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New Crops for Arid Lands

C. Wiley Hinman

Recent decades have witnessed an apparent increase in the rate of desertification of agricultural land. In the United States alone there are now over 200,000 million hectares of arid and semiarid range land, and there are even larger areas in Africa, Australia, and South America (1). More than one-third of our planet's land is now arid. Water for humans and their crops is rapidly becoming a critically short commodity.

further diminishing the land's crop-carrying potential. Tilling and baring the thin topsoils of these delicate ecosystems has caused widespread erosion. As a result of these compounded problems, the deserts advance and farming of cotton and food crops becomes increasingly expensive, energy-intensive, and unproductive; indeed, growing conventional crops in arid regions is proving to be a self-limiting endeavor.

Summary. Five plants are described that could be grown commercially under arid conditions. Once the most valuable component has been obtained from each plant (rubber from guayule; seed oil from jojoba, buffalo gourd, and bladderpod; and resin from gumweed), the remaining material holds potential for useful products as well as fuel. It is difficult to realize the full potential of arid land plants, however, because of the complexities of developing the necessary agricultural and industrial infrastructure simultaneously. To do so, multicompany efforts or cooperative efforts between government and the private sector will be required.

The two most important reasons usually given for desertification are denuding of the land through deforestation in ancient times and overgrazing in modern times, but many other factors may contribute. Farmers have tapped many aquifers to sustain their crops, and in some cases have depleted these nonrenewable underground reservoirs to such an extent that it is no longer economical to use them. Heavy irrigation over long periods has increased soil salinity in many areas,

Of the approximately 350,000 plant species described by botanists, only about 3000 have been tried as sources of food and other useful materials (1). We cultivate only about 100 plant species on a large scale, with about 90 percent of our food coming from a dozen crops. Of the significant crops grown today, none is xerophytic. Thus, there is a need to identify usable xeric plants that can be made to produce abundantly in arid regions.

As Epstein (2) has explained in detail, plants in arid and semiarid regions face severe problems of water economy because the salinity of the soil causes os-

motric withdrawal of water and because hot, dry atmospheric conditions cause excessive loss of water to transpiration. But Epstein also saw potential in the desert (2):

Despite these precarious conditions, the arid and semiarid regions are among the most promising ones to turn to in our quest to increase the production of food, fiber, chemicals, and biomass for energy. The relatively unleached soils of these regions are often inherently fertile, the growing season is long, temperature and light intensity are high, and the atmospheric humidity is low, reducing disease problems. All these features favor agricultural productivity if water and salinity problems can be solved.

Some plants have amazing adaptive powers. One such plant, commonly found as a highway planting in California, is the shrub oleander. It is found from desert regions to mountains, and seems to thrive on neglect. Clones of oleander flourish at temperatures as high as 49°C and as low as 15°C, and mature plants can adjust rapidly and completely to dramatic temperature changes (3). The plant has an inherent ability to change its photosynthetic rate according to its environment.

Although few plants can be expected to be as hardy as oleander, the search for xerophytes of economic value has hardly started. Of the score or so that have been identified so far, I have selected five for discussion in this article: jojoba, guayule, buffalo gourd, bladderpod, and gumweed. The five offer a variety of useful products, and their development status ranges from research curiosity to near-commercial.

Jojoba

Jojoba (*Simmondsia chinensis*) has already received much publicity. Among the five plants it has closest to true commercial status, for a number of commercial jojoba plantations are already in existence.

Jojoba grows naturally as a shrub in

C. Wiley Hinman is an adjunct professor at the University of Arizona and is president of Hinman Associates, 4535 East Paseo La Casita, Tucson, Arizona 85718.

the Sonoran Desert of the United States and Mexico. Its seeds contain about 50 percent oil by weight (4). The oil, obtained by solvent extraction or expression of the seeds (the expressed oil is preferred because it contains fewer impurities), is similar to sperm whale oil. It is remarkably resistant to bacterial degradation, probably because bacteria cannot cleave and metabolize the long-chain esters it contains, mostly hydrocarbons containing 38 to 44 carbon atoms. The esters are usually formed from acids and alcohols of equal, or nearly equal, numbers of carbon atoms.

At present the primary market for jojoba oil is the cosmetics industry, where it is used in lotions, shampoos, and conditioners (5). Jojoba oil and its derivatives have other potential uses, however, such as in lubricants, transmission fluids, anti-foaming agents, and even as a replacement for vegetable oil in food, for the oil does not become rancid. The hydrogenated oil is a hard, white, crystalline wax with potential uses in preparing floor and automobile waxes, waxing fruit, impregnating paper containers, and making candles that are slow-burning and wilt- and drip-resistant.

Maximum yields of jojoba seed in the wild or under cultivation are unknown. It usually takes 3 to 4 years before the plants bear seeds and 10 years to achieve maximum bearing. Plants 3 to 5 m wide and 5 to 7 m high have been found in the wild that yield 14 to 18 kg of clean dry seeds (4). Institutional and commercial studies are being conducted to determine optimum row spacing and plant density, male-to-female ratios, and irrigation and fertilization requirements. Studies of planting and harvesting methods and pest control are also in progress. Even though these studies have been under way for several years, there is no consensus over what constitutes optimum agronomic practice for jojoba. This has not deterred the establishment of plantations, however. Jojoba is grown "commercially" in Australia, Egypt, Ghana, Iran, Israel, Jordan, Mexico, Saudi Arabia, and the United States. Most plantations are small, although some, particularly in the United States, cover 1000 ha or more. According to the Jojoba Growers Association, over 11,000 ha are planted in jojoba in Arizona and California alone.

The large area recently planted in jojoba may convert jojoba from a cottage industry to a more substantive industry. In 1983 the United States produced about 165 tons of jojoba oil. This exceeded demand at the current asking price.

Only about 33 of the 165 tons was derived from plantation jojoba, the major part coming from wild stands in Arizona and Mexico. These 33 tons were produced from plants on fewer than 1000 of the 11,000 ha of jojoba in Arizona and California, as only these were mature enough to bear seeds. This year the 11,000 ha are expected to yield approximately 222 tons, by 1987 33,000 tons, and by 1990 over 130,000 tons. That is a nearly 4000-fold increase in jojoba oil from plantations in 7 years. And more jojoba is being planted every year. New uses must be found if the oil is to be consumed.

As noted earlier, the principal user of jojoba oil has been the cosmetics industry. This has been true because of the oil's high selling price and limited availability. Several years ago it sold for about \$60 per kilogram, and even last year it was selling for \$30. Today a kilogram can be purchased for \$10 or less, and the cost is projected to decline to approximately \$4 within 3 years. As the price declines and the quantity increases many new opportunities for its use become attractive. This may stabilize and secure the industry.

Jojoba may become the first xerophytic plant to be a significant agricultural crop supplying multiple industries with raw materials. This is true despite the fact that a large amount of research on jojoba has yet to be completed.

Guayule

The second xerophytic plant to become a commercial reality will probably be guayule (*Parthenium argentatum*), a rubber-producing perennial shrub native to the Chihuahuan Desert in southwestern Texas and northern Mexico. Its rubber is virtually identical to that produced by the rubber tree (*Hevea brasiliensis*), and it was a commercial source of rubber in the early 1900's. With the emergence of cheaper Malaysian natural rubber, production ceased in the 1930's.

Interest in guayule was renewed during World War II and again in 1975. In the latter case the attention resulted from a search for crops that could be grown with little water and secondarily from the oil embargo. Studies were initiated by state and federal agencies, and in 1978 Congress passed the Native Latex Commercialization and Development Act, which was to support research for 5 years. This year Congress passed the Critical Agricultural Materials Act. It provides for a coordinated effort, headed

by the Department of Agriculture, of all federal groups involved in guayule research.

In another important development, the Gila River Indian Community, located near Phoenix, has awarded a contract to the Firestone Tire & Rubber Company to design and build on tribal lands a prototype plant for processing guayule rubber. Firestone expects to have a pilot plant running in Akron, Ohio, this year. Construction of the Gila River prototype plant will begin in 1986, and the plant is expected to start up in 1988. For their part, the Gila Indian Community has committed itself to planting sufficient guayule shrubs to produce 1000 tons of rubber annually and states that the project is on schedule.

Guayule can be killed by freezing and is not salt-tolerant, which limits the areas in which it can be grown. Usually about 0.6 m tall, it has narrow leaves and bears small flowers on long stems. Rubber is contained in a single layer of thin-walled cells in the stems and in the roots. The rubber is produced only when the plants are under stress, although the use of bioregulating chemicals may alleviate this problem. Irrigation is initially required to establish stands and to develop plants, and then soil water levels must be controlled to limit vegetative growth to enhance rubber production. Reliable data are not available on water requirements or the effect of plant stress on rubber production rates.

Existing strains yield about 1 kg of rubber and 0.75 kg of resins (terpenes and triglycerides) per 6 kg of ground-up, defoliated shrub. The remaining 4.25 kg of material, for which there is no identified use other than as fuel, is termed bagasse. It is estimated that this bagasse contains 3300 Btu's of heat beyond what is needed to grow, process, and recover the 1 kg of rubber (6).

It is still uncertain whether guayule can be grown economically in the United States. To make it a profitable crop, it will be necessary to (i) improve the amount of rubber in the plant through breeding or chemical stimulation; (ii) extend the range of guayule to cheaper lands, such as the cold and high deserts, by developing appropriate cultivars; (iii) improve cultural practices to reduce labor costs and improve productivity; and (iv) perfect the rubber extraction process and by-product utilization.

Research to date is encouraging, but much more needs to be done. As for other countries, particular circumstances in each will dictate when, and if, guayule can be successfully developed.

Buffalo Gourd

Some native arid land plants hold economic potential but are still only in the research stage. Among these, the genus *Cucurbita* has a group of closely related species of particular interest. The best known is buffalo gourd (*Cucurbita foetidissima*).

The plant, a perennial vine, reproduces asexually, grows as a weed in regions of low rainfall, and produces a large crop of seeds rich in oil and protein. A single root may weigh up to 40 kg after three or four seasons and is nearly 20 percent starch (7). This starch can be hydrolyzed chemically or enzymatically to dextrins, maltose, and glucose suitable for use as a sweetener in foods and beverages. It also has unique rheological properties and excellent viscosity and stability for prolonged periods at high temperatures, making it attractive as a food additive. Similar to cassava root starch, it may have uses in preparing such foods as puddings.

The vines grow along the ground prodigiously, and may, because of their protein content (usually 10 to 13 percent) and digestibility (nearly 60 percent), have forage value (8). Oil, about 35 percent of the seed by weight, can be extracted with solvents or by mechanical pressing. It has a high ratio of unsaturated to saturated fatty acids, making it attractive for use in human foods. Linoleic acid, an essential fatty acid, comprises about 65 percent of the total fatty acid content of the oil.

The meal remaining after pressing or extracting the seeds contains nearly equal amounts of protein and fiber and may be used in raw form as a component of animal feeds. Studies with rodents show that the protein quality of seed meal from the buffalo gourd is similar to that of soybean and cottonseed meals.

From presently available varieties it seems reasonable to expect annual yields in excess of 2 ton/ha. Data are insufficient, but root yield may exceed 8 ton/ha annually. There is little if any information on foliage yield.

Commercial development of buffalo gourd is impeded by lack of adequate and consistent support for genetic, agronomic, and process studies. Perhaps an equally important barrier is the need for a single company to coordinate efforts to grow buffalo gourd as a crop and to manage development of its multiple products. It is encouraging, however, that multiple-hectare plots have been seeded in Australia by a private company and that a U.S. company has pro-

cessed 2 tons of buffalo gourd roots for their starch. The starch was reported to be of excellent quality (9). Buffalo gourd is on the threshold of transition from research to development status.

Bladderpod

Of the five genera represented by the plants described in this article, the genus in earliest research status is *Lesquerella*. This is an oilseed producer native to many of the same areas in the United States and Mexico as buffalo gourd. Unlike buffalo gourd, however, its oil is not edible but is a potential source of chemicals, producing hydroxy fatty acids—chiefly lesquerolic acid—homologous to the ricinoleic acid (12-hydroxy-9-octadecenoic acid) of castor oil.

Castor oil is the main source of hydroxy fatty acids and the United States imports approximately 60,000 tons of it annually (10). This oil has many industrial applications, as in protective coatings, plastics, and synthetic intermediates, and additional hydroxylated acids may further extend the range of usefulness of this type of compound. Recent work indicates that when *Lesquerella* oil is polymerized to form polyesters or polyurethanes in the presence of polystyrene, an interpenetrating polymer network is formed. These are a new class of tough plastics (11). Domestic production of castor oil in the United States is small, for the regions of the country receiving adequate rainfall to grow the castor-oil plant (*Ricinus communis*) can grow more valuable cash crops such as corn. Furthermore, castor beans and their de-fatted meal are toxic and cause allergic reactions in workers in the field and in processing.

One member of the genus, *Lesquerella fendleri*, often called bladderpod, holds good potential for becoming a new crop to supply hydroxy fatty acids. Its seeds contain 20 to 30 percent oil, and the oil contains 60 percent lesquerolic acid, a 20-carbon monohydroxy monoene acid (12). It can be grown with less water and on poorer soils than castor and does not have the toxic and allergenic properties of castor beans.

Bladderpod requires only 3 to 4 cm of rain, or its equivalent in irrigation, from September to April, and seems to thrive on calcareous, sandy, and well-drained soils (13). It occurs as a fall-spring annual and has many qualities that make it suitable for cultivation, including drought and cold tolerance. Harvest takes place usually in May and can be

accomplished by combine. Seed yields of over 1 ton/ha have been obtained in experimental plots (14). One possible difficulty in harvesting is a tendency toward hydrostatic dehiscence (rain causes the immediate opening of dried capsules and loss of seed). But the polymorphic nature of bladderpod could supply the plant breeder with adequate genetic material to overcome problems such as dehiscence, as well as to greatly increase yields.

Gumweed

The last arid land plant to be discussed has good economic potential, is relatively unknown, and produces chemicals rather than food. In addition, the bagasse derived from it is an excellent source not only of fuel but of animal feed material and various chemicals as well. The genus is *Grindelia*, comprising several score of species commonly called gumweed. The primary economic product of this species is, as might be deduced from its common name, a sticky resin similar to wood rosin.

The discovery of a new source of wood rosin-like materials (naval stores) has real economic significance. The world naval stores market exceeds 700,000 tons per year. Resins are in demand because of their usefulness in a variety of industrial applications. They are used in adhesives, tackifiers, paper sizings, and many other products, and their derivatives are widely used in the production of synthetic polymers.

The three forms of this raw material are tall oil, gum rosin, and wood rosin; each is produced in a different way. Tall oil, a by-product of paper pulp mills and the most abundant form, is of such inferior quality that it is often burned on site as a low-grade fuel. Gum rosin is obtained by slashing and tapping living pine trees, a labor-intensive and thus expensive operation. Wood rosin, the third type, is extracted only from southern pine stumps in the United States. The best quality material comes from the stumps of pines that are more than 300 years old. The U.S. supply of wood rosin is expected to last no more than 10 to 15 years.

Research on gumweed indicates that this plant may not only prove to be an ideal substitute but may provide completely new resins. The structural components of gumweed resins are more amenable to chemical modification than those of wood resins.

Most *Grindelia* species are found in

arid or semiarid habitats, and all appear to produce resin acids of the grindelic type. One gumweed, *Grindelia camporum*, has been singled out for research and development because (i) it has a high yield of crude resin; (ii) it has an upright, herbaceous growth habit; (iii) many accessions (populations) have an annual life cycle; (iv) many accessions have the ability to sprout from the root crown to produce two crops in a single growing season; (v) it has excellent tolerance to drought, salinity, and disease; and (vi) the chances of significant plant improvement through selection and breeding appear excellent.

Formulations of the resins have been prepared and tested. Independent evaluations indicate that the resin could be substituted for wood rosin in many of its commercial uses, and that it is superior in some applications because of its greater thermal stability.

Preliminary economic analyses indicate a very favorable return on investment, with resin being the sole product, the remaining material, bagasse, being valued only as a fuel. However, this bagasse is too valuable to be used only as a fuel. Even its probable animal feed value exceeds its fuel value. It contains, in addition to grindelic acid resins and the usual lignocellulosic materials common to all biomass, an array of natural products, including terpenoids, steroids, polyphenols, and alkanes. The terpenoids and steroids may be useful in pharmaceutical and agricultural products in addition to chemical starting materials and intermediates. The polyphenols could be valuable in preparing adhesives and thermoplastics. The alkanes are mostly waxes made of predominantly unbranched linear hydrocarbons and esters. There is still a good market for natural plant waxes. The bagasse also contains high molecular weight, water-soluble polymers of possible use as enhanced oil recovery agents.

Conclusion

The single-product orientation inherited from present-day agriculture and the chemical industry must change if we are to make arid land crops an economic reality. For example, rather than regarding bagasse as a waste material to be disposed of, it should be considered a resource to be converted into competitive specialty chemicals. We should be-

gin to view certain plants as multiple-product resources; progress is being held back by the inertia of traditional thinking.

The technical problems inherent in separating complex mixtures economically are being solved. For example, Olin Corporation is marketing starch-based methyl glucoside polyols for polyurethane foam manufacture (15). Pennwalt Corporation hopes soon to market starch-calcium-adduct pesticide encapsulating agents. Second-generation starch-adduct materials are already being evaluated (16). A host of chemicals other than alcohol are being produced experimentally by fermentation, including *p*-hydroxybenzoic acid, *p*-hydroxyphenylacetic acid, vanillic acid, levulinic acid, adipic acid, lactic acid, butanol, and 2,3-butanediol (a new monomer in polyurethane and polyester resins). Imperial Chemical Industries is producing polyhydroxybutyrate, a material similar to polypropylene but with biodegradable properties. It should be particularly useful for sutures, splints, and encapsulation (17). Imperial also plans to build a plant to recover chemicals from the catalyzed acid hydrolysis of agricultural wastes (18). Battelle Columbus has developed biodegradable copolymers of lactic acid with excellent properties that mimic conventional thermoplastics, and Goodyear Tire & Rubber Company has developed a new patented process for converting terpenes to α -dimethyl styrenes and cymenes (19). In addition to these developments, progress is being made in the utilization of the more mundane components of all biomass.

A number of companies have worked with lignin for a long time, but most of the effort was aimed at disposing of it. More recent investigations have been directed at how to better utilize it. New isolation procedures have been developed that yield much purer and unaltered lignin. Then, too, lignins derived from various plant resources have different properties and thus provide additional opportunities.

Strides have been made in recent years in all aspects of lignocellulose conversion. Isolation procedures are being perfected to obtain high yields of good-quality pulp and unaltered lignin simultaneously. Saccharification techniques, both acid and enzymatic, have been greatly improved. There have been so many advances in fermenting hexoses and pentoses to alcohol and other prod-

ucts that it is hard to keep abreast of them.

In short, encouraging progress is being made on all fronts of biomass conversion and utilization. Many wild plant species, such as the five reviewed, yield an economically attractive primary product. Best wild-strain plant selection has not yet been made in most cases, nor are the optimum agronomic growing conditions known. Even so, preliminary economic analyses indicate several to be attractive.

Perhaps the greatest deterrent to rapid development of these plants is that the research sponsor must be concerned with too many diverse problems: growing, harvesting, and transporting plant material and then processing it into multiple products. These products may or may not require different marketing organizations and strategies. This undertaking requires a pioneering mind set and expertise in a spectrum of scientific disciplines. Consequently, commercialization of these plants will most likely occur through multicompany efforts or cooperative efforts between government and the private sector.

Despite these problems, arid land plants hold much promise. By developing this resource our aquifers will be conserved and the world's oil reserves extended. Farmers will have new cash crops without ruining their land and the companies which have the courage and foresight to undertake the necessary research and development effort will prosper.

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