Tropical Products Institute

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Jojoba: an assessment of prospects

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This report was produced by the Tropical Products Institute, a British Government organisation that co-operates with developing countries in helping them to derive greater benefit from their plant and animal resources. It specialises in post-harvest problems and will be pleased to answer requests for information and advice addressed to the Director.

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NOTE

The following exchange rate has been used in this report:

£1 = US $2

Metric units are used throughout. The following conversion factors have been used:

1 hectare	= 2.4711 acres
1 kilogram	= 2.2046 pounds

Summaries

SUMMARY

Jojoba: an assessment of prospects

Jojoba (*Simmondsia chinensis* (Link.) Schneider) is a shrub which grows wild in the semi-arid region of the Sonora desert in northern Mexico and the south-western USA. The plant bears seeds which contain an unusual liquid vegetable wax*. The only natural liquid wax in established use is sperm whale oil for which jojoba oil has been suggested as a substitute. This, indeed, has been one of the main reasons for the species attracting considerable interest. Jojoba oil may also be hydrogenated to form a solid wax which might be used as a substitute for other solid animal and vegetable waxes.

At present, the greater part of jojoba seed produced in the wild is unexploited, but a small proportion is harvested by hand. Research on the selection and cultivation of jojoba is currently under way in the USA, Mexico and Israel. Of particular importance is the need to increase the yield. At present a yield of 2,250 kilograms of clean, dry seed per hectare might reasonably be expected, equivalent to 900 kilograms per hectare of oil, but the economic analysis illustrates that it will be essential to increase this yield significantly before jojoba cultivation is likely to prove viable on any but a relatively small scale. Vegetative propagation by cuttings and tissue culture is likely to have a significant role to play in future breeding programmes.

Since the cost of hand harvesting in many countries will be too great, mechanized harvesting will be required. Many techniques have been proposed for harvesting the seed, but none has so far proved satisfactory.

The present annual production of jojoba oil, amounting to only tens of tonnes, has found a ready market at high prices (£5,500–£7,700 per tonne) for use in the manufacture of cosmetics, candles, etc., and for use by research establishments. The size of this high priced market can be expected to remain in hundreds of tonnes. Thereafter jojoba oil will need to be able to compete with other oils and waxes if it is to find a larger volume market. Although the suitability of jojoba oil has been demonstrated in a range of end-uses, in most cases it does not exhibit special or superior properties compared with alternative oils.

This report examines in detail the sperm oil and animal and vegetable wax markets in an attempt to establish market price and volume parameters for jojoba oil and wax. These market analyses suggest that at £900 to £950 per tonne jojoba wax could compete in the wax markets and might obtain a share of the market of between 2,000 and 5,000 tonnes. At £500 to £600 per tonne jojoba oil could compete with sperm oil which at present has a market of below 20,000 tonnes, although this will

*Called jojoba oil throughout this report probably have been eroded to a substantial extent by synthetics by the time jojoba oil is available in quantities of this order. In particular, in this latter market jojoba oil might be used by the leather, lubricants and pharmaceutical industries.

If, for illustrative purposes, a 25,000 tonne market were to be secured and a future yield of 2.5 tonnes per hectare of oil obtained, a cultivated area of 10,000 hectares of jojoba would suffice. This is a very small area in global terms and it seems, therefore, that jojoba is unlikely to provide more than a minor new source of income for a few developing countries.

Jojoba must be considered as one of a number of possible plant introductions to arid zones and the need is to direct attention to research priorities which aim at overcoming limitations in the cultivation of the crop. If research proves that jojoba can be cultivated satisfactorily it would be reasonable to organize trial plots in selected developing countries to obtain more basic agronomic information on how the plant reacts in different environments. Only when these trials have proved successful and realistic yield data obtained, will the necessary information be available to enable the economic potential for the introduction of jojoba to developing countries to be examined fully.

RÉSUMÉ

Le jojoba: une évaluation des perspectives

Le jojoba (*Simmondsia chinensis* (Link.) Schneider) est un arbrisseau poussant à l'état sauvage dans la région semi-aride du désert de Sonora dans le nord du Mexique et le sud-ouest des USA. La plante porte des graines qui contiennent une cire végétale liquide rare*. La seule cire liquide naturelle d'un usage établi est l'huile de cachalot que l'on a proposé de remplacer par l'huile de jojoba. Assurément, il s'agit là de l'une des principales raisons de l'intérêt considérable porté à cette espèce. L'huile de jojoba peut également être hydrogénée pour former une cire consistante susceptible d'etre substituée à d'autres cires animales et végétales solides.

A présent, la majeure partie des graines de jojoba produites dans la nature est inexploitée, mais une petite partie est récoltée à la main. Des recherches portant sur la sélection et la culture du jojoba sont en cours aux USA, au Mexique et en Israël. Le besoin d'une augmentation des rendements est particulièrement important. A l'heure actuelle, une production à l'hectare de 2,250 kilogrammes de graines sèches et propres peut raisonnablement être envisagée, équivalant à 900 kilogrammes d'huiles à l'hectare, mais l'analyse économique montre qu'il sera essentiel d'augmenter fortement ce réndement avant que la culture du jojoba n'ait des chances de se révéler viable à toute échelle autre que relativement réduite. La multiplication végétative par boutures et culture tissulaire aura vraisemblablement un rôle important à jouer dans les programmes de sélection à venir.

Le prix de revient de la récolte manuelle étant excessif dans de nombreux pays, il faudra utiliser des moyens mécaniques. On a proposé bien des techniques de récolte des graines, mais aucune n'a encore donné satisfaction.

La production annuelle actuelle d'huile de jojoba, qui atteint seulement quelques dizaines de tonnes, a trouvé un marché tout prêt à des cours élevés (£5,500 à £7,700 la tonne) chez les fabricants de cosmétiques, de bougies, etc..., ainsi que dans les établissements de recherche. On peut espérer que le volume de ces marchés rémunérateurs continuera à se chiffrer par centaines de tonnes. Par la suite, l'huile de jojoba devra être en mesure de devenir compétitive par rapport aux autres huiles

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*Appelée huile de jojoba dans tout ce rapport et cires si l'on veut lui trouver un marché plus vaste. Bien que l'on ait prouvé que l'huile de jojoba convient dans nombre d'usages finals, dans la plupart des cas ses propriétés ne s'avèrent ni spéciales ni supérieures par rapport aux huiles alternatives.

Ce rapport étudie en détail les marchés de l'huile de cachalot et des cires animales et végétales en vue d'établir pour l'huile et la cire de jojoba des paramètres de cours et de volume de marché. Ces études de marché indiquent qu'entre £900 et £950, la cire de jojoba serait compétitive sur les marchés de la cire et pourrait obtenir sur le marché une part allant de 2,000 à 5,000 tonnes. Entre £500 et £600 la tonne, l'huile de jojoba serait compétitive face à l'huile de cachalot dont le marché actuel est de moins de 20,000 tonnes, quoique ce chiffre soit vraisemblablement réduit de manière sensible par les produits synthétiques d'ici à ce que l'huile de jojoba soit disponible dans des quantités de cet ordre. En particulier, sur ce dernier marché, l'huile de jojoba pourrait être utilisée par les industries du cuir, des lubrifiants et des produits pharmaceutiques.

A titre d'illustration, si un marché de 25,000 tonnes devait être assuré tandis qu'un rendement futur de 2.5 tonnes d'huile à l'hectare était obtenu, il suffirait de cultiver une surface de 10,000 hectares de jojoba. En termes globaux, il s'agit là d'une très petite surface et il semble donc que le jojoba ait peu de chances de fournir plus qu'une source nouvelle mineure de revenus à quelques pays en voie de développement.

Le jojoba doit être considéré comme l'une parmi un certain nombre d'introductions possibles de plantes dans les zones arides, et il est nécessaire d'attirer l'attention sur les priorités de recherche visant à surmonter les limites propres à la culture de cette plante. S'il ressort de ces études que le jojoba peut être cultivé de manière satisfaisante, il sera raisonnable d'organiser des parcelles d'essai dans certains pays en voie de développement choisis afin d'obtenir davantage de renseignements agronomiques de base sur la façon dont réagit la plante dans des environnements différents. Ce n'est qu'après que ces essais aient été couronnés de succès et que des données réalistes sur les rendements aient été obtenues que l'on disposera des informations nécessaires permettant l'étude complète du potentiel économique impliqué par l'introduction du jojoba dans des pays en voie de développement.

RESUMEN

Jojoba: una evaluacion de sus posibilidades

Jojoba (*Simmondsia chinensis* (Link.) Schneider) es un matorral que crece salvaje en las regiones semiáridas del desierto de Sonora en México septentrional y el sudoeste de los USA. La planta tiene semillas que contienen una cera* vegetal líquida de carácter excepcional. La única cera líquida natural que se utiliza de manera regular es el aceite de ballena, en sustitución del cual se sugiere el aceite de jojoba. Esta ha sido, efectivamente, una de las principales razones para que la especie atraiga considerable interés. El aceite de jojoba se puede también hidrogenar para formar una cera sólida que pudiera utilizarse como sustituto de otras ceras sólidas animales y vegetales.

En la actualidad, la mayor parte de las semillas de jojoba que se producen en estado salvaje no se aprovechan, pero se recoge a mano una pequeña proporción. En la actualidad se realiza investigación sobre la selección y cultivo de jojoba en los USA, México e Israel. Tiene especial importancia la necesidad de aumentar su rendimiento. En la actualidad puede esperarse de manera razonable un rendimiento de 2,250 kilogramos de semillas secas y limpias por hectárea, equivalentes a 900 kilogramos por hectárea de aceite, pero el análisis económico demuestra que será indispensable aumentar este rendimiento de manera importante antes de que el cultivo de la jojoba

*Denominada aceite de jojoba en este informe peuda demostrar su viabilidad en alguna escala que no sea la relativemente pequeña. La propagación vegetativa por medio de esquejes, cultivos con injertos y cultura de tejidos es probable que desempeñe una importante función en los futuros programas de producción.

Como el coste de la recolección manual en numerosos países será demasiado elevado, se necesitará la recolección mecanizada. Se han propuesto numerosas técnicas para recolectar las semillas, pero ninguna de ellas ha demostrado ser satisfactoria.

En la actualidad la producción anual de aceite de jojoba, que asciende tan sólo a decenas de toneladas, ha encontrado un mercado fácil a precios elevados (£5,500 á £7,700 por tonelada) para su uso en la fabricación de cosméticos, velas, etc., y para su uso en establecimientos de investigación. Puede preverse que las dimensiones de este mercado de precio elevado permanezcan al nivel de centenares de toneladas. Después, el aceite de jojoba tendrá que estar en condiciones de competir con otros aceites y ceras si pretende encontrar un mercado de mayor volumen. Aunque de ha demostrado que el aceite de jojoba es idóneo para una gama de aplicaciones, en la mayoría de los casos no presenta propiedades especiales o superiores en comparación con aceites alternativos.

En este informe se examinan en detalle los mercados del aceite de ballena y las ceras de origen animal y vegetal, a fin de tratar de establecer los parámetros de volumen y precio del mercado para el aceite y cera de jojoba. Estos análisis del mercado sugieren que con un precio entre £900 y £950, por tonelada la cera de jojoba podría competir en los mercados de la cera y podría obtener una parte del mercado equivalente a volúmenes situados entre 2,000 y 5,000 toneladas. Con un precio de £500 á £600 per tonelada, el aceite de jojoba podría competir con el aceite de ballena que en la actualidad tiene un mercado un poco inferior a 20,000 toneladas, aunque este volumen se habrá reducido probablemente en gran parte por medio de los productos sintéticos, cuando se halle disponible el aceite de jojoba en cantidades de esta magnitud. En este último mercado, especialmente, el aceite de jojoba podría utilizarse en las industrias del cuero, los lubricantes y farmacéutica.

Si, para fines ilustrativos, se pudiera conseguir un mercado de 25,000 tonelados y un rendimiento futuro de 2.5 toneladas por hectárea de aceite obtenido, sería suficiente una extensión cultivada de jojoba de 10,000 hectáreas. Esto constituye una superficie muy pequeña en términos globales y parece, por lo tanto, que la jojoba es poco probable que constituya más que una nueva fuente pequeña de ingresos para algunos países en vías de desarrollo.

Se puede considerar a la jojoba como una de varias plantas que se podrían introducir en las zonas áridas y existe la necesidad de dirigir la atención hacia prioridades de investigación que tratan de superar las limitaciones en el cultivo de la cosecha. Si las investigaciones demuestran que la jojoba se puede cultivar de manera satisfactoria, sería razonable organizar parcelas en países seleccionados en vías de desarrollo para obtener más información básica de carácter agronómico sorbe la manera en que reacciona la planta en diferentes ambientes. Sólo cuando hayan demostrado su éxito estas pruebas y se hayan obtenido datos realistas de rendimiento, se dispondrá de la información necesaria para permitir un estudio a fondo de las posibilidades económicas para la introdución de jojoba en los países en vías de desarrollo.

Introduction

Jojoba (*Simmondsia chinensis* (Link.) Schneider) is a desert shrub which grows wild in certain areas of the south-western USA and northern Mexico. Its seeds contain an unusual liquid vegetable wax*. Various attempts have been made to domesticate the plant, particularly in the 1940s, but with limited success. Recently, due to the importance being placed on the development of arid zone crops and the possibility of jojoba oil serving as a replacement for sperm whale oil in many of its uses, a renewed interest has been taken in the plant. Research is at present being carried out in the USA, Mexico and Israel to see whether the crop can be cultivated commercially.

The Tropical Products Institute's primary interest in jojoba is that it is one of a number of crops that might be cultivated profitably in the arid and semi-arid zones of certain developing countries. This report assesses the present state of research on the crop and gives an opinion as to its prospects of being of economic benefit to these areas.

The report is divided into five Sections. In Section 1 the plant and its natural habitats are described; current research and the problems to be overcome in cultivating the crop are outlined. In Section 2 the chemistry of jojoba and other waxes is discussed. In Section 3 consideration is given to the end-use potential of jojoba and an attempt is made to forecast the future market demand and price for jojoba oil, both as a liquid and as a solid wax. In Section 4 the economics of jojoba production are discussed in the light of the findings in the earlier Sections. Finally, in Section 5, the wider aspects of plant introductions are considered briefly and conclusions drawn regarding jojoba's potential and its future research needs.

*Called jojoba oil throughout this report

Section 1

Production of jojoba

BACKGROUND

Jojoba is a shrub which is found growing wild in the semi-arid regions of the Sonora desert which covers parts of northern Mexico, southern California and southern Arizona. Within this desert it normally grows in areas where the annual rainfall is between 100 and 500 millimetres, although the range in which it grows best appears to be from 450 to 500 millimetres. The distribution of jojoba within its natural habitat is linked with the winter–spring rains, to which it responds positively. Summer temperatures may be as high as 45°C, and although mature plants can survive temperatures of –9°C, young plants (less than 3 years old) are killed at about –4°C. Jojoba populations are found from sea level on the Gulf of California to elevations of 1,200 metres in the mountains of Arizona. The shrub grows on a variety of soils, but appears to grow best on well-drained, coarse desert soils. It does not grow on wet, lowland or marshy sites.

Within its natural habitat jojoba shows great variation in form, foliage, fruit and yield. It may have many stems branching near the ground, a few stems, or sometimes a single trunk. When fully mature it may reach 3 metres in height and be tree-like, but more commonly it forms a shrub from 0.6 to 2.0 metres tall, which may be dense or fairly open.

Jojoba is dioecious, the female plants bearing seeds after two to five years, and thereafter annually. Seed yield might be expected to rise until the shrub is mature (i.e. 8–12 years old) and from then on to remain fairly constant. Within natural stands of jojoba the variation in seed yield is very large, ranging between 0 and 5 kilograms of clean, dry seed per shrub. The productive life span of a jojoba shrub is unknown, but it may well be over 100 years.

In its natural habitat jojoba is utilized by a number of animals. The shrub is a browse plant for deer, sheep, goats and cattle; rabbits, mice, deer, squirrels and birds eat the seeds.

It has been estimated that natural jojoba stands in the Sonora desert yield between 15,000 and 50,000 tonnes of seed annually, most of which goes to waste because of the difficulties in organizing its collection over a wide area with a harsh climatic environment. In 1978 it was estimated that a record 70 tonnes of seed were harvested by hand in the USA. In Mexico an attempt has been made to make harvesting easier by planting jojoba seedlings within the natural stands. In addition, in the USA private enterprise has established over 1,200 hectares of jojoba plantations, although none of these has yet reached full maturity.

RESEARCH

Research on the cultivation of jojoba is currently concentrated in the USA, Mexico and Israel, although work has also been carried out on a smaller scale in several other countries.

In the USA, the Office of Arid Lands Studies at the University of Arizona and the Department of Botany and Plant Sciences at the University of California, Riverside, are the two principal centres involved in jojoba research. The Office of Arid Lands Studies is working in conjunction with the San Carlos Apache Indians in developing the crop. In addition to these two centres, the regional research centres of the US Department of Agriculture have also been involved in various aspects of jojoba development. In Mexico the main research centre is the Centro de Investigaciones Cientificas y Tecnológicas de la Universidad de Sonora (CICTUS), although small projects are being undertaken by a number of other institutions. In Israel where the possibilities of cultivating jojoba in the Negev desert are being investigated, the research programme is under the direction of the Research and Development Authority of the Ben Gurion University of the Negev.

CULTIVATION AND OIL EXTRACTION

Introduction

It is generally accepted that in order to increase significantly the quantity of jojoba seeds available commercially it is necessary for the shrub to be cultivated in a manner which conforms to modern agricultural practice. Much has been learned from studies of natural jojoba stands, but so far it has proved difficult to translate these findings in any meaningful way to the plantation situation. Estimates suggest that over half the jojoba which has been planted has died for various reasons, including unfavourable soil and climatic conditions. In order to cultivate jojoba successfully, a number of important factors have to be considered.

Genetic variability

Chromosome studies indicate that jojoba is a polyploid which might provide a large potential for breeding agriculturally acceptable varieties. Research work in Israel, however, has not revealed any dominant relationships in hybrids obtained from crosses of phenotypically distinct plants. The genetic potential of jojoba will only become apparent through breeding trials.

Seed yield

Seed yield is the aspect of genetic variability which is most important to the success of jojoba domestication. It has been observed that the yield per shrub may vary between 0 and 5 kilograms in natural stands. Two shrubs in the Huntingdon Botanical Gardens, California, are reported to have yielded 16 kilograms of seed each. In small plantations in Israel some shrubs have yielded over 5 kilograms of seed and made vigorous growth, while others have yielded negligible amounts of seed. In California female plants flower at every node, whereas in Arizona they tend to flower at alternate nodes. This suggests that the Californian stock may have greater yield potential, but it is possible that the difference is merely an adaption to the local environment.

So far it has not been possible to demonstrate that jojoba can be improved genetically to give high-yielding varieties. The problems to be solved are considerable; consistently high-yielding female shrubs must be identified and the hereditability of yield established. A long period is required for experimental trials. Further, the lengthy maturation period of the plant impedes attempts at selection and breeding for additional desirable features, such as a regular shaped and more easily harvested type of shrub.

It is impossible to be precise regarding probable seed yields per hectare for a jojoba plantation established at the present time, a wide range of figures having been quoted. However, following discussions with a number of workers, it is felt that a reasonable yield of clean, dry seed would be of the order of 2,250 kilograms per hectare.

Propagation techniques

Various methods of propagating jojoba both sexual and vegetative, are being explored. Seed material may be obtained from open-pollinated female plants but there is likely to be a very wide variation in the resulting plants. Alternatively, seed may be taken from selected female plants that have been pollinated under controlled conditions from a selected male. Even in this second case there will be wide variations within the F_1 generation from which selections can be made.

Vegetative propagation, by which plants genetically identical to the parent plant are produced, will be important for the multiplication of selected varieties. Two different vegetative propagation techniques for jojoba (cuttings and tissue culture) are being used in research programmes in the USA and Israel. Cuttings show very variable growth rates. Tissue culture seedlings have been produced and experiments are now in progress to harden them so that they can be transferred to the field. Both of these techniques are likely to have significant roles to play in future breeding programmes. However, it will be a number of years before growers in developing countries will be able to obtain proven stock.

Sex determination and plantation configuration

The dioecious nature of jojoba will necessitate the planting of extra seeds or seedlings and the subsequent removal of the excess males in order to ensure the maximum possible number of female plants per unit of land. No satisfactory method of sex determination in the first years of growth has yet been devised.

The optimum ratio of male to female plants in a plantation is not known with certainty. Ratios of between 1:7 and 1:4 have been suggested, with 1:6 appearing to be the most favoured at present. On this basis about 1,370 plants per hectare could be grown of which 1,175 would be female. In addition to considering the number of plants per hectare, since jojoba is wind pollinated, the distribution of male plants through the plantation needs forethought.

Plantation geometry will depend upon the choice of harvesting technique and the equipment used, which will be discussed later. In California experiments are in progress to alter physically the shape of a developing jojoba shrub by pruning and training, in order to form a hedge which should facilitate harvesting.

Irrigation and fertilizer requirements

The irrigation and fertilizer requirements of jojoba also require considerable research input. Jojoba responds positively to nitrogen but in what quantities and in what form is unknown. Although jojoba is an arid zone crop and can survive with only 100 millimetres of rain per annum, it responds well to extra water. The distribution of water appears important; adequate moisture during the winter and spring seasons and at the time of seed germination and seedling establishment are particularly significant. Jojoba, unlike many crops, is tolerant of highly saline water and this is an important factor if irrigation under desert conditions is considered. Tolerance of high salinity, however, is dependent upon good soil drainage.

It is open to discussion how far, when one is looking for crops for arid zones, it is relevant to consider and study the effect of irrigation. If irrigation facilities are available then the cultivation of many other species becomes possible and the return from some of these may be higher than that from jojoba.

Disease control

In its natural habitat jojoba does not appear to be affected seriously by pests and diseases. However, under greenhouse conditions, it is susceptible to Texas rot (*Phymatotrichum omnivorum*), verticillium wilt (*Verticillium dahliae*), *Phytophthora parasitica* and *Alternaria* sp. It is probable that control measures will be required for jojoba plantations.

Harvesting

At present jojoba is harvested by hand. This, however, is a slow and tedious operation which is unlikely to prove economic on a plantation scale. Many techniques have been proposed for harvesting jojoba seed. These include the use of mechanical sweepers or suction equipment to collect seed from the ground. Hand held tools such as rakes, scrapers and shakers have been used on the shrubs, but were found to give poor results because of the excessive amount of foliage removed with the seeds. Powered shears have been found to offer promise, since the seeds were harvested five times more quickly than with hand picking. However, this technique may reduce the yield of seed in subsequent years. Other machines suggested for use include one based on a grape harvester. So far no entirely satisfactory method for the mechanical harvesting of jojoba has been devised.

Seed storage and oil extraction

There is little likelihood of the quality of jojoba oil deteriorating provided that the seed is dried to less than 10 per cent moisture content and it is stored away from pests.

Clean, dry and dehulled jojoba seeds contain about 50 per cent of oil, which may be obtained by conventional methods, either using an expeller, or by solvent extraction. However, a solvent extraction plant processing oilseeds generally requires about 100 tonnes of seed per day to be economically viable. The alternative extraction method of using an expeller can be operated on a smaller scale. Several small expellers are now being used in the USA and Mexico and in trials around 80 per cent of the oil available in jojoba seed has been obtained, i.e. an extraction rate of 40 per cent.

The chemistry of jojoba and other waxes

The most important uses of jojoba concern the liquid wax i.e. jojoba oil, which can be extracted from the seed, and the solid wax made by hydrogenating this oil. In particular these products may be usable as substitutes for sperm oil and for animal and vegetable waxes, such as beeswax, spermaceti, carnauba and candelilla. In this Section the chemistry of jojoba oil and of the waxes for which it might be used as a substitute are discussed.

Jojoba oil is a liquid wax composed almost exclusively of long chain acid-alcohol esters. These esters are predominantly composed of $C_{20\text{-}22}$ fatty acids and alcohols, each having one double bond which makes the oil a liquid with flexibility of end-use potential because of the chemical reactivity of the double bonds. It does not contain glyceride esters which are the predominant constituents of other animal and vegetable oils and fats. The only natural liquid wax in established use is sperm oil.

For comparison the chemical composition of jojoba oil and sperm oil are recorded in Table 1. The major difference between the two oils is that jojoba oil consists of almost pure wax esters whereas sperm oil contains about 25 per cent of glyceride esters. Another difference between the two is the composition of the fatty acids and alcohols; sperm oil is composed of a mixture of saturated and unsaturated fatty acids and alcohols which are of lower molecular weight than the mainly unsaturated ones in jojoba oil.

Research into the development of synthetic liquid waxes has been quite active and a substantial number of sperm oil replacements have been made commercially from fatty acids and alcohols, as a pure wax ester or as a wax ester blended with glyceride

Table 1

Chemical composition of vegetable and animal waxes

	Liquid waxes		*Solid waxes*					
	Vegetable	Animal	Animal		Vegetable			
	Jojoba oil	Sperm oil	Sperma-ceti	Beeswax	Cande-lilla	Carnauba	Japan	Ouricury
Wax acid-alcohol esters (%)	97	75	96	71	28–29	84–85	–	24
Hydroxy-esters (%)	–	–	–	–	–	–	–	46
Glycerides (%)	–	25	–	–	–	–	93–97	–
Hydrocarbons (%)	–	–	–	10–14	50–51	2–3	–	1
Acids (%)	–	–	1	14–15	7–9	2–4	4–6	9
Alcohols (%)	–	–	3	2	12–14	2–3	1	15

Note: – = Nil or negligible

oils. Some of these are replacements for crude sperm oil, others are designed to replace sperm oil derivatives in one or more of their particular applications. Similar derivatives have been made from jojoba oil and their potential uses will be discussed later. Recent research has looked at the possibility of preparing a new range of liquid waxes from polyunsaturated vegetable oils. The idea is to hydrolyse the oil and recover the fatty acids, then chemically to reduce some of the acids to alcohols, and thereafter to esterify the alcohols and acids to produce new waxes.

Table 1 also lists the chemical composition of the more important solid animal and vegetable waxes. On account of its unsaturation, jojoba oil may also be hydrogenated to produce a solid wax. It is interesting to note that virtually none of the waxes recorded in Table 1 are comparable even in their overall constituent group composition. The solid animal waxes, spermaceti and beeswax, differ substantially from each other in their wax acid-alcohol ester content; beeswax also contains over 10 per cent of hydrocarbons. The differences in the composition of the vegetable waxes are even more striking. The major constituent group in candelilla wax is hydrocarbon, in carnauba wax acid-alcohol esters, in Japan wax saturated glycerides and in ouricury hydroxy-esters. Jojoba wax quite closely resembles spermaceti in its constituent groups. Those in jojoba are, however, of a significantly higher molecular weight. Of the vegetable waxes, jojoba wax is most closely related chemically to carnauba; it is different chemically from the others recorded in Table 1.

It is difficult to relate the functional properties of the solid and liquid natural waxes with their chemical composition. Generally speaking a natural wax exhibits a broad range of functional properties and no single synthetic can be expected to duplicate them all equally well. However, synthetics can be made to improve individual functional properties of the natural wax and the technical choice between the two will be made on the functionality important in the particular application.

Jojoba oil and the wax produced by hydrogenation have different and much narrower ranges of chemical species present than sperm oil and the other natural waxes recorded in Table 1. The jojoba products cannot therefore be expected to function in the same way as sperm oil and the natural solid waxes in each of their applications. In some areas they may function better and in others worse. A knowledge of the chemical composition of jojoba oil or wax does not *per se* enable its properties to be forecast. This can be done only through product formulation followed by extensive test trials.

Section 3

Uses of jojoba

INTRODUCTION

A wide range of potential uses has been suggested for jojoba and the more significant of these are recorded in Figure 1. The oil and solid wax, in particular, offer interesting commercial possibilities. In this Section some of the present and potential end-uses for jojoba are examined and an attempt is made to establish market price and volume parameters for the more promising end-uses.

PRESENT USES

Jojoba seeds have been harvested almost exclusively from natural stands over the last few years, and total annual oil production amounts to only tens of tonnes. These small quantities of oil have found a ready market. For example, some 5 tonnes are supplied annually to Japan for use by the cosmetic industry. In the USA cosmetic products containing jojoba oil, including shampoos, hair oils and face creams, are on sale. The Apache Indians on the San Carlos reservation make and sell jojoba candles. The price of jojoba oil in these markets is around £5,500 to £7,700 per tonne (US $5—US $7 per pound). With limited supplies and high pressure sales techniques it is possible to maintain a very high price for these products. Certainly in the 'luxury' cosmetic and novelty markets demand at present exceeds supply. Similarly there is demand from research establishments which are initially able to offer high prices in order to obtain limited supplies.

This present high price market cannot be expected to absorb more than a few hundred tonnes of oil. Thereafter jojoba will need to be able to compete with other oils and waxes if it is to find a satisfactory volume market. Without such a volume market the high research costs required in the pre-harvest areas will not have been justified, unless a unique use for the oil which will command an exceptionally high price can be found.

POTENTIAL USES

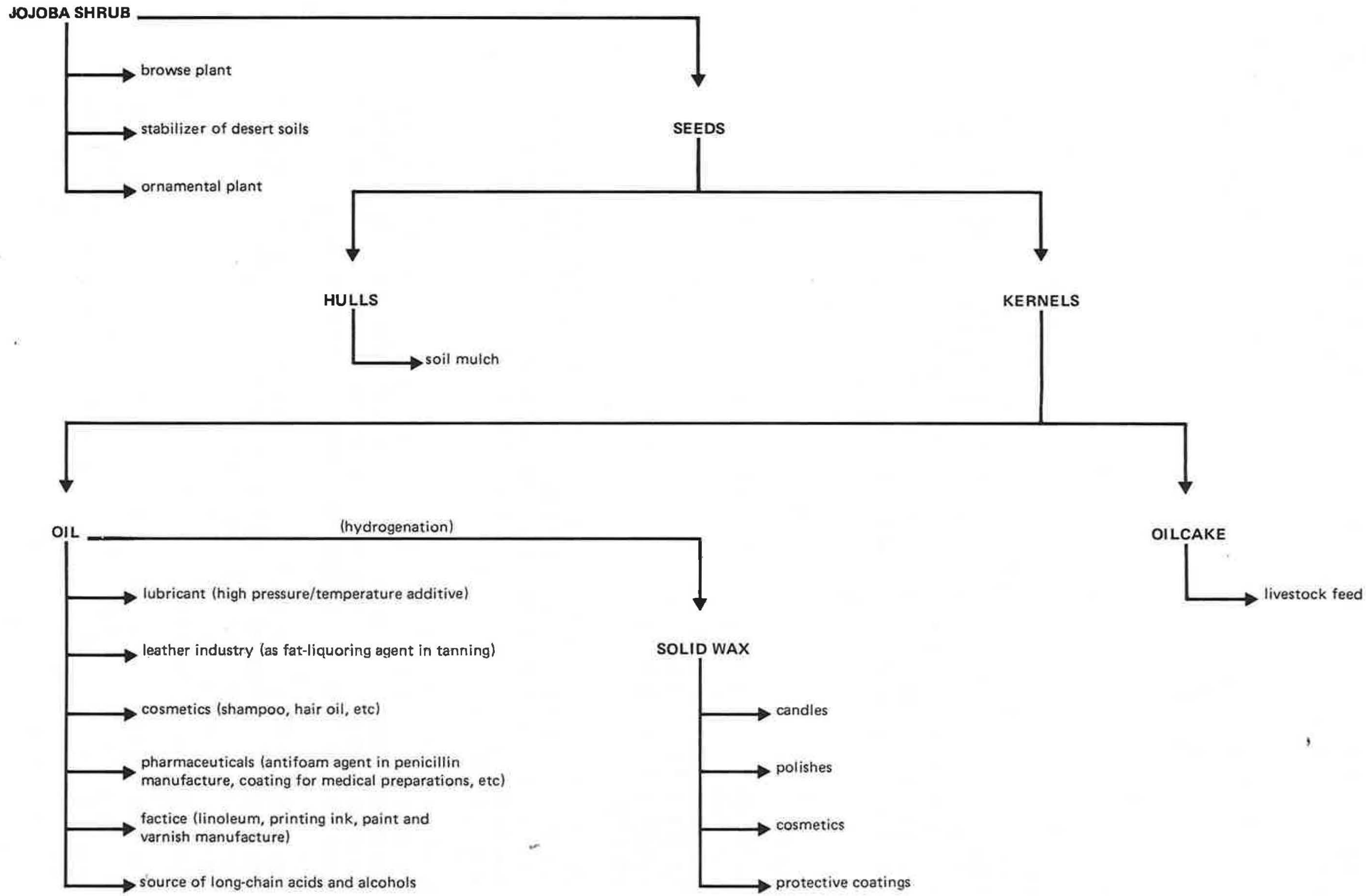
Shrubs

Several uses have been suggested for jojoba shrubs — as a browse plant for livestock, as a stabilizer of desert soils and as an ornamental shrub. The plant is an evergreen and capable of withstanding grazing, whilst the leaves contain a relatively high percentage of carbohydrates. If jojoba were introduced primarily for seed production, the effect of seasonal grazing on seed yield would have to be ascertained. The slow rate of growth of the shrub might be a major drawback in any of these suggested uses.

Oilcake

After the oil has been extracted from the seeds the residual oilcake has potential value as a livestock feed. It contains about 30 per cent of protein which, although

Figure 1
Some potential end-uses for jojoba



rather low compared with the majority of oilcakes used in animal feed, is quite usable. In terms of balance of essential amino acids, the lysine content is good, but the methionine content is poor.

The major drawback to the use of jojoba oilcake is the presence of a toxic factor, simmondsin, which, when fed to laboratory rats, resulted in them avoiding further food and dying of starvation. In the wild, however, desert rodents eat the seeds with no apparent ill effects. The effect of simmondsin on ruminants is not known.

Simmondsin can be destroyed by treating the oilcake with ammonia but whether this would be adequate and economic needs to be assessed. The treated oilcake is likely to command a price based on its protein/amino acid content, in comparison with other oilcakes. Since these do not have to bear the extra processing cost of treatment with ammonia, jojoba oilcake will have an initial disadvantage. Further, even with the removal of simmondsin, the initial presence of a toxic substance could have a psychological influence on buyers and depress demand. In order to assess the value of jojoba oilcake it will be necessary to undertake feeding trials on different types of livestock to study the effects and to check that no hazardous compounds are transmitted to livestock products. Before these investigations can be carried out satisfactorily larger volumes of the oilcake will need to be made available.

Jojoba oil

Considerable end-use research has already been carried out on jojoba oil. Initially, great interest was shown in the oil because of its potential as a sperm oil substitute. Indeed many of the suggested end-uses for jojoba oil which show the greatest potential, and on which the most research has been done, are those where it might serve as a substitute for sperm oil e.g. in the leather and lubricants industries. These are discussed later.

Other potential uses for jojoba oil are in the cosmetic and the pharmaceutical industries. Reference has already been made to the present uses in cosmetics and in the future these uses may be extended. There is however, at present, no scientific data to support the claims regarding the special value of jojoba oil in cosmetics e.g. as a hair restorer or as a skin cream.

Since the human digestive system cannot make use of waxy materials, jojoba oil is not suitable for use as a food. Because of this property it is, however, suitable as a carrier for pharmaceutical preparations that must pass as far as the small intestine before assimilation. A further use by the pharmaceutical industry for which jojoba has shown potential is as an antifoam agent in penicillin production.

By adding sulphur to the oil a factice is obtained which would be suitable for use in the manufacture of linoleum, printing ink, paints and varnishes. Moreover, the liquid oil could provide a source for long-chain alcohols and acids which might subsequently be used in a wide range of industrial applications, particularly as C_{20-22} alcohols containing one double bond are not common.

The other major market sector in which interest has been shown in jojoba oil is the wax market. Jojoba oil can be hydrogenated to form a solid wax and a wide range of end-uses has been suggested e.g. in the manufacture of candles, polishes, cosmetics, protective coatings, etc. In these end-uses jojoba wax would be in competition, as is discussed later, with other natural vegetable and animal waxes e.g. beeswax, spermaceti, carnauba, candelilla, etc.

Although the suitability of jojoba oil has been established in the various end-uses mentioned above, in most cases it does not exhibit superior properties. It must be emphasized that with only small quantities of jojoba oil available now, or in the immediate foreseeable future, and with little indication of the future cost and supply situation, the market potential for jojoba oil or wax is difficult to project. An essential feature of the waxes and oils markets in which jojoba oil must compete is the possibility which exists for substitution. In these circumstances price and availability of supplies are particularly critical in determining market demand. Until greater quantities of jojoba oil are available, end-use research will continue to be carried out largely on a laboratory scale; the functionality of the oil in its suggested end-uses cannot be fully assessed.

THE MARKET FOR SPERM OIL

Market characteristics

Sperm oil is obtained from the blubber and head cavity of the sperm whale. World production of, and trade in, the oil is gradually contracting, as is shown in Tables 2, 3 and 4. At its peak in the mid-1960s production was around 150,000 tonnes per annum with exports in the region of 80,000 to 90,000 tonnes. Since then production has halved, whilst trade has fallen to below 20,000 tonnes per annum.

This drop in production and trade has been brought about largely by pressure from conservationists to save the sperm whale from extinction. Killing quotas are now fixed by the International Whaling Commission, while the USA, formerly the world's major consumer of sperm oil, banned imports at the end of 1971 as part of its conservation policy. There is also continuing pressure for other countries to ban imports.

With these continuing pressures on both production and imports, total trade (which can roughly be equated to utilization outside the producing countries) is unlikely to exceed the current level and may well fall further. The ban in the USA on the use of the oil and the constraints on supply have stimulated considerable research to develop synthetic sperm oil substitutes. Many of these are now available on the market. The development of these products is not, however, without its problems.

The two main users of sperm oil are the lubricants and leather industries. The use of sperm oil by these industries will now be considered, together with the development of substitutes, including jojoba oil.

The leather industry

Sperm oil is used in fat-liquors by tanners in the manufacture of leather. The majority of fat-liquors are prepared by blending natural oils and fats which have either been sulphated or sulphited. The selection of oils for a particular end-use is essentially empirical and based on practical experience. Sperm oil is particularly favoured for the production of soft, non-greasy leathers and in the production of special surface effects e.g. sheen on suede surfaces, or an ability to be polished in full grain leathers. Besides softness, sperm oil also imparts 'run' to leathers, i.e. after the stretching which takes place in manufacture, the leather does not shrink back again — a property particularly important in high quality gloving leathers.

The leather industry is currently experiencing great difficulty in finding satisfactory sperm oil substitutes, particularly for the production of high quality leathers. The major problem in the development of substitutes is that, as noted above, the selection of oils used by tanners is essentially empirical. Little research has been done on the relationship between the chemical composition of sperm oil and leather performance. The breadth of properties considered by tanners to be imparted by sperm oil is a particularly important consideration in the search for substitutes.

Besides sperm oil, appreciable amounts of other natural oils such as neatsfoot and fish oils, as well as smaller quantities of castor oil, are used for fat-liquoring. These oils duplicate some, but not all, of the properties of sperm oil. Neatsfoot oil, for example, cannot be sulphited; neither does it give the finished product as good 'run' as sperm oil, the leather tending to contract after stretching. Similarly synthetic oils have been developed for use in the leather industry. Some have been sold simply

Table 2

World production of sperm oil

Thousand tonnes

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
UK	2	4	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Netherlands	2	3	3	3	—	—	—	—	—	—	—	—	—	—	—	—	—
Norway	13	13	9	9	10	5	5	—	1	1	1	—	—	—	—	—	—
Iceland	—	—	—	—	—	—	—	1	1	1	1	1	1	1	—	1	1
Portugal	2	3	3	3	3	2	2	1	1	1	2	1	1	1	1	1	1
USSR	25	28	48	60	78	82	91	69	78	80	66	50	60	60	59	52	36
Repub. S. Africa	7	10	10	11	12	13	9	6	7	7	7	7	6	7	6	—	—
Japan	32	36	46	47	37	33	33	34	31	38	33	27	26	23	24	17	11
Peru	13	11	10	7	4	3	—	4	6	5	5	5	4	3	2	2	2
Australia	3	4	4	5	5	4	4	4	5	6	6	6	6	6	6	6	3
Others	10	10	9	8	3	6	5	2	—	1	2	2	2	—	1	—	1
TOTAL	109	122	144	153	152	148	149	121	130	140	123	99	106	101	99	79	55

Source: Unilever Ltd

Note: — = Nil or negligible

Table 3

World exports of sperm oil

Thousand tonnes

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Norway	7	10	4	3	—	—	4	3	—	—	—	—	—	—	—	—	—
USSR	—	—	10	21	32	53	20	30	30	22	8	8	12	4	4	2	2
Japan	5	17	26	25	17	14	13	11	11	18	15	9	8	13	10	3	3
Australia	1	4	4	5	5	4	4	4	5	5	5	5	6	6	5	5	5
Repub. S. Africa	6	7	6	8	—	11	12	—	—	—	5	6	5	5	4	4	—
Netherlands	—	1	4	1	—	—	—	—	—	—	1	—	—	—	—	—	—
Iceland	—	—	—	—	—	—	—	1	1	1	1	1	1	1	—	1	1
Portugal	2	3	3	3	3	2	2	1	1	1	2	1	1	1	—	1	1
Peru	13	11	10	7	4	3	—	4	6	5	5	5	4	2	3	2	2
Other countries	10	10	9	8	3	6	5	2	—	1	2	2	2	—	1	—	3
TOTAL	44	63	76	81	64	93	60	56	54	53	44	37	39	32	27	18	17

Source: Unilever Ltd

Note: — = Nil or negligible

Table 4

World net imports of sperm oil

Thousand tonnes

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
UK	12	14	17	21	18	12	19	29	17	11	11	7	6	9	6	5	4
France	5	4	3	3	4	4	3	3	5	3	2	4	4	2	1	(1)	—
Fed. Repub. Germany	8	8	9	9	13	12	7	9	11	9	8	6	5	6	6	7	4
Netherlands	1	—	—	—	4	4	4	6	1	2	—	2	2	—	—	—	(1)
E. Europe	3	2	1	1	—	1	—	—	—	—	—	—	2	2	3	4	4
USA	26	29	28	26	32	25	24	24	19	22	18	2	—	—	—	—	—
Canada	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Italy	—	—	—	1	1	1	2	3	2	2	1	2	2	2	2	2	1
Norway	—	—	—	—	7	4	—	—	2	2	1	1	3	3	2	3	1
Spain	—	—	—	—	1	1	—	4	3	2	—	—	—	3	—	—	—
Taiwan	—	—	—	—	—	—	—	1	1	2	2	—	—	—	—	—	—
N. Korea	—	—	—	—	—	—	—	—	—	—	—	—	2	2	2	1	1
TOTAL	55	58	58	61	80	64	59	79	61	55	43	24	26	29	22	21	14

Source: Unilever Ltd

Notes: — = Nil or negligible
( ) represents a negative value

as alternative leather lubricants, while others have been marketed as replacements for sperm oil. Again none of these products appears to have been completely successful as a sperm oil substitute; certain specific properties can be duplicated, but not the broad range of properties imparted to leather by sperm oil.

The British Leather Manufacturers Research Association (BLMRA) is currently undertaking a research programme to find a satisfactory sperm oil substitute. It has examined a wide range of products from which it has isolated several on which further research was undertaken. One of these was jojoba oil, initial tests having shown it to have promise as a fat-liquoring agent. However, jojoba oil was found to be more difficult to sulphate than sperm oil and it was only possible to prepare sulphited oils after blending it with triglycerides.

In general the products made from jojoba oil were inferior to those made from sperm oil, although jojoba oil seems to impart a similar breadth of properties to the leather when compared with sperm oil. The BLMRA conclude that a substantial amount of developmental work would be necessary to make commercially viable products from jojoba oil. Of particular importance is the need to be able to obtain commercial quantities at a competitive price.

The lubricants industry

Sperm oil is used by the lubricants industry primarily as an additive in extreme high pressure lubricants and in industrial cutting lubricants. For these applications its metallic wetting and non-drying properties are particularly important; the latter property prevents gumming and tackiness.

In comparison with the leather industry, the lubricants industry has found it easier to develop sperm oil substitutes and trade sources in the UK estimate that between 80 and 90 per cent of the sperm oil originally used in lubricants can now be replaced satisfactorily by synthetics. Again in the search for substitutes, jojoba oil is one of the products to have been investigated, and there is no doubt of its potential. In certain lubricant applications sulphurized jojoba oil shows properties equivalent to sulphurized sperm oil. Using a four-ball extreme pressure test jojoba oil appears to be superior to sperm oil as a lubricant, although its solubility in mineral oils is inferior to that of sperm oil. The lubricants industry now requires the guarantee of commercially available quantities of jojoba oil at a satisfactory price so that further developmental work can be undertaken.

The prospects for jojoba oil

Prices of *crude* sperm oil rose significantly in the UK through 1976 and 1977 as shown in Table 5. In 1978, however, prices fell back. In mid-1978 the price range for *refined* sperm oil was around £480 to £580 per tonne depending on quality, quantity and terms of delivery. At the same time, the prices of synthetic substitutes, produced in Europe and the USA, ranged from £400 to £800 per tonne, depending on quality. At the lower end of this range the products were of poor quality in contrast to sperm oil, while those at the upper end were considered to be close to sperm oil in quality. Discussions with the trade in the UK indicate that, if refined jojoba oil were available now, to be competitive with sperm oil and sperm oil substitutes, it would need to be within the price range of, say, £500 to £600 per tonne in order to find a market.

In terms of volume demanded much will depend on price. Within the above price range, however, there is no reason to suppose that jojoba could not take over a significant share of the market presently held by sperm oil, although further developmental work will be required. The total size of this market based on trade statistics has been reduced to below 20,000 tonnes per annum (see Tables 3 and 4; pages 17 and 18). The balance of sperm oil production is consumed mainly in the USSR where its use and the status of synthetic substitutes are largely unknown. This being the case no account of that market has been taken in this analysis.

Table 5

Crude sperm oil prices

£ per tonne c.i.f. UK

Year	Quarter 1	2	3	4
1970	95	125	125	140
1971	155	150	140	115
1972	115	105	115	125
1973	120	140	155	150
1974	180	205	185	185
1975	180	175	175	150
1976	230	320	340	370
1977	390	420	470	400
1978	275	250	n.a.	n.a.

Source: Trade estimates **Note:** n.a. = not available

Jojoba oil faces a major problem of timing if this market is to be developed. The present, and possible continuing cut-back in sperm oil availability is accelerating research work to find substitutes. By the time large volumes of jojoba oil are likely to become commercially available synthetics could already command a good share of the market and would then be difficult to displace.

THE MARKET FOR ANIMAL AND VEGETABLE WAXES

Introduction

The wax market may be divided into two major groups — natural waxes and synthetic waxes. The natural waxes category includes, in addition to animal and vegetable waxes, mineral waxes, such as paraffin wax; these will not be considered here. The most important animal wax is beeswax, spermaceti being the other wax of significance. Carnauba wax and candelilla wax are the most important vegetable waxes. Others of less significance include esparto, Japan and ouricury waxes.

Market size

Carnauba wax is produced almost entirely in Brazil and candelilla wax likewise in Mexico. Because these waxes are specific to these countries the market size can be estimated from the export statistics given in Table 6. These statistics, together with more recent trade estimates, indicate that in round terms the world market for carnauba wax is 9,000 tonnes and that for candelilla wax between 3,000 and 4,000 tonnes. With small quantities of the other waxes the total world vegetable wax market currently approaches 15,000 tonnes.

The size of the market for the animal waxes is more difficult to establish since beeswax is produced in a number of countries. However, the International Trade Centre UNCTAD/GATT recently estimated that world trade in beeswax amounted to between 5,000 and 5,500 tonnes annually during the period 1972–76, much of these supplies coming from the developing countries in Africa and South America. Besides this trade, beeswax is produced in developed countries which have sophisticated bee-keeping industries. However, this wax tends to be used in the production of new comb foundations rather than being traded commercially.

The International Trade Centre's figure thus gives a good indication of total size of the market. Since spermaceti production is estimated at under 2,000 tonnes per annum the total world animal wax market amounts to around 7,000 tonnes per

Table 6

Exports of carnauba and candelilla waxes
(a) Exports of carnauba wax from Brazil

Tonnes

	1970	1971	1972	1973	1974	1975	1976	1977
TOTAL	13,602	12,717	12,570	14,150	8,705	7,320	9,223	8,588
of which to:								
USA	5,090	4,756	3,771	4,275	3,415	2,581	3,054	2,452
Fed. Repub. Germany	1,569	1,378	1,660	1,668	777	780	985	1,074
Japan	1,586	1,290	1,275	1,486	654	625	777	775
Italy	795	922	577	907	443	483	970	729
UK	1,042	836	837	716	534	466	557	508
Netherlands	505	408	599	851	548	422	453	483
Spain	576	562	788	1,119	418	362	557	384

(b) Exports of candelilla wax from Mexico

Tonnes

	1970	1971	1972	1973	1974	1975	1976
TOTAL	1,437	1,751	1,871	1,474	4,143	1,836	2,464
of which to:							
USA	1,068	1,452	1,496	1,073	1,733	1,062	1,317
Spain	31	13	48	25	584	76	347
Argentina	2	1	—	1	533	190	159
UK	109	84	87	102	235	125	119
Fed. Repub. Germany	16	12	29	49	197	50	113

Source: Country trade statistics **Note:** — = nil or negligible

annum. The total animal and vegetable wax market is, therefore, about 22,000 tonnes per annum.

If the import statistics for the more important wax importing countries given in Table 7 are examined a similar pattern emerges. In 1977, the six countries listed imported some 13,000 tonnes of animal and vegetable waxes. It is estimated that these six countries account for three-quarters of world consumption which suggests a total market of slightly below 20,000 tonnes per annum — a lower figures than is obtained by using export statistics, but very much in the same order of magnitude.

The competitive situation

Although the main animal and vegetable waxes are roughly comparable in their properties, they rarely act as substitutes in the end-use markets. Each has specific uses and although there may be a few products, e.g. polishes, where substitution can take place, this rarely happens in practice. The most important uses for beeswax are in cosmetics, pharmaceuticals and candles. Carnauba wax is primarily used for carbon paper, floor and car polishes and cosmetics, while the major user of candelilla wax is the US chewing gum industry.

The demand trends in the animal and vegetable wax markets are also somewhat different. Consumption of beeswax for example, has remained relatively stable over recent years and at present this wax is in short supply. However, as the total volume of trade is relatively small it must be appreciated that the addition of only a few hundred tonnes could reverse the market situation. At the same time the vegetable wax markets have been declining and are in a relatively depressed state. This is especially so with regard to Brazilian exports of carnauba wax which have declined

Table 7

Imports of vegetable and animal waxes into six major markets

Tonnes

	1972	1973	1974	1975	1976	1977
1 **USA**						
Carnauba	4,116	4,462	3,327	2,571	3,055	2,277
Candelilla	1,747	1,197	1,606	1,035	1,193	1,153
Other vegetable waxes	185	268	97	68	229	252
Beeswax	1,300	1,272	1,768	1,040	1,413	1,293
Other animal waxes	135	141	159	180	170	172
Total	7,483	7,340	6,957	4,894	6,060	5,147
2 **Fed. Repub. Germany**						
Carnauba*	–	–	–	710	919	1,062
Other vegetable waxes	2,241	2,525	1,075	138	377	202
Spermaceti	1,547	1,875	1,734	688	950	533
Beeswax & other insect waxes	728	859	797	718	945	924
Total	4,516	5,259	3,606	2,254	3,191	2,721
3 **UK**						
Carnauba, candelilla, esparto, ouricury	973	1,108	1,092	654	711	} 774
Other vegetable waxes	23	12	29	30	19	
Spermaceti	70	103	338	119	201	260
Beeswax & other insect waxes	488	705	662	614	741	830
Total	1,554	1,928	2,121	1,417	1,672	1,864
4 **Japan**						
Carnauba	1,376	1,580	874	473	701	923
Other vegetable waxes	46	71	140	33	54	74
Spermaceti	39	103	101	82	10	36
Beeswax	760	812	880	461	689	675
Other insect waxes	11	13	24	2	8	12
Total	2,232	2,579	2,019	1,051	1,462	1,720
5 **France**						
Vegetable waxes	728	698	628	363	457	450
Spermaceti	48	61	53	35	41	120
Beeswax & other insect waxes	491	443	528	354	411	525
Total	1,267	1,202	1,209	752	909	1,095
6 **Netherlands**						
Vegetable waxes	529	627	460	293	397	457
Spermaceti	60	75	99	12	52	10
Beeswax & other insect waxes	376	395	325	311	364	369
Total	965	1,097	884	616	813	836
TOTAL IMPORTS INTO THE SIX MARKETS	18,017	19,405	16,796	10,984	14,107	13,383

Source: Country trade statistics

Notes: *Included with 'other vegetable waxes' before 1975
— = nil or negligible

by over one-third from a peak of 14,000 tonnes. This has led to stock-piling of carnauba wax in Brazil. The candelilla wax market is now more or less static.

One of the reasons for the overall decline in the natural wax market has been the increasing competition from synthetics. These have the major advantages that their specifications can be guaranteed and that supplies and prices fluctuate less, which makes them preferred by some end-users. Actual price levels are not as important as stability in price – some synthetics are in fact more expensive than the natural products. At the same time manufacturers are looking for cheaper waxes that can be used as extenders and thus bring down prices.

Prices

Prices of the three major natural waxes, carnauba, candelilla and beeswax, are given in Table 8. These are for *unrefined* wax and should be regarded as no more than a general indication of market price. Of the three waxes, beeswax has the highest price. In mid-1978 the UK price for *refined* BP beeswax was around £3,200 per tonne. At the same time the price for spermaceti was around £1,000 per tonne. Of the vegetable waxes prime yellow grade carnauba is not in high demand, the fatty grey grade at £900 to £950 per tonne being a better guide to the price of carnauba wax. *Refined* candelilla wax was slightly higher priced at £1,400 per tonne.

As previously stated, one of the reasons for the high beeswax prices is the current shortage of supply. Another reason is that about two-thirds of beeswax is used by the cosmetic and pharmaceutical industries. Due to strict health controls product development by these industries is a very costly business and, once a formula has been accepted, changes are only made when absolutely necessary, making demand very inelastic. Vegetable wax prices are much lower due to over-supply in this sector. The price of carnauba is controlled by Brazil, the only exporter, and any increase

Table 8

Prices of carnauba, candelilla and beeswax

£ per tonne c.i.f. UK

Year	Quarter	Carnauba wax		Candelilla wax	Beeswax (Ex Dar-es-Salaam)
		Fatty grey	*Prime yellow*		
1970	1	317	449	531	737
	2	315	489	531	732
	3	312	533	531	727
	4	325	477	531	705
1971	1	374	517	536	714
	2	371	548	541	714
	3	369	625	541	692
	4	355	636	472	689
1972	1	338	659	528	638
	2	330	654	522	599
	3	340	664	522	597
	4	351	648	531	622
1973	1	358	642	536	622
	2	375	675	542	705
	3	402	675	545	800
	4	608	822	558	833
1974	1	1,382	1,743	n.q.	1,167
	2	1,917	2,097	640	1,300
	3	1,875	2,000	630	n.q.
	4	1,200	1,700	590	1,325
1975	1	1,133	1,838	590	1,325
	2	1,000	1,500	590	1,325
	3	933	1,500	607	1,325
	4	967	1,647	680	1,313
1976	1	988	1,675	798	1,398
	2	972	1,675	832	1,440
	3	985	1,700	845	1,700
	4	1,225	1,958	983	1,925
1977	1	1,117	1,875	1,027	2,150
	2	1,043	1,725	965	2,539
	3	1,012	1,708	985	2,693
	4	995	1,700	980	2,635
1978	1	965	1,667	980	2,425
	2	955	1,630	n.q.	2,389

Source: *The Public Ledger*

Note: n.q. = not quoted

in demand could easily be satisfied by that country. The development of other competing vegetable waxes would, at present, probably result in a price war with falling prices.

The position of jojoba wax

To assess the possible place of jojoba in the natural wax market is not easy. The literature contains many general statements to the effect that jojoba wax is a potential substitute for various animal and vegetable waxes. However, as has been pointed out, each of these waxes tends to be used in specific market outlets. Where jojoba fits into this spectrum needs to be considered in future research, but a final answer will probably have to await the availability of commercial supplies. Indications from the trade, however, suggest that the price of fatty grey carnauba wax, around £900 to £950 per tonne in the UK, would be the most likely competitive position for any new wax such as jojoba coming onto the market at present.

In terms of volume, the total world animal and vegetable wax market is around 20,000 to 22,000 tonnes per annum. The degree of substitution for any new wax would depend very much on its quality and price. A 10 per cent share in the market would give jojoba wax a 2,000 tonne market, whilst if 5,000 tonnes were reached this would place it among the most important of the natural waxes.

CONCLUSIONS

In the absence of commercially available supplies in any quantity and lack of information on likely future prices, any assessment of the future size of the markets for jojoba oil and wax must be tentative and depend on the functionality of the oil being proven. Based on the analysis in this Section, at the current high prices of £5,500 to £7,700 per tonne (US \$5—US \$7 per pound) the market for jojoba oil will remain in hundreds of tonnes. At £900 to £950 per tonne (US \$0.82—US \$0.86 per pound) jojoba would compete in the wax market and might obtain a share of between 2,000 and 5,000 tonnes. At £500 to £600 per tonne (US \$0.45—US \$0.54 per pound) it would compete with sperm oil which at present has a market of less than 20,000 tonnes per annum, although this market will probably have been eroded to a substantial extent by synthetics by the time jojoba oil is available in quantities of this order of magnitude. However, other markets, especially in the cosmetic and pharmaceutical industries, exist for jojoba oil, although it is impossible to estimate their size at present.

Below £500 per tonne, market prospects are even harder to predict. The best potential uses for jojoba oil appear to be in the higher priced markets discussed in this Section. At prices below £500 per tonne demand may be inelastic. On the other hand, when the oil is available commercially the possibility should not be excluded of other new uses being developed.

Economics of jojoba production

HAND HARVESTING

Jojoba seeds are at present obtained almost exclusively from natural stands. Costs of production are thus limited to harvesting, which is carried out entirely by hand. The seeds are small (2,000 to 3,000 per kilogram) and workers are reported to be able to pick from 1.5 to 4 kilograms per hour, with an average of around 2 kilograms. Almost half the weight as harvested is lost subsequently, mainly with the removal of the hulls and through moisture loss on drying. With an oil extraction rate of around 40 per cent the yield of oil represents about one-quarter of the weight of the seeds as harvested, i.e. the average picking rate represents about 0.5 kilograms of oil harvested per hour.

It is difficult to find hand pickers for the natural jojoba stands. Wright and Foster (1978) estimated an average harvest cost in California and Arizona of £1.38 per kilogram (US $.1.25 per pound) for clean, dry seed. With an extraction rate of 40 per cent and an estimated cost of extraction of £0.28 per kilogram of oil (US $0.25 per pound) they calculate a hand harvesting cost of about £3.75 per kilogram (US $3.40 per pound) in oil equivalent. In other words except for very small volumes of jojoba oil, which at present fetch between £5,500 and £7,700 per tonne, hand harvesting costs in the USA amount to well over the market prices which might be expected in the event of larger volume markets arising (£900–£950 per tonne for jojoba wax and £500–£600 per tonne for jojoba oil).

In Mexico, with lower rates of pay, hand harvesting costs amount to £0.88 per kilogram of seed (US $0.80 per pound) equivalent to about £2.50 per kilogram of oil (about US $2.25). Even if a very low labour rate of £0.05 per hour is assumed, as might be the case in some developing countries, the hand harvesting costs of £0.10 per kilogram of oil (US $0.09 per pound) would still represent a high percentage of the market price ranges mentioned above. With many other costs, including establishment costs and transportation, to be accounted for this cost must be considered as marginal. However, the labour situation in developing countries is often complex and any full economic analysis would need to be undertaken on a case study basis, taking into account the opportunity cost of labour.

The conclusion to be reached from these figures is that the cost of hand harvesting in many countries is likely to be too great and that machine harvesting will therefore be required, on the assumption that this will reduce harvesting costs. The possibilities for developing machine harvesting were mentioned in Section 1. Machine harvesting in turn requires organized cultivation, with its attendant costs.

PLANTATION PRODUCTION

Economic assessments of plantation developments of jojoba have been carried out in both the USA and Israel. The most detailed economic study (Stubblefield and Wright, 1977) was undertaken for Indian reservations in Arizona and California. Costs based on local conditions were used to obtain a series of break-even costs for a jojoba plantation. In particular, three variables were examined: (i) yield (1,420 plants per hectare producing 1,970 kilograms of dry seed per annum and 1,850 plants per hectare producing 5,040 kilograms of seed); (ii) hand harvesting versus mechanical harvesting; (iii) type of land i.e. undeveloped 'raw' land, or already developed, but 'idle' land. It will be remembered from Section 1 that a yield of 2,250 kilograms per hectare of dry seed is the maximum that could be realistically expected at the present time.

The break-even costs obtained are presented in Table 9. In this Table a cost for the oil has been obtained assuming a 40 per cent extraction rate and an extraction cost of £0.13 per kilogram of oil (US $0.12 per pound). From these figures hand picking, which results in a cost of production of £3,630 per tonne of oil, again appears uneconomic for all but very small volumes of production (see Table 9, column 2).

Table 9

Break-even costs for jojoba plantations on Indian reservations in Arizona and California

£/kg of dry, clean seed, (US $/lb)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Year	Hand harvesting 1,970 kg/ha (1,760 lb/ac) 'Raw' land	Machine harvesting 1,970 kg/ha (1,760 lb/ac) 'Raw' land	Machine harvesting 1,970 kg/ha (1,760 lb/ac) 'Idle' land	Machine harvesting 5,040 kg/ha (4,500 lb/ac) 'Raw land'	Machine harvesting 5,040 kg/ha (4,500 lb/ac) 'Idle' land
4	2.65 (2.40)	2.02 (1.83)	1.58 (1.43)	1.69 (1.53)	1.33 (1.21)
5	2.11 (1.91)	1.28 (1.16)	1.00 (0.91)	0.87 (0.79)	0.69 (0.63)
6	1.65 (1.50)	0.67 (0.61)	0.53 (0.48)	0.60 (0.54)	0.49 (0.44)
7	1.60 (1.45)	0.57 (0.52)	0.46 (0.42)	0.50 (0.45)	0.41 (0.37)
8	1.60 (1.45)	0.57 (0.52)	0.46 (0.42)	0.42 (0.38)	0.34 (0.31)
9	1.60 (1.45)	0.57 (0.52)	0.46 (0.42)	0.35 (0.32)	0.30 (0.27)
10	1.60 (1.45)	0.57 (0.52)	0.46 (0.42)	0.32 (0.29)	0.26 (0.24)
11	1.40 (1.27)	0.39 (0.35)	0.39 (0.35)	0.21 (0.19)	0.21 (0.19)
12	1.40 (1.27)	0.39 (0.35)	0.39 (0.35)	0.20 (0.18)	0.20 (0.18)
Equivalent cost of oil* Year 12	3.63 (3.30)	1.10 (1.00)	1.10 (1.00)	0.63 (0.57)	0.63 (0.57)

Source: Based on Stubblefield and Wright (1977) **Note:** *at 40 per cent extraction rate and an extraction cost of £0.13/kg of oil (US $0.12/lb)

Only when break-even costs fall to £0.20 per kilogram of seed (see Table 9, columns 5 and 6) does the production of oil for the larger volume market start to look economically feasible. Even with these cost levels, no account has been taken of transport and other marketing costs.

The calculations carried out by Stubblefield and Wright (1977) assume that higher prices can be obtained in the earlier years. As the market analysis in Section 3 showed, this might well be the case for the first few hundred tonnes. Thereafter however, a lower price can be expected throughout the production period. The most favourable situation analysed has therefore been recalculated assuming a price of £0.20 and £0.22 per kilogram (US $0.18 and US $0.20 per pound) for the seed throughout. This is equivalent to an ex-farm oil cost of around £0.63 and £0.68 per kilogram (US $0.57 and US $0.62 per pound), at which level—depending on marketing costs—a market might exist for a few thousand tonnes of jojoba oil. Interest payments have been excluded from the calculation. Table 10 shows that the cumulative cash flows remain negative until year 65 at £0.20 per kilogram and until year 27 at £0.22 per kilogram. In the latter case a 30-year project will show an internal rate of return of 1.3 per cent.

A more recent economic analysis (Wright, 1978) reviewing the potential for growing jojoba in the south-western USA is even less favourable. This analysis gives break-even costs at maturity (year 12) as follows:

(i) for a yield of 1,580 kilograms per hectare (1,410 pounds per acre) a break-even cost at year 12 of £2.01 per kilogram of oil (US $1.82 per pound);

(ii) for a yield of 5,270 kilograms per hectare (4,700 pounds per acre) a break-even cost at year 12 of £1.21 per kilogram of oil (US $1.10 per pound).

This analysis clearly illustrates that it will be essential to increase yields significantly over those so far achieved before jojoba cultivation is likely to prove an economic proposition on any but a relatively small scale.

In different countries and under different conditions the economics of production will obviously vary widely. With so little information available, wider analysis is not possible. In developing countries labour costs will be lower, whilst capital cost can be expected to be higher. In particular it is worth noting that the US economic studies assume the application of irrigation water. If research confirms that jojoba does need irrigation to yield satisfactorily in the arid zones of developing countries, it is not sufficient to analyse the economics of jojoba alone. A comparative analysis will need to be made with other possible irrigated crops, including a consideration of how the timing of jojoba's demand for water fits that of other crops.

Throughout this Section all the prices quoted are ex-farm; the costs of marketing have not been considered. These costs, however, are significant, though they will vary between regions. The majority of the suggested end-uses for jojoba are industrial, the main markets being in the developed countries. With no proven use for jojoba as an edible oil, consumption in the majority of developing countries would as such be low for the time being, and consequently high marketing costs to industrialized countries would be incurred.

Table 10

Cash flow analysis of a jojoba plantation*

Year	Establish-ment costs	Cultivation costs	Harvesting and cleaning costs	Total cost	Yield of clean, dry seed	Price of clean, dry seed at £0.20/kg			Price of clean, dry seed at £0.22/kg		
						Return	Net cash flow	Cumulative cash flow	Return	Net cash flow	Cumulative cash flow
	(£/ha)	(£/ha)	(£/ha)	(£/ha)	(kg/ha)	(£/ha)	(£/ha)	(£/ha)	(£/ha)	(£/ha)	(£/ha)
1	224	–	–	224	–	–	(–224)	(– 224)	–	(–224)	(– 224)
2	255	–	–	255	–	–	(–255)	(– 479)	–	(–255)	(– 479)
3	255	–	–	255	–	–	(–255)	(– 734)	–	(–255)	(– 734)
4	–	360	282	642	630	126	(–516)	(–1,250)	139	(–503)	(–1,237)
5	–	360	316	676	1,255	251	(–425)	(–1,675)	276	(–400)	(–1,637)
6	–	360	351	711	1,880	376	(–335)	(–2,010)	414	(–297)	(–1,934)
7	–	431	385	816	2,520	504	(–312)	(–2,322)	554	(–262)	(–2,196)
8	–	431	418	849	3,080	616	(–233)	(–2,555)	678	(–171)	(–2,367)
9	–	431	447	878	3,640	728	(–150)	(–2,705)	801	(– 77)	(–2,444)
10	–	431	479	910	4,200	840	(– 70)	(–2,775)	924	+ 14	(–2,430)
11	–	431	502	933	4,620	924	(– 9)	(–2,784)	1,016	+ 83	(–2,347)
12–Onwards	–	431	525	956	5,040	1,008	+ 52	(–2,732)	1,109	+153	(–2,194)
								Becoming positive in year 65			Becoming positive in year 27

Source: Based on Stubblefield and Wright (1977)

Notes: *assuming machine harvesting and a mature yield of 5,040 kg clean dry seed per hectare on 'idle' land
– = nil or negligible

Section 5

Discussion

PLANT INTRODUCTIONS

The main concern of the Tropical Products Institute in the study of jojoba is to assess its potential as a crop for the arid and semi-arid zones of developing countries. In order to do this it is necessary to look wider than jojoba itself and to consider the overall requirements for successful plant introductions.

The whole subject of plant introductions to the arid and semi-arid zones is one of considerable complexity and involves the whole ecological, social and economic situation in these areas. Present systems of agriculture in arid zones normally revolve around livestock production, but such systems are poorly researched and understood. Any new plant introductions will have effects right through these systems. Initially, therefore, research needs to concentrate on testing their overall suitability in the regions concerned.

The type of plant species is of particular importance. There is often a shortage of wood for fuel and of browse plants for livestock. The introduction of those species best suited for these purposes might therefore be of greater value than the introduction of cash crops.

Multi-purpose species would seem to be of particular value and research could usefully concentrate on small projects to try out several species. Expensive, plantation-type developments could not sensibly be recommended until very careful examination on a pilot scale has been successfully completed and evaluated.

THE PROSPECTS FOR JOJOBA

Jojoba must be regarded as one of a number of possible plant introductions to arid and semi-arid zones. Research to date has illustrated that because of the properties of its oil, jojoba might one day be a commercial crop in certain parts of the world. However, a number of factors need to be developed if it is to become economically viable. Primarily, it is necessary to increase seed yield considerably and to develop an economic means of harvesting the crop. Other aspects for study include those discussed in Section 1.

Until the crop has been cultivated and more information obtained, it is possible to make only crude estimates of the costs of producing jojoba oil on a commercial scale. The present indications are that the economic viability of jojoba cultivation is unlikely for more than small-scale production for very specialist, low-volume purposes that can command a high market price. The need now, therefore, is to direct attention to the research priorities which aim at overcoming the limitations to the cultivation of the crop. If production costs could be brought down to competitive levels, there seems little doubt that jojoba would have several potential end-uses. A final assessment will have to await the availability of larger supplies to allow industrial users to examine the commercial prospects on an appropriate scale.

It has been suggested in Section 4 that a yield of at least 5,040 kilograms of dry seed per hectare is required before the cultivation of jojoba can even begin to be considered economic; this is equivalent to a yield of slightly under 2.5 tonnes of oil per hectare. If for illustrative purposes, a wax market of 5,000 tonnes and an oil market of 20,000 tonnes per annum could be achieved, 10,000 hectares of jojoba would meet this market demand – this is a very small area in global terms. On the basis of these figures, therefore, jojoba is unlikely to provide more than a minor new source of income for a few developing countries.

The possibility of introducing jojoba into developing countries needs careful consideration. Brooks (1978a) in discussing the possible introduction of jojoba to the Sahel region concluded that careful site testing to examine how the plant might react under different environmental conditions was a prerequisite to its cultivation. In arriving at this conclusion, he considered that in the southern Sahel region climatic conditions were closest to those found in jojoba's natural environment and that soil texture generally appeared favourable. On the other hand, lack of winter rainfall, a climatic factor to which jojoba responds in North America, may suppress growth unless supplementary water is available. Possible diseases and insect pests would also need to be studied. The same author (Brooks, 1978b) has delineated an area in western Saudi Arabia which also seems suitable for the establishment of jojoba. This area has the advantage of late winter and spring rains.

If current research shows that jojoba can be cultivated satisfactorily it would then be reasonable to organize a series of small carefully monitored trial plots in developing countries. Initially, the aim should be to obtain basic agronomic information on the reaction of the plant to different environments. Only when these trials have proved successful, and yield data obtained, will the necessary information be available to begin to examine fully the potential for the introduction of jojoba into developing countries from the all important standpoints of economics and marketing.

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