



Five-year-old jojoba research nursery at the University of California, Riverside.

Various kinds of jojoba seeds.



Jojoba - a crop whose time has come

'Its prospects of developing into a profitable, energy-related, renewable resource appear to be excellent.'

Demetrios M. Yermanos

The demand for a substitute for sperm whale oil and for a lubricant to replace depleting fossil fuel reserves has been a powerful incentive for development of jojoba, a plant native to California. Jojoba has long been known to scientists for its drought resistance and for the versatile liquid wax that can be extracted from its seeds, but since 1974, when several hundred acres have been planted to jojoba in the U.S., Mexico, and Israel, it has begun to attract attention as a possible commercial crop.

It is not difficult to explain its popularity. Jojoba grows in soil of marginal fertility, needs little water, withstands salinity, and does not seem to need fertilizers or other polluting chemical treatments. It is not afflicted yet by major diseases or insect pests, and it can withstand many chemical sprays

should they be needed for control. It requires no specialized cultivation equipment, and its oil can be extracted like other oilseeds. In addition, jojoba is a low labor-intensive crop that is easy to grow.

Besides being known for its superior lubricating properties, jojoba has attracted interest as a landscape and soil conservation plant. It is a perennial, evergreen, nonpoisonous, drought-resistant, low-maintenance, long-lived, and low-fire hazard plant with a deep root system, and therefore it can be used in highway and roadside plantings and hedges. It can also be used as a soil stabilizer in green belts around desert cities suffering from particulate air pollution.

Because jojoba has never been grown commercially, no data are available on cost of production, yields of seed and wax, mar-

ket demand, and price. The absence of such basic data does deter establishing large commercial plantations, but preliminary production and marketing data, collected for 10 years, and a better acquaintance with its agronomic aspects have led to optimism about jojoba's economic potential.

A yield of 3,000 pounds of seed per acre (3500 kg/ha) from a 9- to 10-year-old plantation appears to be a realistic expectation. A price of \$2 per pound of oil (\$4.4/kg) could also be realized in the beginning for low-volume, high-priced products; a progressive long range drop to \$1 per pound (\$2.2/kg) may be necessary for the oil to ensure a larger market for low-priced, high-volume products; at that price it would compete successfully with other lubricants and sperm whale oil.



(a)



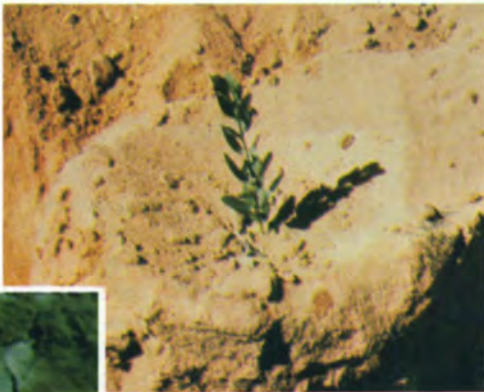
(b)



(c)

Different types of fruiting in jojoba: one (a), four (b) and thirty-one (c) fruit per node.

Six-month-old seedlings growing in the desert by El Obeid, Sudan (12° N. latitude).



One-year-old jojoba seedling growing at Erkowit, Sudan (18° N. latitude).



One-year-old jojoba seedling growing under high soil salinity at the Cabazon Native American Reservation.

Training jojoba plants to grow upright: below left, wrapping the plant with plastic screen; below right, tying branches with twine.





Jojoba seedlings grown for five months under different photoperiods: 12 hours (left), 18 hours (center), and 24 hours (right).

These two price levels correspond approximately to 65 cents and 30 cents per pound (\$1.43 and 66 cents per kilo) of seed respectively. Assuming costs of production that are comparable to those for walnuts or almonds (although the latter require twice as much irrigation water and heavy nitrogen applications) the net income per acre of jojoba at the higher price would be exceeded only by that from avocados. At the lower price, jojoba would rank seventh in net income. Real net income, however, would be considerably higher because as the price would drop to the lower level yield would rise above 3,000 pounds per acre as bushes would grow larger and as cultural technology would improve.

This favorable outlook has set the stage for a "getting acquainted" phase in its commercial development. Most of the 1,500 acres (600 hectares) planted in 1977-1978 in California are in small plots ranging from 1 to 20 acres (1/2 to 8 hectares) each. A few large plantations more than 100 acres each were established early in 1979. If these initial plantings live up to expectations, acreage is expected to increase rapidly. This report summarizes the art of growing jojoba.

Locating plantations

Latitude. Natural populations occur between 23° and 35° north latitude. Vegeta-

tive development responds strongly to photoperiods. In greenhouse experiments seedling growth rate increased dramatically as the photoperiod approached 24 hours of light. Until the effects of varying photoperiods on quantity and quality of jojoba seed and wax production are better known, it would seem safer to establish plantings within the latitude zone of natural populations. A few plants do grow in California outside this zone: in the Botanical Garden of Santa Barbara, in La Purisima Mission by Lompoc, in the West Side Field Station of the University of California at Five Points and on a private ranch in Fresno. Seed has been harvested from all these plants indicating that the zone of adaptation of jojoba may be extended at least as far north as Fresno. Additional encouraging evidence was obtained from jojoba plantings in the Sudan; 1-year-old plants growing in Erkowit (18° N latitude) are much larger than plants of similar age in California. Two- to 3-year-old plants in El Obeid (12° N latitude) are 60 to 90 cm tall and bloom profusely.

Soil type. Practically all natural jojoba populations occur on coarse, light or medium textured soils with good drainage and good water penetration. Experimental plantings established on heavy soil bloomed much later and grew slower than did those on light soils. In jojoba nurseries estab-

lished on Hanford, Ramona and Greenfield soils at U.C., Riverside, growth the first two years was not luxuriant, then accelerated progressively and last summer, on the fifth year of development, plants exhibited superior performance. Extensive pH soil measurements around jojoba populations in Mexico and the U.S. gave readings from 5 to 8, indicating that this may not be an overly critical factor.

Soil fertility. Jojoba grows naturally on soils of marginal soil fertility. Fertilization of field plots at UCR with nitrogen and phosphorus for three consecutive years (50 pounds of nitrogen, 50 pounds of phosphorus, or 50 + 50 pounds of nitrogen and phosphorus per acre annually) has not induced any obvious superiority in vegetative development. By contrast, similar fertilization treatments in the greenhouse with potted plants, where root growth is confined, indicated a dramatic, favorable response. Lack of response in the field might be attributed to jojoba's deep, extensive root system which enables it to draw nutrients from a much deeper soil profile than most other plants; also, to the fact that fertilization was applied to young plants which produced low yields of seed, therefore having lower nutritional needs. The roots of direct-seeded jojoba plants were in excess of 7 feet (2 m) in depth and consisted of one or few major tap roots growing straight down with very few fibrous side roots in the upper 2 feet (0.60 m) of the soil profile. Jojoba plants growing in Hoagland nutrient solution in the greenhouse for 6 months exhibited no clearcut deficiency symptoms when individual nutrients were eliminated, except in the case of nitrogen.

Irrigation

Natural jojoba populations grow in areas receiving 3 to 18 inches (76 to 450 mm) of precipitation annually. Since some precipitation is always lost as run-off, it would seem that jojoba can grow with little water. The best jojoba plants observed so far, 15 feet (5 m) in height, were in areas with 10 to 15 inches (254 to 380 mm) of annual rain. Heavier applications of water in experimental plots with relatively good drainage stimulated more luxuriant vegetation. Whether this increased growth would result in higher seed yield is not known.

Jojoba utilizes most water during late winter and spring and thus does not compete for water with traditional irrigated crops. Since new flowers appear in late summer, a midsummer irrigation in excessively dry years might insure good flower production and, thus, good seed yield.

Jojoba appears to tolerate soil salinity.

Robust jojoba plants grow as close as 10 feet (3.3 m) from the ocean. Further verification of jojoba's salt tolerance has been offered by greenhouse experiments and by experimental field irrigations with brackish water. In one large planting by the Salton Sea, seedlings are growing with no obvious sign of stress in spite of a brackish water table at 6 feet (1.80 m) below the surface and electroconductivity in excess of 24.

Temperature

Temperature may be the most critical factor in growing jojoba. In Riverside, the temperature drops gradually after sunset and remains at the lowest level for 3 to 5 hours usually between 1 and 6 a.m. When temperatures reach 20° to 22° F (-6° to -5° C), flowers and terminal portions of young branches of most jojoba plants are damaged. During early seedling development, excessive cold may kill entire plantations. As plants grow taller, frost may not endanger their survival to the same degree but it may curtail yields. In this regard, frost damage in the early flowering stages may not be as destructive as at later stages; given enough time, a new crop of flowers will replace the damaged one. Monitoring of temperatures during the last two years in sites where natural populations of jojoba occur lead to some striking observations: (a) Minimum temperatures of sites with southern exposure at 4,600 feet (1500 m) elevation were higher than those recorded at sea level in the same latitude. (b) Old plants exhibited no serious frost damage symptoms although temperatures dropped to 16 F° (-9 C°). (c) Snow was on the ground in January within the area occupied by wild jojoba. (d) High temperatures do not have adverse effects unless they exceed 122° F (50° C).

Propagation

Jojoba may be propagated through seed, rooted cuttings, and tissue culture. Present sources of seed are the natural populations. Single plant selections have been based generally on seed yield per plant and large seed size. In some cases, growth habit, high wax content, and fruiting pattern have been considered. Single plant variability in seed size, yield, morphology, and wax content is striking, both within and among natural populations. Wax composition, however, is extremely uniform throughout the area of adaptation, in spite of broad botanical variability and differences in geographic origin. Differing cultural practices do not seem to cause major departures in wax composition and no mutants have been encountered as yet.

It is still not possible to distinguish male

from female seedlings before flowering. This would seem to create a problem in following a given planting plan regarding position and frequency of male and female plants. This difficulty, however, can be circumvented by overplanting, especially when seeds rather than seedlings are planted. A grower can rogue out extra males and

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a large number of inferior female plants from the field soon after blooming.

Rooted cuttings have not been used widely to establish commercial fields because of lack of long-term performance records from mother plants verifying their superiority as sources of cuttings. In addition, production of cuttings proceeds slowly and requires considerable controlled greenhouse facilities. As soon as superior genetic material is available for propagation, use of rooted cuttings and tissue culture may become popular. Vegetative propagation will enable growers to plant according to planting plans.

Planting plan

Until recently little was known about plant development or performance, components traditionally used to arrive at an optimum number and arrangement of plants per acre. The planting plan we now recommend is based on the following observations:

1. During the first 10 years and under favorable soil and climatological conditions in California, jojoba grows 1/2 to one foot (15 to 30 cm) per year in diameter and in height. Under warmer conditions, this growth rate may double.
2. The seed is borne on new growth and most of it is found on the plant's outer periphery.
3. The ratio of male to female plants that should be expected in commercial plantings is about 1:1 or slightly in favor of males by about 5 percent.
4. Crowding of plants does not seem to depress plant growth and production.
5. When several seeds are planted per hill it is time consuming and expensive to rogue out extra male plants.
6. Jojoba pollen travels distances in excess of 100 feet (33 m) with relatively mild breezes.

With these observations in mind, the following planting plan is practiced at UCR.

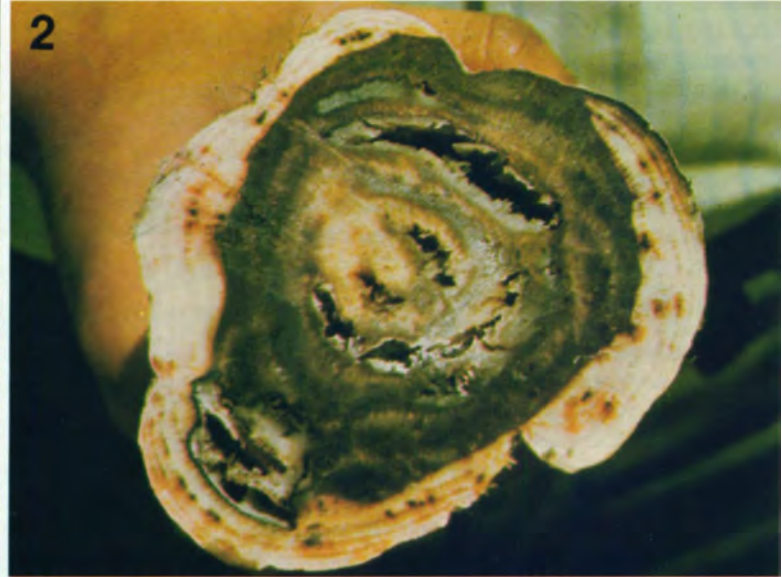
Individual seeds or seedlings are planted 1 to 1 1/2 feet (30 to 45 cm) apart. As male plants flower, they are thinned out to one male every 40 feet (13 m) on the row. As female plants flower, usually in the third year, any slow-growing, obviously late and unproductive plants are rogued out, leaving a female plant at every 2 to 3 feet (60 to 90 cm) on the row. Spacing between rows depends on the harvester to be used and on the expected rate of growth. With hand harvesting and cultivation, rows could be as close as 10 feet (3.3 m) apart. In mechanized farms space should be allowed between rows for vehicular traffic with optimum spacing closer to 14 to 16 feet (4 to 5 m). If these planting patterns are excessively dense after the tenth year or so, every other row and a few plants from each row could be taken out. For optimum pollen distribution, male plants are thinned so as to develop a rombic rather than a square distribution pattern over the entire field.

Plants are allowed to grow naturally for about three years. After thinning is completed, the rows are pruned vertically with the kind of cane cutter used in vineyards. The vertical sickle bar cutter moves parallel to the planted row and is adjusted to cut one foot away from the center of the row on each side. This gives the planted row the shape of a continuous rectangular hedgerow, approximately 2 feet wide and 3 feet tall (60 x 90 cm); branches which are initiated 4 feet (1.2 m) or higher from the ground are allowed to develop sideways and as the plants continue to grow in height the cross-section of the hedgerow starts to resemble a tree's center cross-section.

It may be unnecessary to allow plants to grow any taller or wider than 10 to 15 feet (3 to 5 m). This decision, however, will have to wait until yield data from various types of 10- to 20-year-old hedgerows are available. We anticipate that hedgerows will be pruned back to a uniform height and width and then sprayed with one of the growth regulators that has been found to stimulate new and profuse branching on jojoba. Because flowers and seeds occur on new growth, a balanced system of pruning and spraying will, it is hoped, both maximize and stabilize yields in time and will promote uniformity in seed maturity, size, wax quantity, and quality.

This planting plan involves overplanting initially; as much as 7 to 9 pounds of seeds per acre (6 to 8 kg per hectare) may be needed. Overplanting is recommended, however, because it enables a grower to adjust the density and pattern of males in his field, to eliminate low-producing females and to maximize yield per acre during the first

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rotting in the root center and the characteristic blackening of vascular elements scattered throughout the periphery. (3) An electron micrograph of *Erwinia betavasculatorum*. Hair-like flagella give the bacterium mobility. (4) Inoculated plants show great differences in resistance to the *Erwinia* pathogen. After three cycles of selection, plants on the left show little infection while parent plants on the right are severely rotted.



Jojoba *Continued from page 7*

critical 10 years. If future data will indicate that higher yields may be obtained by lower population densities, these can easily be adjusted downward by removing plants or entire rows at the appropriate stage of development. An additional advantage of this

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plan is that it does away with tying, wrapping and staking of individual plants which, although necessary for research plantings where individual plant performance needs to be evaluated, are time consuming and expensive for commercial enterprises.

Stand establishment

Direct seeding. Most of the direct-seeded commercial jojoba fields were planted with commercially available planters on raised beds. With two planters mounted on a tool bar, one tractor operator can plant 60 acres a day. Large seed, easier to harvest and usually with a higher wax content, is preferred in planting because it is likely to produce large-seeded plants. Large seed produces more vigorous seedlings than small seed during the first 2 to 3 months of growth; however, this superiority disappears later. After planting on dry beds, seed is irrigated up.

For faster emergence, plantings should be made during the warm months of the year and depth of planting should not exceed 1 1/2 inches (2 to 3 cm). With soil temperatures of 70° F (21° C) or higher, germination occurs within a week; the tap roots develop rapidly, at first at the rate of about one inch (2.5 cm) a day. Emergence occurs in about 20 days. Low soil temperature may delay emergence by 2 to 3 months. Irrigation should be applied as needed during the first 2 to 3 months to maintain adequate moisture near to the surface of the raised bed to insure good germination and root establishment. Later, irrigations may be applied at monthly intervals between September and June to supply the field with a total of about 1 1/2 acre-feet (45 hectare cm) of water. Overwatering jojoba seedlings or planting the seed inside the irrigation furrow may be disastrous to seedling emergence and survival.

No jojoba cultivars exist as yet and, therefore, no varietal recommendations can be made. One should, however, avoid using seed harvested from natural stands in warm climates if plantings are to be made in areas where frost is common.

Production and transplanting of seedlings. Planting seedlings speeds the establishment of plantations and gives jojoba a headstart over weeds. In seedling production at UCR seeds are pregerminated in large containers filled with vermiculite, sand or similar material at about 80° F (27° C). As soon as germination starts and before a radicle starts to grow (usually in 2 days), single seeds are transplanted 1 inch deep (2.5 cm) in 2x2x5-inch (5x5x12.5 cm) square paper containers, filled with potting mix, that are open at both ends. The paper containers are placed in plastic 16x16-inch (40x40-cm) flats, with large holes at the bottom, 64 per flat. Jojoba does not seem to require a particular potting mix; a mix of 30 percent to 40 percent organic matter with a medium or light loamy soil has given satisfactory results. With such a mix watering in a greenhouse is needed only every 4 to 5 days. Emergence occurs in about 15 to 20 days, and the seedlings are ready for transplanting when they are 6 to 12 inches (15 to 30 cm) tall, usually in 8 to 10 weeks. At that time, the paper container is partly disintegrated and may be left undisturbed or may be peeled off as seedlings are transplanted.

As soon as the jojoba tap root outgrows the 5-inch (12.5-cm) deep container and gets outside the soil column it self-prunes. This triggers initiation of many fibrous side roots. Side roots do not develop if the containers are closed at the bottom; instead, the tap root continues to grow in an abnormal coiled pattern which persists unchanged in the plant's later life.

soil around each jojoba seedling and contributes to lower transplanting losses. The grain stalk may be nipped off at transplanting. Equipment is now available for mechanically transplanting such seedlings.

To insure fibrous (rather than tap root) development, the flats or styrofoam blocks should not rest on the soil. If they do, the tap root is not air-pruned but penetrates and continues to grow into the soil and few if any side roots develop.

Planting in large containers, e.g., gallon pots, appears to be unnecessary unless the plants are to be kept in them for more than 8 to 10 months before transplanting. As jojoba is susceptible to root rot (*Phytophthora parasitica*) and other soil-borne pathogens in the very early seedling stage, the soil should be sterilized before it is used in the potting mix. Overwatering and high temperature increase this disease's severity.

Expected yields

What kind of seed and oil yields can be expected from jojoba under domestication? That cannot be answered at this time. Approximations are based on information gained from the harvest of wild plants and from the few experimental plots here and abroad.

Seed yields in natural populations range from a few seeds to more than 30 pounds (14 kg) of clean dry seed per plant. The high yields have been recorded on plants approximately 15 feet (5 m) tall with as large a diameter, following warm and wet years.

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Instead of paper containers, styrofoam blocks with 128 pyramidal perforations each, 2x2 inches at the top and 1/2 x 1/2 inches (5x5 cm and 1x1 cm) respectively at the bottom, have also been used successfully for seedling production. When seedlings are 6 to 8 inches tall (15 to 20 cm) in about 8 to 10 weeks, they are pulled off the styrofoam blocks and are transplanted. To avoid damaging the seedlings as they are detached from the styrofoam blocks and to produce firm seedlings, the following technique is utilized: On the sixth week after planting, a grain of barley or wheat is planted next to each jojoba seedling in the block. The dense, fibrous grain root system binds the

These high yields were observed on a small number of plants and in certain years only. The mean yield of several hundred wild plants harvested in California over a period of 5 years was about 4 pounds (1.8 kg). The average height of these plants was about 6 feet (2.7 m) and the diameter 5 feet (2.3 m). Years of no seed production by entire wild populations were observed following extended drought spells.

A 5-acre (2 ha) cultivated jojoba plot with rows 10 feet (3.3 m) apart and plants 5 feet (1.5 m) apart on the row, having about 900 female seedlings per acre, produced the following yields: On the fourth summer after planting, in 1977, less than 10 percent

(about 400) of the female plants produced any seed and of the latter less than 10 percent (about 40) plants approached a yield of 1/2 pound of dry clean seed per plant. On the fifth year (1978) practically all female plants produced some seed; the average yield of the best strain was 350 pounds per acre (400 kg/ha). Some plants exceeded 1 pound (450 g) per plant; the best producers of 1977, however, were not among the best in 1978. This fluctuation in yield did not seem to be a typical case of alternate bearing; more data are needed to fully understand the year-to-year production pattern. If the number of female seedlings in this field was increased to 1,800 per acre, by planting 2 1/2 feet apart on the row, the above yields could have been doubled. There is little doubt that jojoba yields could be raised substantially through plant breeding; there are also clear indications that large amounts of hybrid vigor are available to be exploited in the genetic makeup of this species.

The oil content of the seed of both cultivated and wild plants has been about 52 percent with a range extending from 44 to 59 percent. A significant positive correlation has been observed between seed size and oil content. The quality of oil has exhibited very little variation regardless of the geographic origin of the seed. No mutants have been identified with an oil composition radically different from that reported in recent publications.

Jojoba breeding

The most significant yield components in jojoba include: large seed; high oil content; flowers at every node; more than one seed per node in clusters; early flowering to escape frost damage; precocious seed production starting before the fifth year; consistent high production from year to year, and upright growth habit.

The combination of all of these desirable components in one superior variety will require years of persistent breeding research followed by years of testing. By contrast, the development of cultivars having some of the above botanical traits, such as large seed, fruit at every node and seeds in clusters, could be accomplished through vegetative propagation in a relatively short time.

Conclusion

In summary, the establishment of commercial plantations of jojoba does not require agricultural methodology or specialized equipment. Of particular significance may be the choice of locations for the first commercial plantations. Although jojoba is not demanding of soil fertility, water quality and altitude, it might be a mistake to

start plantations in locations where environmental stresses often reach extreme levels. It may be wiser to locate plantations where environmental factors offer the best chances of success and then explore progressively the ability of jojoba to produce, not merely survive, under more extreme environmental stresses.

Jojoba made the move from obscurity into the real world of agriculture with unprecedented speed. Its prospects of developing into a profitable, energy-related, renewable resource appear to be excellent. If it succeeds in this, jojoba may be cited in the future as an example of a well-conceived, appropriate technology.

Current expectations are that the small

quantities of wax that will be available initially from cultivated plantations will be absorbed by the more lucrative markets such as the cosmetics, waxes, and possibly pharmaceuticals. The real challenge for jojoba will be to penetrate the vast market of lubricants. This may not be too difficult, however, because with the rapid disappearance of fossil oils, cheap sources of lubricants will also be lost. Lubricants will be needed in the near future, as badly as fuels. None of the new sources of energy now contemplated (solar, atomic, geothermic) has lubricants as byproducts.

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Eight-month-old jojoba seedlings growing in styrofoam blocks.

