.00	30.4	-36.4
1982	43.4	1.20	52.1	16.5	3.00	49.5	-2.6	250			95	23.8	37.5	.50	61.3	75.0	28.5	3.00	85.5	24.2
1983								250			100	25.0	56.3	.34	81.3	165.0	62.7	2.00	125.4	44.1
1984								250			105	26.3	75.0	.26	101.3	292.5	111.2	1.25	139.0	37.7
1985								250			110	27.5	93.8	.21	121.3	457.5	173.9	1.25	217.4	96.1
1986								250			115	28.8	93.8	.15	122.6	640.0	243.2	1.25	304.0	181.4
1987								250			120	30.0	93.8	.11	123.8	825.0	313.5	1.25	391.9	268.1
1988								250			125	31.3	93.8	.09	125.1	1010.0	383.8	1.25	479.8	354.7
1989								250			130	32.5	93.8	.08	126.3	1177.5	447.5	1.25	559.4	433.1
1990								250			135	33.8	93.8	.07	127.6	1307.5	496.9	1.25	621.1	493.5
1991								250			140	35.0	93.8	.07	128.8	1400.0	532.0	1.25	665.0	536.2
1992								250			145	36.3	93.8	.06	130.1	1455.0	552.9	1.25	691.1	561.0
1993								250			150	37.5	93.8	.06	131.3	1475.0	560.5	1.25	700.6	569.3

TOTAL NATURAL STAND AND PLANTATION

	wild lbs. (1000)	plant lbs. (1000)	total (1000)	value (1000)	STOCKPILE this year (1000)	STOCKPILE accum. balance (1000)	PROFIT (1000)	*** accumu-lated (1000) Balance
Spring*								
1976	2.0		2.0	10.0	-	-	10.0	10.0
Fall								
1976	10.0		10.0	50.0	-	-	21.1	31.1
1977	15.0		15.0	75.0	-	-	0.8	31.9
1978	20.0		20.0	95.5	-	-	1.2	33.1
1979	30.0		30.0	135.0	-	-	5.5	38.6
1980	30.0		30.0	127.5	-	-	- 8.4	30.2
1981	27.4	7.6	35.0	140.0	-	-	-13.2	17.0
1982	16.5	28.5	45.0	135.0	-	-	21.6	38.6
1983		60.0	60.0	120.0	2.7	2.7	44.1	82.7
1984		110.0	110.0	137.5	1.2	3.9	37.7	120.4
1985		170.0	170.0	212.5	3.9	7.8	96.1	216.5
1986		240.0	240.0	300.0	3.2	11.0	181.4	397.9
1987		310.0	310.0	387.5	3.5	14.5	268.1	666.0
1988		380.0	380.0	475.0	3.8	18.3	354.7	1020.7
1989		460.0	460.0	575.0	-12.5	5.8	433.1	1453.8
1990		500.0	500.0	625.0	- 3.1	2.7	493.5	1947.3
1991		500.0	500.0	625.0	32.0	34.7	536.2	2483.5
1992		500.0	500.0	625.0	52.9	87.6	561.0	3044.5
1993		500.0	500.0	625.0	60.5	148.1	569.3	3613.8

* from 1975 subsidized harvest

** oil extraction figured at 0.38 (38%)

*** all oil considered sold

Source: Apache Marketing Cooperative Association, Inc. San Carlos Indian Reservation, Arizona

ASSUMPTION OF SEED YIELD

Plant Production

year	#/shrub	#/acre
5	0.55	400
6	1.5	1100
7	2.5	1800
8	3.5	2550
9	4.5	3300
10	5.5	4050
11	6.5	4800
12	7.5	5500
13	8.0	5900

TABLE 6 Cost Analysis Worksheet: Jojoba Plantation Production Costs for Mature (12 years or older) Plantation–1976.

PRE-HARVEST CASH COSTS	PER ACRE PER YEAR
General Plantation Maintenance	$ 25.00
Fertilizer	30.00
Tillage and Harvest Preparation:	
(7 hours labor + 7 tractor hours)	31.50
Irrigation: (7 times 6 hours labor)	18.00
Water: 1 acre foot @ $6 + tax @ $6	12.00
County taxes	32.00
Repairs except tractor	10.00
Office and Business Costs	10.00
Misc. labor: 6 hours labor + 1 tractor hour	19.50
TOTAL PRE-HARVEST CASH COSTS	$188.00
HARVEST COSTS	
Pick, dry, hull and haul	$150.00
TOTAL HARVEST COSTS	$150.00
TOTAL CASH COSTS	$338.80
DEPRECIATION	
Irrigation System: $300 cost, 12 year life	$ 25.00
Buildings and Equipment: $150 cost, 12 year life	12.50
Tractor: 8 hours @ $1.50	12.00
Trees: $3,600 cost, 50 year life	72.00
TOTAL DEPRECIATION	$121.50
INTEREST ON INVESTMENT @ 7%	
Irrigation System: 1/2 cost, $150	$ 10.50
Buildings and Equipment: 1/2 cost, $75	5.25
Tractor: 8 hours @ 90¢	7.20
Trees: 1/2 cost $1,800	126.00
Land: @ $1,000/acre	70.00
TOTAL INTEREST ON INVESTMENT	$218.95
TOTAL COST OF PRODUCTION	$678.45

SAMPLE COSTS AND RETURNS (seed @ 50¢/lb.) AT VARYING YIELDS

Yields lbs/acre	1000	1500	2000	2500	3000	3500	4000
Cash costs/ton	676.00	507.00	338.00	295.75	253.50	211.25	169.00
TOTAL COSTS/TON	1,356.90	1,017.68	678.45	593.64	508.84	424.03	339.23
Gross return/acre	500.00	750.00	1,000.00	1,250.00	1,500.00	1,750.00	2,000.00
Net return/acre	(-178.45)	71.55	321.55	571.55	821.55	1,071.55	1,321.55

Status of Present Jojoba Plantations on Indian Reservations

Experimental jojoba plantations have been established on Indian reservations during the past few years. In 1973, the first experimental jojoba plot on an Indian reservation was planted on the Papago Indian reservation. This 1-acre plot is located on the grounds of the Baboquivari High School and is used for education and training of Papago students in agricultural methods.

In 1974, 30 acres of jojoba were planted on the Barona Mission Indian reservation in Southern California. Subsequently, in December 1975, this experimental jojoba plot had to be abandoned because the plants could not survive the winter's frost and other adverse environmental elements in that geographic area.

In 1975, 10 acres of jojoba were planted on the Pauma Mission Indian reservation. The plants on this experimental plot are growing well.

In 1976, an additional 85 acres of jojoba were planted--60 were cultivated on the Cabazon Mission reservation in California, and another 25 acres were planted on the San Carlos Apache reservation in Arizona. These plants are healthy and undergoing normal growth. Table 7 summarizes the status of Indian developed jojoba plantations.

Potential Land Areas Suitable for Plantation Development

There are almost six million acres of land suitable for jojoba cultivation distributed among at least thirty-two reservations, rancheros and missions in Arizona and California. Approximately 56,000 acres of this land is Class I irrigated but retired

TABLE 7

STATUS OF DEVELOPMENT OF INDIAN ALLOCATED AND PLANTED RESERVATION JOJOBA PLANTATIONS ACRES IN ARIZONA AND CALIFORNIA
(September 1976)

	ACRES		
	Cleared	Planted	Total Allocated
A. Plantation Acres in Arizona			
1. San Carlos[1]	80	25	80
2. Papago		1*	
B. Plantation Acres in California[2]			
3. Barona		(30)**	(30)
4. Pauma		10	10
5. Cabazon	100	60	600
6. Chemehuevi			1,000
7. Santa Rosa			80
8. Morongo	100		640
TOTALS	280	96	2,420

* Water harvesting experimental acre at Baboquivari High School.

** Most plants were destroyed during the winter of 1975. Research indicated that the environmental conditions at Barona are not suitable for jojoba cultivation at this time.

1 Apache Marketing Cooperative Association, Inc.

2 Southern California Jojoba Project, Inc.

agricultural land. Table 8 identifies these major Indian land areas, the total acres, average rainfall and temperature range.

Although current environmental information appears to indicate that these reservations are suitable for cultivating jojoba, the committee recommends that each prospective reservation be scientifically studied in order to determine that the specific environmental characteristics necessary for successful jojoba cultivation do in fact exist.

The plantations should initially be cultivated on those land areas of the reservation which are within the known limits of jojoba tolerances as, for example, where winter temperatures seldom fall below freezing, on soils determined suitable for jojoba growth and at elevations between 2,000 and 4,000 feet.

To reduce development costs, the committee also recommends that priority be given to establishing plantations on those reservations which presently have idle agricultural land. Table 9 identifies the 56,000 acres of idle tribal and individual land acreage which appear to be suitable for cultivating jojoba. Table 7 presents the status as of September 1976, of the total acres of Indian lands allocated for jojoba plantation development, and the number of acres cleared and planted.

COMMERCIAL PROCESSING

Jojoba nut processing methods will be determined primarily on the basis of the volume and costs of the total current and potential native shrub yields per annum and the potential plantation acre yields beyond 1982.

In 1976, California and Arizona Indians produced less that 7 metric tons of oil from the jojoba nut harvest. Production of 13-14 metric tons of oil is projected for 1977 by Apache Marketing Cooperative Association, Inc. and the Southern California Jojoba Project Inc. Prices for this low volume have been set at $5.00 per pound FOB for U.S. markets and $6.00 per pound FOB for international markets.

As more efficient techniques are developed for harvesting a larger geographical area of the natural jojoba stands in Arizona and California (estimated potentially to be more than 15,000 metric tons of oil annually) and for processing this greater volume, production prices can be lowered to approximately $3.00 per pound. However, until cultivated plantations are producing crops which are harvested mechanically, the Indians cannot hope to compete in the larger volume market with products such as lubricants, polishing waxes and substitutes for high priced imported vegetable waxes. In 10-12 years this potential demand for such products is estimated to be more than 128,000 metric tons when the price for jojoba is projected to be approximately $0.50-$0.75 per pound. These two types of markets suggest that two processing methods should be considered in planning a commercial processing operation; the first phase, processing the natural stand yields and the second phase, processing the cultivated plantation yields.

First Phase: (Processing Nuts from Native Shrubs)

In the first phase, nuts from the natural stands are harvested and processed into basic and secondary high cost products.

TABLE 8

MAJOR INDIAN LAND AREAS (1) SUITABLE FOR JOJOBA CULTIVATION

Reservation	Reservation Population 1972	Land Area (acres)	Average Rainfall (inches)	Temperature Range (°F)
1.* Papago (Az.) 7,073		2,773,377.56	7"	100 to 50°
2. Gila Bend (Az.) 264	8,044	10,377.00	7"	110° to 30°
3. San Xavier (Az.) 707		71,095.00	7"	110° to 30°
4. Cocopah (Az.)	441	1,772.53	3"	115° to 33°
5. Ft Yuma (Az.)		480.00	3"	115° to 33°
6. Ft Yuma (Ca.)	1,290	8,801.88	3"	115° to 33°
7. Gila River (Az.)	8,321	371,932.63	7"	110° to 33°
8. Ak Chin (Az.)	258	21,840.00	8"	110° to 30°
9.* San Carlos (Az.)	4,772	1,854,692.00	16"	95° to 30°
10. Salt River (Az.)	2,470	73,974.00		110° to 30°
11. Ft McDowell (Az.)	345	24,680.00	7"	110° to 30°
12. Colorado River (Az)(Ca)(Nv)	2,072	264,092.00	5.5"	100° to 30°
13. Ft Mohave (Az)(Ca)(Nv)	359	41,883.00	8"	110° to 35°
14.* Cabazon (Ca)	6	1,701.53	3.4"	112° to 21°
15. Augustine (Ca)	0	502.29	4"	120° to 22°
16.* Santa Rosa (Ca)	199	11,092.60	8"	110° to 20°
17. Soboba (Ca)	178	5,035.68	4"	110° to 26°
18.* Pauma (Ca)	59	5,877.25	3"	110° to 28°
19.* Morongo (Ca)	242	32,242.43	3"	110° to 18°
20.* Chemehuevi (Ca)	32	30,653.87	5" to 10"	110° to 30°
21. Aqua Caliente (Ca)	74	25,431.87	3.6"	122° to 26°
22. Cahuilla (Ca)	23	18,272.38	4.5"	112° to 23°
23. Torres-Martinez (Ca)	42	25,103.76	3.4"	120° to 128°
24. Campo (Ca)	30	15,010.00	6"	95° to 28°
25. La Jolla (Ca)	23	8,233.00	15"	110° to 28°
26. Pala (Ca)	255	7,722.00	3"	110° to 22°
27. Pechanga (Ca)	21	4,097.00	3.9"	120° to 22°
28. Rincon (Ca)	91	3,975.00	3"	108° to 22°
29. Santa Ysabel (Ca)	106	10,000.00	15"	100° to 29°
30. Sycuan (Ca)	31	640.00	6.5"	90° to 32°
31. Los Coyotes (Ca)	42	25,049.63	3"	95° to 15°
32. San Pasqual (Ca)	19	1,379.58	3"	110° to 28°

Reservation acres under the jurisdiction of Bureau of Indian Affairs (BIA), Department of Interior.

Source: (1) BIA "Annual Report of Indian Land," June 30, 1975.

* Reservations which have allocated a total of 2,460 acres for jojoba cultivation land as of April, 1976. It is conservatively estimated that, out of the 5,724,593.26 acres of tribal and individually owned land, listed above, more than 30,000 acres could be free to be utilized for jojoba development provided the tribal councils desired to develop jojoba commercially.

TABLE 9

Reservations having desirable Environment (Soil, Temperature, Water and Elevations) to cultivate Jojoba (1).

Reservation	Res. Total Indiv/Trbl. Land Acreage*	Idle Trbl.	Idle Indiv.	Land/ Grzng.	Class I Irrig.	Dry Farm	Total Acres Idle
Cocopah	1,411	1,080	-0-	1,070	16	-0-	1,086
Colo. River (2)	225,996	556	200	-0-	756	-0-	(AZ)756
Ft. McDowell	24,680	975	-0-	720	255	-0-	975
Ft. Mohave (3)	41,883	25,209	-0-	-0-	2,497	-0-	25,209
Gila Bend (4)	10,409	212	-0-	-0-	212	-0-	212
Gila River (5)	371,933	129,493	50,134	144,844	34,786	-0-	179,630
Ak Chin (6)	21,840	6,678	-0-	-0-	6,678	-0-	6,678
Papago	2,855,874	1,257	702	-0-	547	1,000	1,978
Quechan (7)	10,693	1,648	1,349	2,440	486	-0-	3,007
Salt River	73,974	17,679	4,438	19,451	8,795	-0-	24,084
San Carlos	1,854,697	205,297	585(8)	205,605	277	-0-	205,882
San Xavier	71,095	-0-	721	-0-	721	-0-	721
Cabazon, CA	1,702,000	-0-	-0-	?	?	?	-0-
Morongo, CA	32,242	-0-	-0-	?	?	?	-0-
Totals	7,298,727	390,084	58,129	374,130	56,026	1,000	450,218

*BIA "Annual Report of Indian Land", June 30, 1975.

(1) BIA Land use Inventory and Production Record, Report 50-1, 1974.

(2) Arizona (AZ), California (CA), and Nevada (NV) - 114, 960 idle.

(3) AZ, CA, and NV wild lands included (22,712).

(4) Private irrigated acres.

(5) 3,670 idle irrigated acres privately held.

(6) Private irrigated acres.

(7) AZ and CA, 81 acres of wild lands.

(8) Fee Patent, non-trust land.

The committee suggests that during this phase, two small capacity (100-130 kg./hour) oil expeller extraction facilities be established, one on an Indian reservation in Arizona and one in California. Each plant should be located near a major commercial transportation center.

The establishment of two small capacity plants during the first phase would provide an opportunity for Indian tribes to be educated and trained at a reasonable cost (approximately $14-19,000 per plant) to process their own commercial quantities of jojoba oil. In addition this equipment provides an opportunity to conduct pilot experiments on processing and to perform research and development on establishing new and improved methods of mechanical extraction. This extraction process should be designed to provide the following products: hulls, meal, raw oil, blanched oil, and flaked wax.

In addition, from a cost-benefit analysis, the two plants, located on Indian lands, are justified in order to reduce current high freight costs estimated to be approximately $0.50-$1.09 per pound. The anticipated savings of approximately $0.34-$0.75 per pound in freight costs would reduce the production cost per pound by more than 68 percent. Thus, the investment of approximately $28,000-$38,000 for the two plants, could be amortized within two years.

Second Phase: (Processing Nuts from Plantations)

The first phase processing objective should dovetail with the planning, development and implementation of a second phase project to construct a large commercial plant designed to meet the maximum cultivated plantation production yield targets of the recommended 50,000 acre plantation as determined by the proposed master jojoba development plan. Investigations should be conducted to determine the proper size of an extraction plant that could be built within the next seven years and that could economically and efficiently process the total projected Indian tribal jojoba output until at least the year 2000.

It is suggested that the plant use the more efficient solvent-extraction process. Approximately 7-15 percent of the oil is left in the cake following mechanical extraction. This residue represents 14-26 percent of potential revenues. Therefore, when there is sufficient raw material (jojoba nuts) to process, the solvent-extraction plant offers a greater economic return on initial investment. This type of plant could also process other oilseed crops.

LIMITATIONS AND SPECIAL REQUIREMENTS

The establishment of an Indian based agro-industrial enterprise will not be easy and the problems must be recognized. The rate of transfer of Indians out of low productivity agriculture and related activities into more profitable agro-industrial production pursuits has been slow. Given the relative lack of a modern economic infrastructure and technological expertise on most developing reservations, it will remain slow if innovative development principles are not used. Most of the tribal people on reservations face varying degrees of poverty and their poverty will increase if population continues to expand at its present rate of more than 3.5 percent annually while development is hindered by limited access to their natural resources, technology, institutions and organizations. Reservations have land, a trainable labor force and access to capital (tribal and federal government) but appropriate infrastructures--such as irrigation works, industrial parks, suitable roads, new appropriate production technology, new types of agricultural institutions and organizations to implement the production system--need to be developed, reorganized or modernized.

Large scale cultivation of Indian land and water use for jojoba oil production may increase the potential for negative impacts on some lands presently used for grazing.

Thus, government, both federal and tribal, should find effective ways to decrease these potential impacts.

In addition, the potential for adverse social costs of rapid technological change resulting from jojoba agro-industry must be recognized, along with any possibility of adverse environmental impacts on wildlife and natural ecosystems. Any use of Indian lands for jojoba farming must be consistent with other tribal land-use plans, with other values such as wildlife habitat, with other water uses, and with patterns of reservation growth and development.

Given the appropriate and innovative development assistance framework, Indian jojoba agro-industry should include: improvement of technology; education for management, research and development; investment of the necessary capital and government planning around the social, developmental and technical desires of the tribe.

Education and Training

Currently, the Indian population lacks the training and experience necessary to successfully manage, operate, and develop jojoba enterprises. Therefore, to efficiently achieve the required production targets it is imperative to establish a short and long range education and training program to prepare Indian farmers, managers, and researchers to effectively use seeds, cuttings, fertilizers, labor, machinery, water and other resources. It is suggested that the Bureau of Indian Affairs, the Universities of Arizona and California, the Agricultural Extension Service and the participating tribal governments fully cooperate in this training effort.

Initially, training should specifically offer Indians a better understanding of the jojoba plant and teach methods and techniques for increasing the yield of the natural shrubs and decreasing the costs of harvesting them. Training and education approaches should be developed in the following areas: pruning; supplemental irrigation such as water harvesting; clearing competitive vegetation, if determined feasible; weed control; nutrient additives; temperature controls; protection of plants from animals; propogation and breeding of jojoba seeds and plants; preparation and maintenance of the jojoba plantation lands; hulling, clearing, and storing of nuts; operating small capacity mechanical oil expellers; management of jojoba enterprises; and marketing of products.

To provide for top quality management and operation of jojoba plantations and jojoba based agro-industrial enterprises, the committee suggests that a talent search be immediately conducted to identify and recruit those Indians who have the requisite backgrounds and aptitudes to become potential Indian plantation managers, industrial managers, marketing specialists, plant scientists, agricultural economists and planners, botanists, agricultural engineers, chemists, etc. Fellowships and internships could be provided to carefully selected students who then could pursue their professional careers at designated universities offering specialized courses geared to the jojoba agro-industry development.

RECOMMENDED FEDERAL ASSISTANCE FOR THE DEVELOPMENT OF AN INDIAN RESERVATION JOJOBA PRODUCTION SYSTEM

The committee suggests that the Bureau of Indian Affairs should serve as lead agency to develop and implement a jojoba development assistance project specifically designed to: 1) Advise and work with Indian leaders, businessmen, and economic specialists in developing a comprehensive, long-range diversified jojoba industry blueprint for participating tribal reservations in Arizona and California; 2) Create the appropriate organizational and staffing structure to assist the tribes in the Sonoran Desert area of Arizona and California to participate fully in planning, constructing, operating, and sharing of income produced by a new well-managed jojoba production system and related agro-industry to serve local, national, and international markets; 3) Assist tribes to determine and develop an innovative corporate financing and organizational structure, which, based on rigid feasibility standards and built-in tax and other economic incentives, would attract major corporations, major lending institutions, and appropriate other government agencies to participate directly with the tribes in the planning, building, and operation of an expanded capital structure for the development of an Indian owned and managed jojoba agro-industrial enterprise; 4) Assist tribes in creating incentives for talented Indians who have left the reservation to return to help build a sounder, more dynamic economy on the reservation; 5) Assist tribes in controlling the development of physical infrastructure, transportation, industrial, commercial, and housing programs so that they are consistent with ecological limitations and with the Indians' traditional culture and expressed desire for self-determination and prosperity; 6) Assist tribes to maximize opportunities for every jojoba worker to own shares in and to become employed by a large scale jojoba enterprise in order to increase private incomes. Table 10 shows the financial assistance for federal agencies for the development of an Indian jojoba industry for FY 1971-FY 1976.

The committee suggests that the jojoba agro-business enterprise should be financed mainly by federal and private loans. However, since the existing Indian cooperatives lack management and agricultural technical know-how, the committee recommends that the government provide the tribes and organizations with grant funds to educate and train those tribal members who are involved in developing the jojoba production system. Funds should also be provided for the necessary technical and management backup to assure that the enterprise will succeed. Funds for the establishment of the cultivated plantations should initially come from development grants or other special congressional appropriations for a period of at least three years.

COOPERATION WITH OTHER COUNTRIES

Interest in developing jojoba plantations has spread to several other countries. Considerable research and development work has been done in Mexico and Israel; both countries are in the process of starting commercial scale projects. The Israeli plantations initially received loans from the World Bank. The Israelis have been looking for commercial partners who are prepared to invest $1.5 million in their venture. In Mexico, extensive harvesting of the natural populations started in 1975 and is expected to continue with support from the government. The first attempts to establish plantations began in 1976. Research projects have been initiated in several other countries including Japan, Australia, Sudan, and Great Britain.

The appearance of jojoba projects in these countries is viewed with a great deal of optimism. The establishment of a broad, international basis of support for jojoba development as a "commercial crop" will give impetus to jojoba research workers in government and private agencies to solve the technical problems involved in creating a superior non-variable jojoba variety which will produce a higher content of oil. Furthermore, information developed on growing jojoba under different environmental and managerial conditions will be most valuable.

The widespread interest in jojoba as a commercial crop provides outstanding opportunities to international cooperation to promote all aspects of production, marketing and utilization of the nut and its by-products. Lines of communication must be maintained and opened to new interested groups, not only among research personnel but also among all groups and individuals involved with the cultivation, harvesting, processing, utilization, marketing and advertising of

TABLE 10

FEDERAL AGENCY FINANCIAL ASSISTANCE
FOR THE DEVELOPMENT OF AN INDIAN JOJOBA INDUSTRY*

FY '71 THRU FY '76

(ALL FUNDS FROM OEO AND ONAP EXCEPT ITEM #4, BIA)

	GRANTEE	DATES	PURPOSE	AMOUNT
1.	University of California	2/8/72	Jojoba Conference	2,500
2.	University of Arizona	5/5/72 - 12/31/72 Additional Tasks Extended to 3/1/73 " to 6/30/73 " to 12/31/73	87,007 Harvest R&D/TA to tribes 40,000	127,007
3.	University of California	5/10/72 - 5/10/73	R&D/TA to tribes	78,691
4.	University of Arizona	5/24/73 - 5/25/73	Harvesting Workshop (BIA)	2,500
5.	University of Arizona	6/1/73 - 5/31/74	Harvest R&D/TA to tribes	129,520
6.	University of California	6/1/73 - 5/31/74	Harvest R&D/TA to tribes	115,636
7.	National Academy of Sciences	3/23/73 - 3/23/74 Extended to 12/31/74	Technological Assessment	10,900
8.	Mission Indian Development Council (CA)	6/1/74 - 5/31/75	Harvest, Development & Operations	77,000
9.	Apache Marketing Cooperative Association, Inc.	6/1/74 - 5/31/75	Harvest, Development & Operations	95,000
10.	University of Arizona	6/26/74 - 5/31/75	R&D & TA to tribes	145,800
11.	University of California	6/26/74 - 5/10/75	R&D & TA to tribes	167,104
12.	Inter-tribal Council of California	2/7/75	Jojoba distribution study	2,500
13.	Apache Marketing Cooperative Association, Inc.	6/1/75 - 5/31/76	Development & Operations	227,500
14.	Southern California Jojoba Project, Inc.	6/1/75 - 5/31/76	Plantation Development & Operations	227,500
15.	National Academy of Sciences	6/30/75 - 6/30/76 Extended to 12/76	Jojoba Feasibility for Cultivation	28,640
16.	Apache Marketing Cooperative Association, Inc.	7/1/76 - 11/30/76	Plantation, Commercial Development & Operations	227,500
17.	Southern California Jojoba Project, Inc.	7/1/76 - 11/30/76	Plantation Development Research & Operations	227,500
			TOTAL	$1,665,298

* Does not include costs to BIA to develop 80 acres of land on Apache Reservation estimated to be approximately $16,000.

jojoba. The international conferences held in 1972 and 1976 and the smaller regional meetings and site visitations organized in the last few years have helped the overall jojoba effort.

The committee endorses the International Council for Jojoba Development, an international scientific research group, which was organized in 1972 at the conclusion of the First International Conference on Jojoba. Although the council was initially formed by representatives from Mexico and the U.S., membership in the council is open to all interested parties and countries. The purpose of the council is to function as an international body to foster the technical, agricultural and commercial aspects of jojoba development; to promote the dissemination of information; to sponsor meetings; to encourage new research activities and to serve as an international focal point for jojoba-related activities and information.

SUMMARY

The production system should be clearly designed to assist Indians in becoming owners and managers of jojoba agro-enterprises in order to increase tribal productivity and income. The Bureau of Indian Affairs has been directed by the Office of Management and Budget to take the lead role in working with other federal agencies in assisting tribal governments and Indians to develop their economies. Because of the magnitude and complexity of the proposed project, the Bureau should enlist the assistance and cooperation of other agencies, such as Department of Agriculture (USDA), Department of Health, Education, and Welfare (HEW), Department of Commerce (COM), Department of Housing and Urban Development (HUD), and the Small Business Administration (SBA), in allocating financial and technical resources sufficient enough to provide adequate jojoba development assistance to tribes establishing a jojoba industry . The Bureau should take great pains to ensure that the system will develop within the context of the special needs and specific limitations of the people of the Indian reservations.

Further, private foundations and industrial corporations could, and should, cooperate with Indian enterprises, possibly through joint ventures, in developing jojoba as a domestic source of a very valuable lubricant and as a substitute for high priced imported oils and waxes. The following specific recommendations and project development elements are proposed for establishing a government financed and managed development assistance project to help tribal governments and Indian organizations establish a viable jojoba production system.

1) A national "master plan," a program of action for the commercialization of jojoba, together with supporting national, regional, and local agency policies and adequate financing arrangements should be immediately developed by the government, along with a socioeconomic and technological impact study of developing jojoba based agro-industries on Indian lands.

The master plan must be objectively developed and should detail land management requirements, staffing, harvest and planting schedules, capitol purchases, technical, research and scientific assistance. It must be based on an economic analysis of the financial feasibility and commercial desirability of the jojoba agro-industries emphasizing financial risk and projected return on the grant and loan investments.

The socioeconomic and technological impact study should evaluate the growth and consequences of an Indian reservation-based jojoba based agro-industry. Specifically, the study should identify and evaluate the consequences of the projected commercial potential and impact in the economic, social and environmental areas. It should further develop strategies to alleviate problems that may hinder the development of this industry and strategies to neutralize negative impacts.

2) A strong development organization in the Bureau of Indian Affairs should be created with the cooperation of the Departments of Labor, Agriculture, Commerce, HEW, and HUD. The purpose of this structure would be to coordinate federal government categorical grant and loan programs to assure interagency funding, coordination and cooperation. The Bureau of Indian Affairs and the Agricultural Research Service should play strong leadership roles in implementing the project.

3) Appropriate decentralization based on effective machinery at the regional and reservation levels to coordinate the activities of federal departments should be an essential part of the project organizational structure.

4) Full participation by the tribal governments in the planning and implementation processes through tribal economic/resource development committees, cooperatives and other forms of tribal group organization is imperative.

5) Well managed tribal corporations, cooperatives and/or stock-ownership trusts should be created based on analysis to determine the most appropriate entity form for specific tribal characteristics.

6) With the use of small mechanical aids, annual harvesting of the natural populations of jojoba must begin immediately with a goal of harvesting as many of the nuts as is economically feasible.

7) Product development should begin immediately to market jojoba oil and waxes for use in specialized cosmetics, and as substitutes for those higher priced wax-oils such as beeswax ($1.80-2.20/pound); carnauba ($1.00-2.20/pound); Candelilla ($0.80-1.20/pound); and specialized synthetic lubricants ($1.00-2.20/pound). Conservative annual market estimate for these four products is 8750 metric tons.

8) To process the jojoba nut oil and at the same time train Indian plant managers and workers, the committee suggests that two small-scale processing plants costing approximately $14,000-$19,000 each should be established. One should be located in Arizona and one in California, close to the areas where natural populations of jojoba exist. Both plants should be close to railway, road, and airline transportation centers.

9) Each year, one thousand acres should be established as cultivated on at least four to eight reservations in Arizona and California. The cost per acre is estimated to be from $400-$800 for establishment; $150 for maintenance; and $150-200 for harvesting. This process should continue on the same 4-8 reservations and on various other reservations until at least 50 thousand acres are cultivated.

10) The plantation system, to be economically feasible, will require mechanical harvesting equipment. The committee suggests that the USDA/ARS be designated as the lead government agency for the research and development of this equipment.

11) Because at the present time the return on investment to establish the production system may take from 12-14 years, the committee suggests that government initially subsidize the development

of this system by allocating sufficient special funds for a period long enough to assure the economic success of the project.

12) To assure that the necessary scientific research, technological, and management assistance is provided on a timely basis to Indian jojoba enterprises, the committee suggests that two jojoba scientific research and development support centers be established, one in Arizona and one in California.

As an integral part of a successful Indian jojoba production system the two centers should be especially designed for the purpose of providing specific scientific and technological research on all aspects of the production of jojoba oil and its agronomic, industrial, marketing uses. These support centers will assure that tribal governments and organizations receive a full range of the above listed support services in order to achieve the goal of making the jojoba agro-enterprises profitable.

The committee suggests that these centers be established at the Universities of Arizona (Tucson) and California (Riverside) which are central to the major potential jojoba producing reservations and to the natural jojoba shrub populations in those states. These institutions have already developed a combination of jojoba expertise and expert personnel ideally suited for an interdisciplinary approach to jojoba agriculture. The University of Arizona has an unexcelled collection of jojoba and related agricultural materials in the Office of Arid Lands Studies (OALS). With its sophisticated arid lands computerized data system (search and retrieval) these data could be shared with other U.S. and foreign institutions, as could the specialized laboratories and experimental farms at both institutions. Such centers could be called "Jojoba Scientific Research and Development Support Centers."

Funds to support these centers should come from those appropriations earmarked by government for the commercialization of jojoba on Indian reservations. Funds should also come from private institutions interested in supporting U.S. efforts toward self-sufficiency in production of a domestic renewable source of strategic importance or as a substitute for sperm whale oil and high priced imported waxes.

PART III

JOJOBA PRODUCTS AND THEIR COMPOSITION

During 1975, the Committee on Jojoba Utilization of the National Research Council, NAS, produced a report entitled "Products from Jojoba: A Promising New Crop for Arid Lands." The report was a general survey of what was known about jojoba products, the major gaps in knowledge, and made recommendations for future actions. Details of information given below are reported in the Proceedings of the Second International Conference on Jojoba and Its Uses, to be published by the Consejo Internacional sobre Jojoba. Earlier information on jojoba can be found in the Selected References listed at the end of this report.

JOJOBA OIL

In chemical structure, jojoba nut oil is not a fat but a liquid wax. Fats, including the seed oils of all other plants, are triglycerides (a molecule of glycerol esterified with three molecules of fatty acids). Waxes like jojoba and sperm oil are wax esters (one molecule of a long-chain alcohol esterified with one molecule of a long-chain fatty acid). Jojoba oil is unique among vegetable oils, as sperm oil is unique among animal oils.

The jojoba plant is apparently the result of an evolution that produced a plant with its own enzymes and biosynthetic pathways that produce the oil. Such a vegetable oil has never before been available to industry. It seems likely that in the current programs, making jojoba oil available for the first time, industrial chemists will soon uncover many uses.

The following general characteristics should make jojoba oil valuable:

- its natural purity and molecular simplicity
- its stability: it is a nondrying oil, having such high resistance to oxidation that it can be stored for years without becoming rancid

- its lubricity after sulfurization
- its source of chemicals with 20 and 22 carbon atoms
- its unsaturation (double bonds)

The wax and protein content of nuts from 20 bushes are shown in Table 1. Most jojoba nuts are between 45 and 60 percent oil, and the average is close to 50 percent. The clear, unsaturated oil can be obtained by the pressing or solvent-extraction methods used commercially to isolate vegetable oils from cottonseeds, soybeans, coconuts, and corn.

Jojoba oil from plants throughout California and Arizona has the same wax-ester composition. The acids and alcohols that make up these esters do not vary appreciably with location, soil type, rainfall, or altitude. The oil of a rare prostrate variety of jojoba that grows only along the Pacific coast of Baja California differs slightly from that of the more common variety of jojoba in that it contains a larger proportion of the higher homologs.

The oil does not change in composition during storage. Nuts analyzed 25 years after harvest show no change in oil-ester composition. Thus nuts (if dried) can be stored without deterioration or chemical change.

Chemical Structure

Jojoba oil is composed almost entirely of esters of high molecular weight, straight-chain mono-ethylenic acids and mono-ethylenic alcohols. The unsaturated acids are a mixture of cis-11-eicosenoic (C_{20}) and cis-13-docosenoic (C_{22}, erucic), with small quantities of oleic (C_{18}) and nervonic (C_{24}) acids. The unsaturated alcohols are a mixture of cis-11-eicosenol, cis-13-docosenol and cis-15-tetracosenol, with small quantities of alcohols of lower molecular weight (see Table 2).

The conventional position for a double bond in a natural fat or oil composed of C_{18} acids is Δ^9 (i.e., between carbon 9 and carbon 10 on each of the fatty acids) but jojoba oil has mainly Δ^{11} and Δ^{13} alcohols and acids, because of the large amount of C_{20} and C_{22} chains. However, counting from the methyl end of the chains, all of these monoenes can be placed in one of the two homologous series, W-9 acids or W-9 alcohols.

TABLE 1 Wax and Protein Content of Nuts from Individual Jojoba Plants

Seed Sample (High Wax %)	Wax %	Protein %	Seed Sample (Low Wax %)	Wax %	Protein %
1	56.9	27.7	11	49.1	27.7
2	56.4	26.6	12	45.8	31.2
3	56.4	27.3	13	45.5	29.7
4	57.9	26.3	14	48.6	32.0
5	56.9	27.5	15	46.8	29.8
6	58.6	32.0	16	43.2	33.4
7	56.9	28.7	17	45.4	30.8
8	56.8	28.4	18	47.5	29.6
9	56.5	30.5	19	47.7	30.8
10	56.7	30.3	20	47.5	29.6
Mean	57.0	28.5	Mean	46.7	30.7

Source: D. M. Yermanos.

TABLE 2 Alcohol/Acid Structures of Jojoba Oil Determined by Gas Chromatography, Mass Spectrometry, and Ozonolysis

Carbons and Double Bonds	Alcohol	Percent	Carbons and Double Bonds	Acids	Percent
14:0	Tetradecanol	trace	12:0	Dodecanoic	trace
16:0	Hexadecanol	0.1	14:0	Tetradecanoic	tr.
17:1	Heptadec-8-enol	tr.	15:0	Pentadecanoic	tr.
18:0	Octadecanol	0.2	16:0	Hexadecanoic	1.2
18:1	Octadec-9-enol	0.7	16:1	Hexadec-9-enoic	0.2
18:1	Octadec-11-enol	0.4	16:1	Hexadec-7-enoic	0.1
20:0	Eicosanol	tr.	17:1	Heptadecenoic	tr.
20:1	Eicos-11-enol	43.8	18:0	Octadecanoic	0.1
21:1	Hencos-12-enol	tr.	18:1	Octadec-9-enoic	10.1
22:0	Docosanol	1.0	18:1	Octadec-11-enoic	1.1
22:1	Docos-13-enol	44.9	18:2	Octadecadienoic	0.1
24:1	Tetracos-15-enol	8.9	18:3	Octadecatrienoic	tr.
			19:1	Nonadecenoic	tr.
			20:0	Eicosanoic	0.1
			20:1	Eicos-11-enoic	71.3
			20:2	Eicosadienoic	tr.
			22:0	Docosanoic	0.2
			22:1	Docos-13-enoic	13.6
			23:1	Tricosenoic	tr.
			24:0	Tetracosanoic	tr.
			24:1	Tetracos-15-enoic	1.3

Source: G. F. Spencer and T. K. Miwa.

Jojoba oil is chemically purer than most natural substances; 97 percent is liquid wax esters (see Table 3). Yellow vegetable pigment can be removed with bleaching earth. The oil also has an unusually narrow range of wax-ester structures--over 83 percent of the esters present are combinations of C_{20} and C_{22} acids and alcohols (see Table 4).

The NMR spectrum of jojoba oil appears in Figure 1. Cis-trans isomerization of the double bonds can be induced with selenium and nitrous oxide catalysts, producing up to 80 percent trans and 20

TABLE 3 Gas-Chromatographic Composition of Expeller-Pressed Jojoba Oil from Arizona

Wax esters	%	Free alcohols	%		%
C-33	0.02	C-16	0.01	Campesterol	0.05
C-34	0.08	C-18	0.04	Stigmasterol	0.08
C-35	0.04	C-20	0.49	Sitosterol	0.21
C-36	1.16	C-22	0.49	Others	0.52
C-37	0.02	C-24	0.07		
C-38	6.23	C-26	0.01		
C-39	0.04		1.11		
C-40	30.56				
C-41	0.10	Free acids	%		
C-42	49.50	C-16	0.08		
C-43	0.06	C-18	0.23		
C-44	8.12	C-19	0.01		
C-45	0.03	C-20	0.60		
C-46	0.86	C-21	0.03		
C-48	0.16	C-22	0.03		
C-50	0.06	C-24	0.02		
	97.05		1.00		

Source: T. K. Miwa.

TABLE 4 Wax Ester Combinations of Jojoba Oil Determined by Gas Chromatography/Mass Spectrometry

		%
Octadecenyl Hexadecanoate	C-34	0.1
Eicosenyl Hexadecanoate	C-36	1.1
Octadecenyl Octadecenoate	C-36	0.3
Eicosenyl Octadecenoate	C-38	5.9
Octadecenyl Eicosenoate	C-38	1.0
Eicosenyl Eicosenoate	C-40	30.9
Docosenyl Eicosenoate	C-42	43.2
Eicosenyl Docosenoate	C-42	7.6
Tetracosenyl Eicosenoate	C-44	6.2
Docosenyl Docosenoate	C-44	1.8
Eicosenyl Tetracosenoate	C-44	0.8
Tetracosenyl Docosenoate	C-46	0.9
Tetracosenyl Tetracosenoate	C-48	0.2
Hexacosenyl Tetracosenoate	C-50	trace

Source: G. F. Spencer and T. K. Miwa

percent *cis* double bonds. The product is a soft solid with a melting point of about 44°C. The amount of isomers formed can be controlled to obtain any melting point between that of the pure oil (7°C) and 44°C. The product with a melting point close to that of the human body could be of potential use to the pharmaceutical and cosmetics industry.

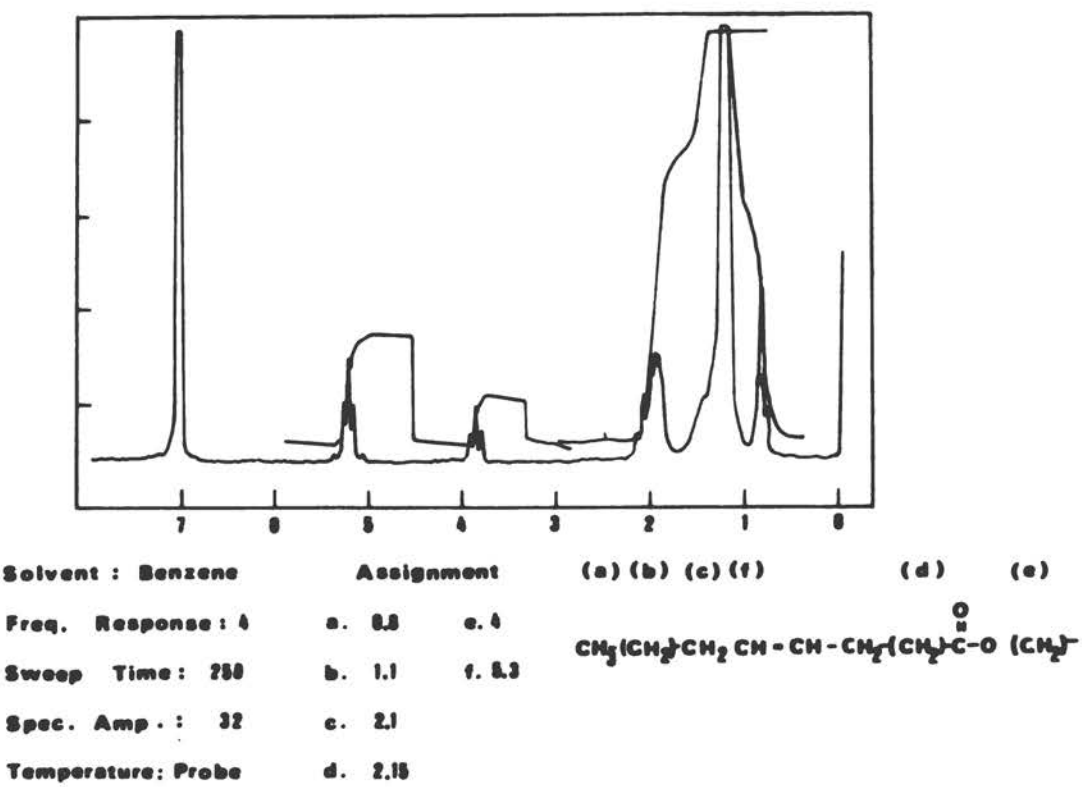

FIGURE 1 N.M.R. Spectrum of Jojoba Oil. (Source: J. Wisniak and H. Benajahu.)

Physical Properties

Jojoba oil is soluble in common organic solvents such as benzene, petroleum ether, chloroform, carbon tetrachloride, and carbon disulfide, but it is immiscible with alcohol and acetone. Some detailed properties are listed in Table 5.

The density, viscosity, refractive index, dielectric constant and conductance have been measured in a wide range of temperatures. The oil's high viscosity index, high flash and fire points, high dielectric constant, and high purity are key properties for select industrial uses.

The endotherm by differential scanning calorimetry for frozen jojoba oil from Arizona nuts is shown in the upper portion of Figure 2. The amorphous nature of the frozen oil and its melting process are reflected in the broad endotherm, which cannot be deduced by conventional melting point determinations.

Jojoba Oil as a Lubricant

Jojoba oil may be made to react with sulfur to yield a stable product containing a relatively large amount of sulfur, which could serve well as a lubricant or as a lubricant additive.

Sperm oil is widely used in lubricants because of the oiliness and metallic wetting properties it imparts and its nondrying characteristics that prevent gumming and tackiness. The composition and physical properties of jojoba are close enough to sperm oil to suggest the use of jojoba oil as a substitute for most of the uses of sperm oil (see Table 5).

Jojoba oil has several advantages over the similar product from the sperm whale:

- it has a mild, pleasant odor
- it contains no glycerides and very little besides the liquid wax

TABLE 5 Properties of Jojoba Oil[a]

Freezing point	10.6–7.0°C	Smoke point (AOCS Cc 9a-48)[b]	195°C
Melting point	6.8–7.0°C	Flash point (AOCS Cc 9a-48)[b]	295°C
Boiling point at 757 mm under N_2	398°C	Fire point (COC)	338°C
Heat of fusion by differential scanning calorimetry	21 cal/g	Iodine value	82
Refractive index at 25°C	1.4650	Saponification value	92
Dielectric constant (27°C)	2.680	Acid value	2
Specific conductivity (27°C)	$8.86 \cdot 10^{-13}$ mho/cm	Acetyl value	2
Specific gravity, 25/25°C	0.863	Unsaponifiable matter	51%
Viscosity		Total acids	52%
Rotovisco (25°C)		Iodine value of alcohols	77
MV-1 rotor in MV cup	35 cp	Iodine value of acids	76
Plate and cone with Pk-1	33 cp	Average molecular weight of wax esters	606
Brookfield, spindle #1, 25°C	37 cp		
Cannon-Fenske, 25°C	50 cp		
Cannon-Fenske, 100°C	27 centistokes		
Saybolt, 100°F	127 SUS[c]		
Saybolt, 210°C	48 SUS[c]		

[a]Oil from expeller-pressed jojoba nuts starts to freeze at 10.6°C (51°F). It solidifies into a thick paste at 7°C. Frozen oil, allowed to warm up, melts at 7°C (45°F).
[b]Smoke and flash points determined according to the official method, Cc 9a-48, of the American Oil Chemists' Society.
[c]Saybolt Universal seconds.
Source: T. K. Miwa, J. Wisniak

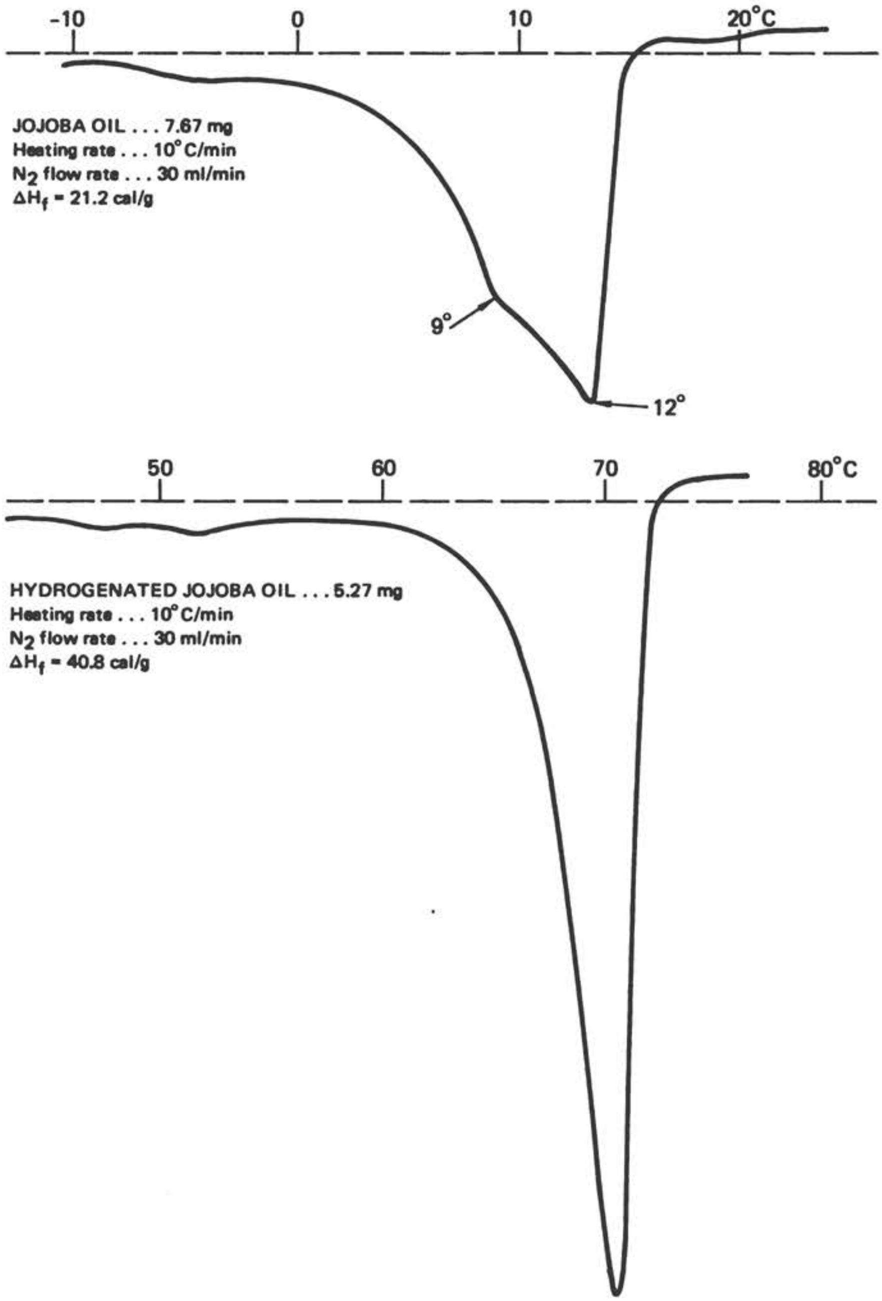

FIGURE 2 Differential Scanning Calorimetry for Frozen Jojoba Oil from Arizona Nuts.

- it requires little or no refining to prepare it for most lubrication purposes
- it is a vegetable product that can be produced in many resource-poor countries.

Sperm oil has been used as an extreme-pressure and antiwear additive in lubricants for gears in differentials and transmissions, in hydraulic fluids that need a low coefficient of friction, and in cutting and drawing oils. In some of these, sperm oil has been used directly, but it is usually sulfurized (sometimes epoxidized, chlorinated, or fluorinated). Gear lubricants (e.g., in automobile transmissions) commonly contain 5 to 25 percent of sulfurized sperm oil.

Experiments have been conducted on jojoba oil to test (using Four-Ball Extreme Pressure and Falex machines) whether it has lubricating and antiwear properties comparable to those of sperm oil (H. Gisser, Frankford Arsenal, U.S. Department of the Army, Philadelphia, personal communication 1974). On the basis of the performance evaluations already conducted, sulfurized jojoba oil shows properties equivalent to sulfurized sperm oil in lubricant applications. (The accuracy of these results has been substantiated by H. Gisser.) The characteristics of sulfurized jojoba oil are remarkably similar to those of sulfurized sperm oil (see Table 6). The sulfurized jojoba and sulfurized sperm oils are essentially equivalent in improving the load-carrying capacity under extreme-pressure conditions of both naphthenic and bright stock base oils. They exhibit approximately equivalent extreme-pressure (EP) properties when tested neat. Small amounts of sulfurized jojoba and sulfurized sperm oils are also equally effective antiwear additives to the naphthenic and bright stock base oils (see Figures 3 and 4).

Sulfurized products from unrefined jojoba oil tend to foam in some lubricant tests and also increase their viscosity two or three fold after heat treatments. These undesirable charactersitics are readily eliminated by short heat treatment of the raw oil at 300°C and subsequent removal of the caramelized flocculants by filtration. Sulfurized products from this treated jojoba oil show EP properties superior to sulfurized sperm whale oil (see Table 7).

Sulfur-chlorination of jojoba oil can be performed at room temperature. The viscosity of the product changes rapidly with sulfur content; above 9 percent sulfur it becomes an elastic factice with good adhesive properties. The liquid derivatives show excellent lubricating and antiwear properties (see Tables 8, 9, and 10). For sulfur contents between 0 to 8 percent the average molecular weight of the sulfurized oil varies between 600 and 3,400. The NMR spectrum of a partially sulfur-chlorinated oil appears in Figure 5.

Tests on sulfurized jojoba oil as a component in a lubricant composition for typical shop metal-cutting operations are in progress, and laboratory tests are being conducted. Figure 6 shows the markedly improved performance of both sulfurized jojoba and sperm oils as compared with that of base mineral oils, as well as comparable performance characteristics of jojoba and sperm products.

TABLE 6 Characteristics of Sulfurized Jojoba and Sperm Oils

Test	Sulfurized Jojoba Oil	Sulfurized Sperm Oil
Sulfur, percent	9.88	9.98
Viscosity, at 37.8 C	3,518 SUS[a]	1,961 SUS[a]
Viscosity, at 99 C	491 SUS[a]	201 SUS[a]
Specific gravity at 15.6 C	0.9476	0.9613
API at 15.6 C	17.82	15.71
Flash point	250 C	243 C
Fire point	282 C	280 C
Free fatty acids (oleic)	1.55	2.35
Saponification no.	162	195
Pour point	16.1 C	15.6 C
Corrosion, 90/10, 3 h at 100 C	2A	2A
Color, API, 10% in 1¾ color oil	4¾	8+

Source: H. Gisser.
[a]Saybolt Universal seconds.

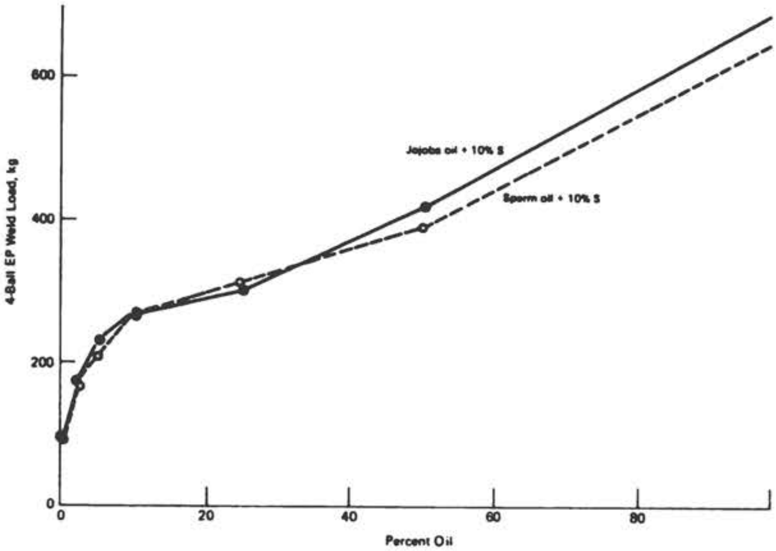

FIGURE 3 Sulfurized Oil in Naphthenic Oil. (Source: H. Gisser.)

Jojoba Oil as a Source of Acids and Alcohols

Jojoba nut oil could become a source of straight-chain monounsaturated alcohols and acids. There are no other readily available sources for these acids and alcohols, and in jojoba oil they are present in relatively high concentrations. They can be isolated almost uncontaminated by any impurity. These compounds could be used as intermediates in the preparation of numerous other compounds--disinfectants, surfactants, detergents, lubricants, driers, emulsifiers, resins, plasticizers, protective coatings, fibers, corrosion inhibitors, bases for creams and ointments, antifoamers, and

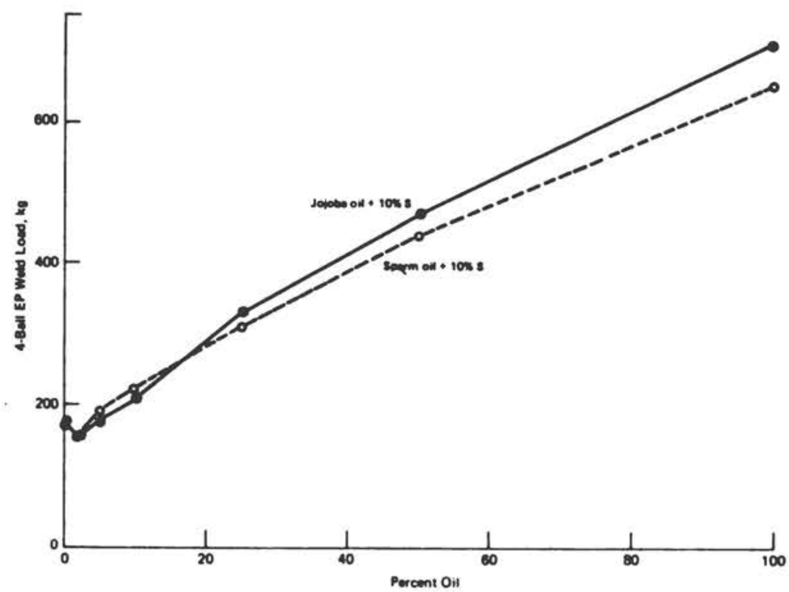

FIGURE 4 Sulfurized Oil in Bright Stock Oil. (Source: H. Gisser.)

TABLE 7 Properties of Sulfurized Oils from Raw and Treated Jojoba Oil and from Sperm Whale Oil.

Test	Raw Jojoba	Treated Jojoba	Sperm Whale
Pour point, °F	53	54	64
Freezing point, °F	48	50	59
Flash point, °F	434	491	464
Fire point, °F	560	509	536
Wear test scar diameter, mm	0.620	0.465	0.558
Extreme pressure test-weld, Kg	260	240	230

Source: T. K. Miwa and J. A. Rothfus

TABLE 8 Mechanical Behavior of Sulfur-Chlorinated Jojoba Oil Four-Ball Scar Diameter (mm)*

Dilution, wt. % S	S % In Jojoba Derivative					
	0.57	3.01	4.41	6.45	7.10	7.70
0.1	0.573	0.574	0.605	0.715	0.580	0.720
0.2	0.576	0.584	0.637	0.661	0.563	0.524
0.5	0.584	0.787	0.782	0.613	0.535	0.506
1.0	–	0.660	–	0.566	0.550	0.512
2.5	–	0.415	–	0.439	0.635	0.552

*BLANK (NAPHTHENIC OIL) = 0.888 mm
CONDITIONS: 1 HR/1200 RPM/75°C/40 KG
Source: J. Wisniak and H. Benajahu

TABLE 9 Mechanical Behavior of Sulfur-Chlorinated Jojoba Oil Four-Ball EP Weld Points (kg)*

Dilution, wt. % S	S % In Jojoba Derivative					
	0.57	3.01	4.41	6.45	7.10	7.70
0.1	190	190	190	190	190	210
0.2	190	250	270	260	270	270
0.5	320	350	410	450	450	420
1.0	–	470	–	500	510	480
2.5	–	–	–	500	500	480

*BLANK (NAPHTHENIC OIL): 170 kg
ONE MINUTE RUNS TILL WELD LOAD IS REACHED.
Source: J. Wisniak and H. Benajahu

TABLE 10 Mechanical Behavior of Sulfur-Chlorinated Jojoba Oil Falex Seizure Loads (lb)*

Dilution, wt. % S	S % In Jojoba Derivative					
	0.57	3.01	4.41	6.45	7.10	7.70
0.1	500	500	750	750	750	4500
0.2	500	500	750	750	4500	4500
0.5	750	750	4500	4500	4500	4500
1.0	–	4500	–	4500	4500	4500
2.5	–	4500	–	4500	4500	4500

*NAPHTHENIC OIL. THE 4500 LB RATING IS THE HIGHEST ATTAINABLE WITH THIS TEST.
Source: J. Wisniak and H. Benajahu

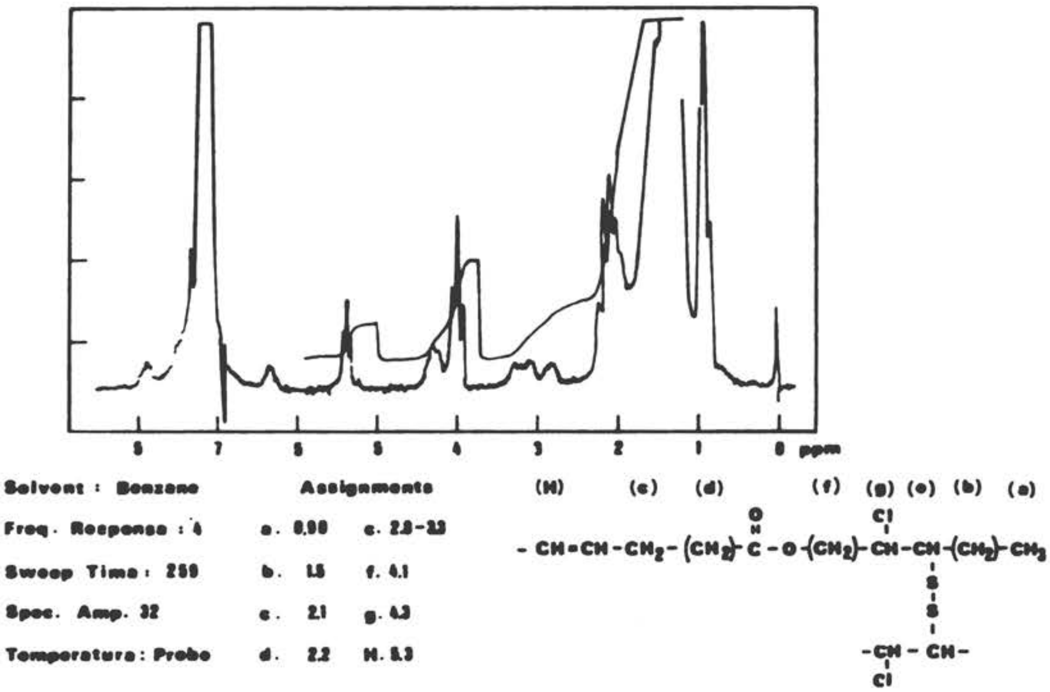

FIGURE 5 N.M.R. Spectrum of Jojoba Oil Sulfurized with $S_2 Cl_2$ (Source: J. Wisniak and H. Benajahu.)

other products. Long-chain unsaturated alcohols have been prepared by sodium reduction of jojoba oil (Molaison et al. 1959).

Miscellaneous Uses

Jojoba's antioxidation characteristics, which give it high resistance to rancidity, suggest that field uses requiring a stable vegetable oil

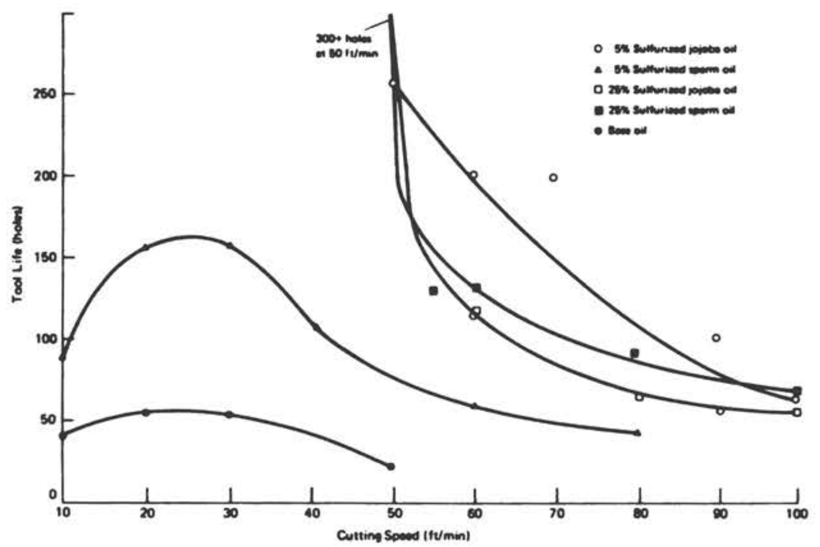

FIGURE 6 Relationship Between Tapping Tool Life and Cutting Speed. (Source: J. Messina.)

may prove an important market for jojoba oil. Possibilities that come to mind include using it as a carrier for pesticides and plant hormones, as a water-evaporation retardant, for sizings and waterproofing, and for softening leather, paints, and adhesives. When compared with sperm whale oil as an antifoam agent in fermentation processes, jojoba oil enhances the productivity of penicillin and cephalosporin antibiotics by 15-20 percent.

Jojoba oil reacts with sulfur chloride to form compounds with a wide range of properties, from oils to rubbery solids known as Factices. Varnishes, rubber, adhesives, and linoleum can be produced from such preparations (Ellis 1936, Spadaro and Lambou 1973). A patent covers the use of jojoba Factice in the manufacture of printing ink (Whitner 1940). The array of Factices with widely different viscosities that can be produced offers a wide open field for research and product development.

Although this report does not consider uses for jojoba oil in food, it is worth noting that its different chemical structure may make it resistant to hydrolysis by lipases, the digestive enzymes that hydrolyze fats. A great deal of expensive research would be needed for proof and acceptance, but this property might eventually lead to its use in low-calorie fatty foods and as masks to protect ingested materials from acid and enzymic degradation in the stomach.

Its resistance to rancidity and several other properties are promising for its use in cosmetics. Although initial skin-sensitivity testing looks promising, much expensive research still remains to be done.

Polyethylene dissolves readily in hot jojoba oil. The jojoba becomes microencapsulated and, over a period days, diffuses out. (see Figure 7). This appears to be a fruitful area for research and product development.

HYDROGENATED JOJOBA OIL

Jojoba oil can be hydrogenated readily under mild conditions using a variety of commercial nickel catalysts (for example, 3g of Girdler Catalyst G-53 per liter of oil, 90-100°C, 100-200 psi hydrogenates the material completely in 15-30 minutes). The effect of the operating variables pressure, temperature, percent catalyst, and agitation rate, on the rate of hydrogenation and the rate of formation of *trans isomers* has been reported. Steam sparging removes hydrogenation odor. The costs of hydrogenation to convert the oil into a solid wax in

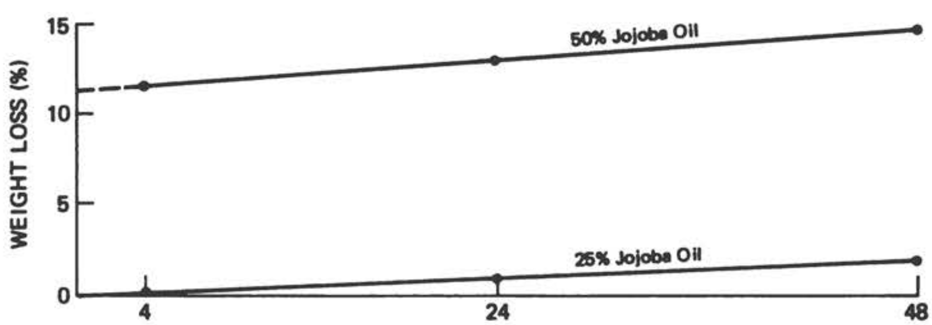

FIGURE 7 Microencapsulation and Diffusion of Jojoba Oil in Polyethylene. (Source: T.K. Miwa)

larger-scale commercial operations is expected to be in the range of $0.04-0.10 per pound.

Jojoba oil can be hydrogenated to a hard white wax. The catalysts and conditions used to hydrogenate vegetable oils to margarine or shortening can be used to make a sparkling white semicrystalline material. A hard product with a high melting point, it has properties competitive with beeswax and candelilla, carnauba, and spermaceti waxes. Solid jojoba wax is not yet available in quantities suitable for industrial purposes, but the other waxes are subject to steeply rising costs and uncertainties of supply. Candelilla and carnauba are imported into the United States; imports of spermaceti have recently been banned because of the endangered status of sperm whales. So hydrogenated jojoba oil appears to have considerable commercial promise. Virtually 100 percent wax esters, hydrogenated jojoba oil is made up of saturated C_{20} and C_{22} fatty alcohols--no triglycerides are present. X-ray diffraction has shown that the ester molecules are lined up in hexagonal arrays, but the samples are paracrystalline rather than completely crystalline, probably because slightly differing carbon-chain lengths prohibit perfect ordering. The structure is monoclinic with orthorhombic O1 chain packing. Cell dimensions are: $a = 4.98$, $b = 7.44$, $c = 55.2A$, $\beta = 90°$. A larger secondary unit cell is observed and identified as permitting the hydrocarbon ester chains freedom of rotation. The high solvating power in jojoba wax for paraffinic polymers, such as polyethylene, resides in the similarity of their interchain affinities and the duplication of their unit cell packing dimensions.

Hydrogenated jojoba oil has a lower melting point and is softer than carnauba (the "king of waxes"); nevertheless, it has several properties, such as purity, whiteness, and crystallinity, that may make it competitive in many applications. Where crystallinity is a disadvantage, hydrogenated jojoba oil can easily be made amorphous (like carnauba) by adding small amounts of other waxes or polyethylene.

Furthermore, hydrogenated jojoba oil is produced from the liquid unsaturated oil, which is more readily purified than a solid, natural wax such as carnauba. Jojoba oil's double bonds offer chemical functionality that can be capitalized on to produce partially hydrogenated jojoba oil, which offers exciting possibilities for industry because an array of soft white waxes and creams can be produced at will. Thus, the jojoba product is structurally modifiable, whereas the saturated waxes are not.

Hydrogenated jojoba oil is miscible with paraffin, solid triglycerides, and polyethylene. It appears to be broadly useful for upgrading cheap waxes such as paraffin wax. Its combinations with polyethylene offer an array of blends with a wide range of properties and potential uses (see Table 11).

Melting Point and Hardness

The fully hydrogenated wax has a melting point of about 70°C (158°F). It is also very hard, approaching the hardness of carnauba wax. Comparison of its hardness with that of other waxes is shown in Table 11.

The marked synergistic improvement in hardness and texture of the jojoba/low-density polyethylene mixtures is shown in Figure 8.

TABLE 11 Hardness of Hydrogenated Jojoba Wax, Other Vegetable Waxes, Some Plastics, and Some Jojoba Blends

Wax				Hardness Index[a]
Jojoba (Emery)				1.29
Jojoba (SRRC, Centry)				1.17
Jojoba (Nutrilite)				0.74
Paraffin ("Paroseal")				0.36
Paraffin ("Parowax")				0.44
Beeswax (High-Grade, Yellow)				0.55
Beeswax (Delmar Candles)				0.26
Cane Wax (Dark Brown)				2.10
Carnauba (High-Grade)				2.84
Polyethylene (Low-Density)				2.01
Polyethylene (High-Density)				3.51
Poly (tetrafluoroethylene)				2.57
Milk Carton Plastic				4.34
Polypropylene				Not Measurable
Candles				
Jojoba	Paraffin	Polyethylene	(mp°C)	
1.00	2.00	0.03	(53-58)	0.67
1.00	2.00	0.15	(54-59)	0.75
1.00	2.00	0.75	(58-61)	1.10
Beeswax Replacement				
Jojoba	Paraffin			
1.00	2.00			0.57
Carnauba Replacement				
Jojoba	High-Density Polyethylene			
1.00	4.00			2.84
Other Blends				
Jojoba	Polypropylene			
1.00	1.00			2.67
4.00	1.00			1.61
Jojoba	Jojoba Oil			
95	5			0.74

Source: T. K. Miwa

[a]Hardness expressed as load, in kg, needed to force a 30-degree conical aluminum needle to penetrate 1.00 mm. into flat wax surface in 60 seconds at 25°C.

Uses

The main uses for saturated waxes are in floor finishes, carbon paper, and polishes for furniture, shoes, and automobiles. They are also widely used to raise the melting point, gloss, and hardness of other waxes for use in paper, textiles, insulating materials, batteries, candles, matches, soap, salves, chalk, and crayons. Waxes are used for film coatings in the food industry to retard shrinkage, reduce spoilage, minimize aging, and retain flavor. In the United States, fruits, vegetables, and chocolate confections are also treated in this way. Hydrogenated sperm oil (spermaceti) and other waxes are used as release agents and lubricants in bakeries and as coatings, masks, and sizings in nonfood products. Hydrogenated jojoba oil appears to have commercial potential for many of these uses.

Probably, hydrogenated jojoba oil's most outstanding and valuable characteristic is its hardness. This should make it useful in polishes and the hard ink coatings required for carbon paper and similar products.

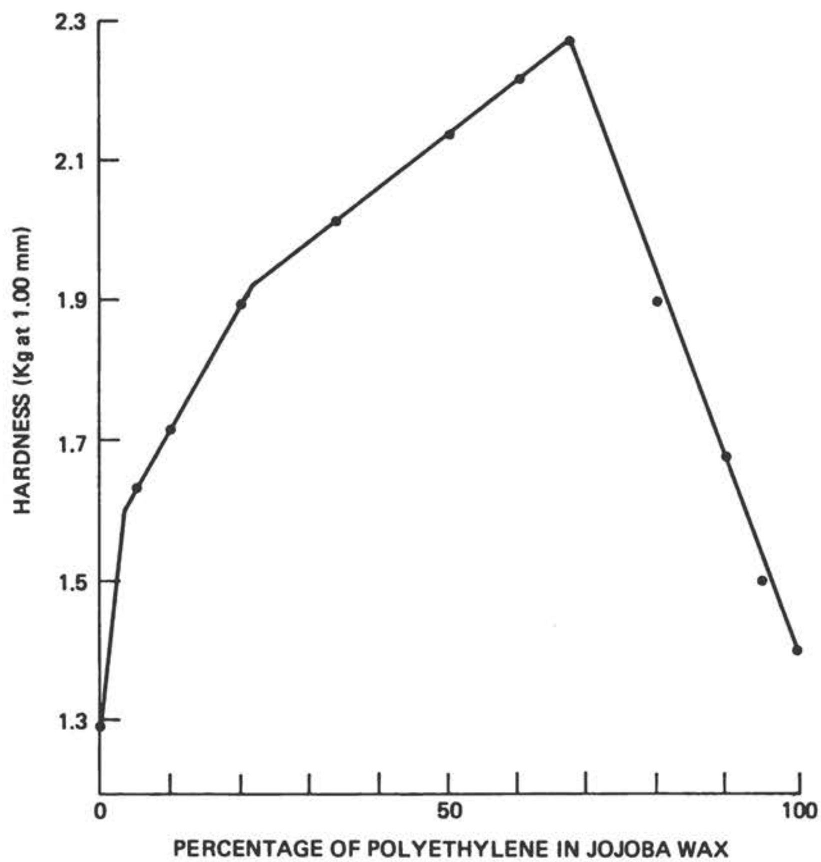

FIGURE 8 Synergistic Behavior in Hardness of Jojoba Solid Wax/Low-Density Polyethylene Solid Solutions. (Source: T. K. Miwa)

Emulsifiability with water for self-lustering floor polishes and aqueous creams for pharmaceutical products and furniture polishes also is a highly valued property of some waxes. A 30 percent wax-in-water emulsion has been prepared from hydrogenated jojoba wax using 4 percent stearic acid and 2 percent triethanolamine as emulsifying agents. The wax emulsified easily, and the prepared emulsion after more than one month shows no sign of water separation--an indication of good stability. This good stability, combined with the excellent hardness of the hydrogenated product, should enhance its desirability for emulsions in a variety of applications.

Hydrogenated jojoba oil has important potentials in candlemaking industries. It is combustible and smokeless and has a low ash content. The pure wax makes a brittle, unsatisfactory candle, but it blends with other waxes or with 1 percent polyethylene to produce a high-quality product. Its melting point is high enough to produce candles that do not readily melt or drip around the edges or melt during storage in warm climates. A particular use might be in dipped candles with a layer of hydrogenated jojoba oil deposited on the outside of softer waxes or fats to support them and prevent sagging and dripping. The market for beeswax-jojoba and paraffin-jojoba candles, in particular, appears promising.

Plastic flow is an important property for high-gloss buffing waxes and in high-pressure lubricants. Hydrogenated jojoba oil buffs satisfactorily and leaves a coat hard enough for use in both solvent- and emulsion-type floor waxes. Some initial tests suggest that hydrogenated jojoba oil has industrial potential in solvent-type waxes, especially in self-polishing wax formulations. But one test indicates that jojoba wax is unsatisfactory for paste or liquid formulation or in carbon-paper inks because it crystallizes to a dry powder from an oil or solvent without swelling (because of poor solvent retention). It could, however, be used as a blend with petroleum waxes, which tend to form gels instead of lattice crystals with solvents.

If wax is to be used for insulators, a high dielectric constant is an important property, and hydrogenated jojoba oil has it. Because of its crystallinity, hydrogenated jojoba oil appears unsatisfactory as a mold-release agent and as a plug for making molded objects; too many fracture lines develop as the molten wax cools and solidifies. However, a small amount of additive (such as polyethylene or another wax) destroys the crystallinity. Such combinations, though still requiring much research, may prove to be valuable industrial products in the future. Hydrogenated jojoba wax may also prove valuable as a hardening agent for existing molding-wax formulations. Partially hydrogenated jojoba oil gives soft white waxes whose properties are yet unknown, but they may have important potential in lipstick and cosmetic manufacture.

Although toxicity studies on hydrogenated jojoba oil have not yet been reported, a cosmetic company (Koei Perfumery, Japan) has reported the absence of any acute toxicity in laboratory and clinical tests using jojoba oil as its source for cosmetics. Similar favorable results were reported by a research corporation that conducted a series of toxicity studies for the San Carlos Apache Marketing Cooperative Association, Inc.

JOJOBA NUT MEAL

A by-product of jojoba nut is the meal remaining after the oil has been extracted. It should prove of particular interest to livestock producers in arid areas where the plant is grown. The meal contains 26 to 32 percent protein, as well as carbohydrate and fiber. Its amino acid analysis is shown in Table 12. Of the essential amino acids, the lysine content is good, but the methionine content is poor. The nutritional effectiveness of jojoba meal in animal feeds is very uncertain at present because of an unusual toxic factor in the meal. The meal contains an unusual material, simmondsin (Figure 9), whose ingestion causes laboratory rats to avoid food, even their regular diet, to the point where they die of starvation. Its effect on ruminants (if any) is unknown at this time. Although the appetites of laboratory rodents are suppressed by simmondsin, ground squirrels, desert chipmunks, mule deer, and rabbits gather and feed on the nuts. Experiments have recently shown that the pocket mouse is able to survive on a jojoba nut diet. Apparently, simmondsin has little or not effect on this animal. (Information supplied by C. Wade Sherbrooke.)

The adverse effects of simmondsin can be readily rectified by treatment of the meal with ammonia, converting the cyano group to a nontoxic amide group. Mice no longer avoid the jojoba meal when fed as a supplementary diet and show normal growth rates.

TABLE 12 Amino Acids in 1-Year-Old Nuts After Extraction of the Wax by Pressure, Followed by Solvent Extraction with Hexane

Amino Acid	Grams of Amino Acid per 100 g of Meal	Percentage of Amino Acids
Lysine[a]	1.4	5.7
Histidine	0.6	2.5
Arginine	1.9	7.8
Aspartic acid	2.6	10.6
Threonine[a]	1.3	5.3
Serine	1.3	5.3
Glutamic acid	3.2	13.1
Proline	1.5	6.1
Glycine	2.4	9.8
Alanine	1.1	4.5
Cystine (half)	0.6	2.4
Valine[a]	1.5	6.1
Methionine[a]	0.1	0.4
Isoleucine[a]	0.9	3.7
Leucine[a]	1.8	7.3
Tyrosine	1.1	4.5
Phenylalanine[a]	1.2	4.9
TOTAL	24.5	100.0

Source: D. M. Yermanos, private communication.
[a]Essential amino acid.

If jojoba meal is to become acceptable as a livestock feed, Food and Drug Administration requirements will have to be met. In this respect, answers are needed to at least three basic questions:

• Does the material cause any adverse effects when fed to livestock (e.g., cattle, swine, and poultry)?
• Are any hazardous compounds transmitted into the meat, milk, or eggs?
• If detoxification is required, is a reliable method available to assay detoxified meal to ensure the absence of toxic factors?

The nutritional value of the protein fed to animals must also be evaluated.

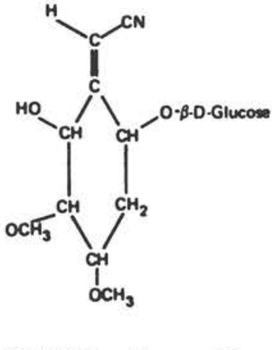

FIGURE 9 Simmondsin.

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