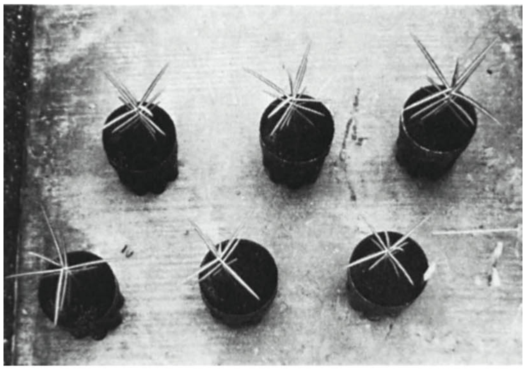
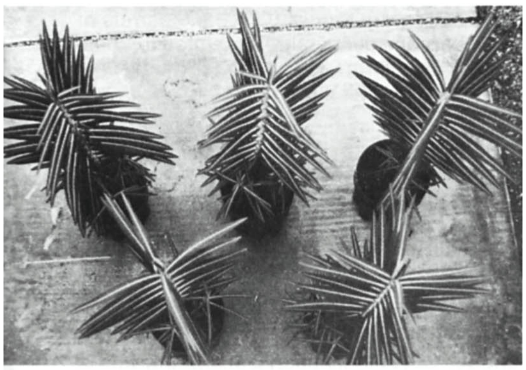
Fig. 1. Top views of *Euphorbia lathyris* (on 30-cm centers) show radial symmetry and delayed branching. From top, counterclockwise, plants are 1, 4, and 6 months old.





Euphorbia lathyris: a potential source of petroleum-like products

Hydrocarbons from **E. lathyris** *would have to sell for $150 to $200 a barrel to be a practical source of fuel.*

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Reports that *Euphorbia lathyris* may be a source of fuels to replace petroleum products have generated interest in its cultivation. The latex of Euphorbiaceae in general is rich in reduced hydrocarbon materials, largely isoprenoids, which can be extracted from dried plants with a solvent and converted to compounds with properties similar to those prepared from petroleum. Whether this practice is economically sound depends largely on yields of reduced hydrocarbons (per unit area per unit time) that can be obtained from plantations. Yields of 19.8 to 24.7 barrels per hectare (bbl/ha) of petroleum-like compounds (greater than 16,000 Btu per pound) have been reported using single plant data from small test plots. We began studies at Davis to determine yield in relation to two important agronomic inputs—irrigation and fertilization—in relatively large plots. We also investigated temperature requirements for germination, importance of planting date, planting design, and disease and weed control.

Plant materials and culture

Euphorbia lathyris is an annual, biennial, or even perennial plant introduced from Mediterranean regions but now widely naturalized in California and elsewhere in the United States. It is known as caper spurge, gopher plant, or mole plant, based on the appearance of its fruit or its reputed rodent-repelling properties.

Terminal flower clusters appear in midsummer at a height of 1 to 2 meters on profusely leaved branches. Broken stem and leaf tissue exudes the sticky, isoprenoid-rich, white latex. Irregular branching begins relatively late in the growing season when the main axis is about 30 to 60 cm tall. Mature plants, before bloom, have more or less radial symmetry (fig. 1) and occupy approximately a 0.3-meter-diameter area. Seed, about 0.2 to 0.3 cm in diameter, are borne in three-lobed fruit, each about 1.3 cm in diameter; seed are ripe for harvest in late summer or early fall.

The latex is a potent skin and eye irritant, and the seed are considered poisonous.

We used seed from a northern California selection of *Euphorbia lathyris,* equivalent to a southern California selection in rosin yield but more resistant to frost injury. The seed, first collected at the Healdsburg, California, ranch of Dr. M. Calvin, were used throughout this study.

For germination, flowering, and disease studies, seed were sown in petri dishes or in a greenhouse potting mix of peat, sand, bark, and mineral amendments and irrigated with a complete nutrient system. Field plantings began in April 1980 at three sites near Davis. About 247,000 seed per ha were sown at all three sites.

Preliminary studies at Santa Ana indicated that canopy closure might occur in July with plants on 30-cm centers and offset in a diamondlike distribution. Hence, about 0.02 ha was sown for plants on 30-cm centers with plants in adjacent rows offset by 15 cm. Extensive thinning was required about 6 weeks after sowing. The plot was essentially flat and plants were sprinkler irrigated every other week. Ammonium sulfate was applied after emergence at 112 kg nitrogen per ha. Residual phosphorus and potassium were judged adequate by standard soil analyses.

A second plot of 0.3 ha with plants sown on rows 75 cm apart was left unthinned. At harvest, the plot had 190,000 plants per ha with a 5- to 7.5-cm spacing between plants in rows. A central sprinkler irrigation line was installed (fig. 2). At several locations, catch cans measured the water applied, and 300-cm-deep neutron probe access tubes permitted computation of soil moisture content at the catch cans.

A Troxler neutron probe was used to measure soil moisture frequently throughout the growing season so that soil moisture utilization, a function of rooting depth, could be observed. Weekly irrigation replaced evapotranspiration (ET) at the catch-can locations nearest the sprinkler line. Thus, at these locations plants grew in soil with little or no moisture deficit. Those at the plot extremities grew with no additional irrigation except for about 5 cm applied after sowing to ensure germination; soil moisture deficits below the initial readings were recorded in the upper 180 to 210 cm, indicating root penetration to at least these depths. Ammonium sulfate was applied before emergence to give a total nitrogen content in the upper 90 cm of soil of 56 kg per hectare.

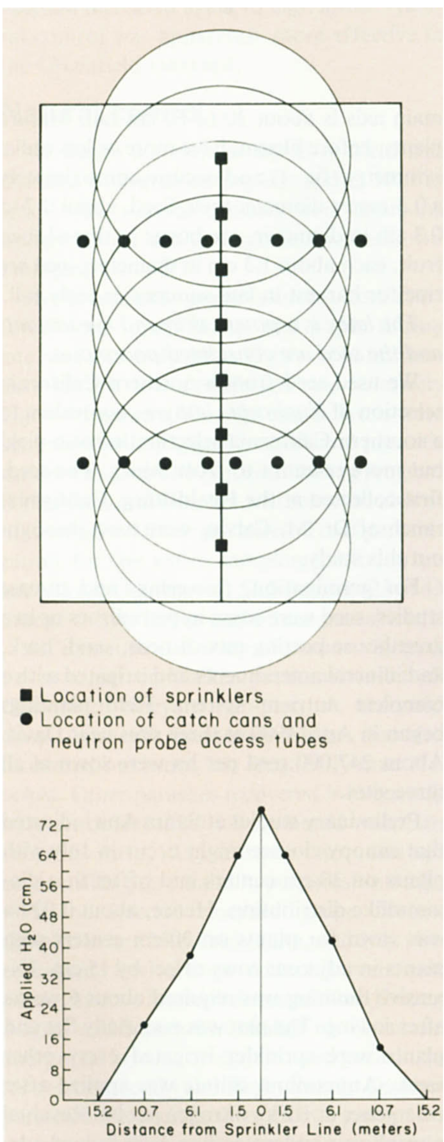

Fig. 2. Above: Irrigation design of plot. Below: Irrigation, April to November 1980, at various distances from sprinkler line.

To determine yield in relation to nitrogen, a third plot, about 0.07 ha, was established similar to the second plot, except that furrow irrigation was used after seedlings emerged. Irrigation to replace ET was at approximately 10-day intervals. For undetermined reasons the seedling stand was considerably smaller than earlier stands. Final counts at harvest indicated that plants were spaced irregularly at about 15-cm intervals. Plant density varied from 81,600 to 105,600 plants per ha. Ammonium sulfate was applied after emergence to give 56, 112, 168, and 224 kg nitrogen per ha above the 86 kg residual nitrogen per ha.

Plant samples from 4.6 square meters were harvested about 7 months after sowing and weighed fresh in the field. Subsamples were oven dried at 70° C for about 6 days. Dried plants were milled and thoroughly mixed for further analysis. Approximately 15- to 20-gram samples were extracted with hexane for 24 hours using the Soxhlet extraction technique, and the hexane fraction weighed. Triterpenoids, which we will refer to as rosin, are the major components identified in this fraction.

Seed production

We studied requirements for flowering and fruiting to ensure an adequate seed supply. Seedlings were grown in a 26° C day/20° C night greenhouse until they had 10 expanded leaves. Then they were moved into a 4° C lighted chamber (10,000 lux mixed fluorescent/incandescent illumination, 8 hours daily) for 4 to 12 weeks.

The northern California selection required 6 to 8 weeks of chilling at 4° C for flowering; the southern California selection, 4 weeks. In field seed production, *E. lathyris* must be treated as a biennial—sown in one calendar year and harvested the next. For high rosin yields in temperate climates, seed cannot be sown in the fall, because the seedlings will receive their low temperature requirement during the following winter and flower very early in the spring before making adequate vegetative growth. However, in all tropical and some subtropical regions, where chilling below 10° C does not exceed 1,000 hours, year-round plantings are satisfactory and planting dates can be chosen to exploit rainfall or cropping rotations.

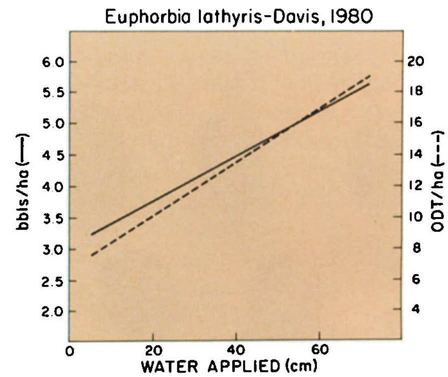

Fig. 3. Oven-dry tonnes (ODT) and barrels of hydrocarbons per hectare as related to irrigation. At lower irrigation amounts, lines reflect difference in total plant rosin.

Seed germination and emergence

Temperature plays a major role in determining germination percentage and emergence time. At 12° C, less than 2 percent of the test seed germinated after 22 days; at 15° and 18° C, seed germinated in less time and at a much higher percentage. Germination in greenhouse tests with soil temperatures at 23° C, was as high as 90 percent after 5 days. Field germination in April 1980 was good, but 19 days were required for emergence. Soil temperatures at 5 cm (sowing depth) varied between 26° C during the day and less than 10° C at night. Planting earlier when soil temperatures are lower delays emergence and lowers germination percentage.

Yield and irrigation

In the sprinkler-irrigated plots, dry matter production was clearly related to irrigation during the April to November growing season (fig. 3). Plants receiving no irrigation (except the 5 cm applied after sowing) produced approximately 7 to 10.2 tonnes per ha. With 66 cm water, which was essentially total replacement of evapotranspiration, yield was about 16.3 to 19.3 tonnes per ha. Even at the highest growth rates, complete canopy cover was not achieved.

The percentage of rosin content was somewhat greater in nonirrigated (6.2 percent) than in irrigated (4.4 percent) plants (fig. 4). The greater hexane extractable fraction obtained from low-irrigation plots is completely accounted for by the greater proportion of leaf to stem dry weight (fig. 5). Leaves from both fully irrigated and minimally irrigated plants contained about 8 percent rosin, whereas the stems contained less than 3 percent on a dry-weight basis.

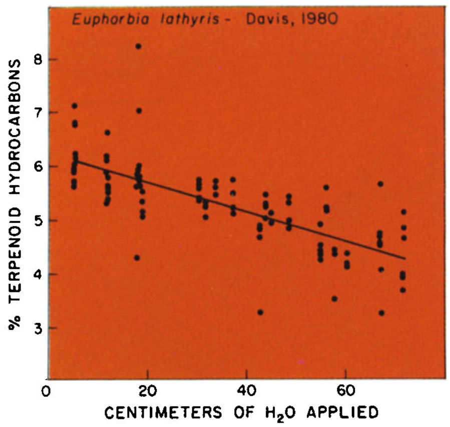

Fig. 4. Percentage of hexane extractable rosins as related to irrigation.

Yield and fertilizer

Little or no response to additional nitrogen was observed in this experiment. Dry-matter yields were 10.3 to 14.7 tonnes per ha. Replication was not adequate to analyze the responses statistically, but clearly residual nitrogen in the fields met requirements for a crop of this growth rate. This experiment should be repeated with higher population densities to ensure competition for available soil nitrogen.

Disease problems

In field plantings in California and Arizona, *Pythium aphanidermatum* and *P. ultimum* were identified as possible pathogens of *E. lathyris,* and pre- and post-emergence damping-off caused by *Pythium* spp. was believed to be important in limiting initial stands in some earlier California field trials. We conducted greenhouse experiments to determine whether seed treatment fungicides at rates nontoxic to *E. lathyris* could satisfactorily control damping-off. The fungicide diazoben (Lesan), widely used as a seed treatment to control Oomycetes, was effective against *P. aphanidermatum, P. ultimum, P. carolinum,* or *P. vexans* at rates as low as 0.1 gram active ingredient per kg seed. Thus, all field plantings at Davis in 1980 were diazoben-treated seed.

Another disease, unrelated to *Pythium* damping-off or root rot, occurred to some degree in each of the 1980 field plots. Affected plants had stunted, yellowed foliage, and main and lateral roots were blackened up into the crown and lower stem tissue. Microscopic examination showed the blackening to be large numbers of small, black sclerotia in the tissues. When affected tissues were cultured on potato dextrose agar, they consistently gave rise to the

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Plant exudes a sticky white latex considered a possible petroleum substitute.

sclerotial state of *Macrophomina phaseolina,* which has also caused disease of *E. lathyris* in Arizona.

Macrophomina phaseolina is a serious pathogen of many crop species and partially depends on high temperature and water stress in its invasion of plant tissues. Indeed, in the Davis field plantings, disease symptoms appeared in early- to mid-summer, and were most severe in plants under varying degrees of water stress; well-irrigated plants showed

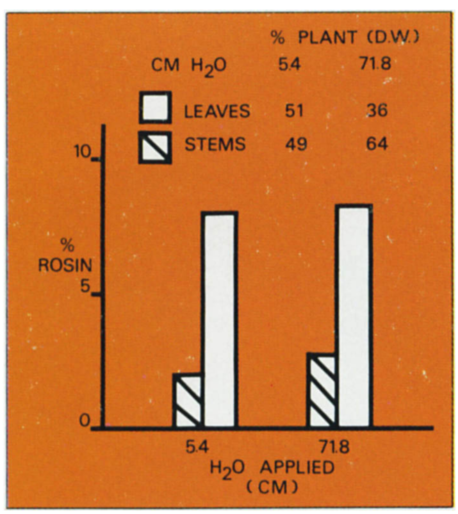

Fig. 5. Percent hexane extractable rosins of leaves and stems at two extremes in irrigation regimes. (D.W. = dry weight.)

no symptoms. The source of inoculum in these plots is not known, but the severe levels of disease observed in one plot suggest that the pathogen may have become established in the soil on some other crop previously grown at the site. However, *M. phaseolina* also is known to be seed-borne on many crops, and when diseased plants grown for seed at San Jose, California, were examined, the pathogen was detected in host tissues at least 50 cm above the soil line. Although our limited examination of *E. lathyris* seed failed to detect the pathogen either on or in seed, or in seed debris, this question may warrant further investigation if *E. lathyris* becomes widely cultivated.

Prospects

In these field trials, *E. lathyris* grew very slowly in the spring, and weed competition was severe. No suitable herbicide formulations have been found, and hand cultivation is expensive. Early canopy closure would have reduced weeding costs. In late warm-season plantings problems occurred with seedling emergence and crop establishment; *M. phaseolina,* high temperatures, and inadequate irrigation combined to cause severe "charcoal rot" symptoms. Thus, it may be difficult to grow a crop without irrigation, which was one of the advantages claimed for *E. lathyris.*

Another concern with *E. lathyris* is the much longer growing season required to obtain yields equivalent to those of an oilseed crop like sunflower. Sunflower matures in about 4 months with oil yields at least equivalent to rosin yields from a 7-month *E. lathyris* crop.

These results suggest that the economic potential of *Euphorbia lathyris* ecotypes is very low. The rosin will have to be valued considerably more than the triglyceride seed oils to warrant culture of *E. lathyris.* In U.S. agricultural production systems, the least expensive vegetable oils are by-products from cotton and soya crops, selling for about $60 to $100 per barrel in bulk. The hydrocarbons from *E. lathyris* would have to sell for $150 to $200 per barrel, even with credit for by-products from the oil extraction process.

At Davis, drying *E. lathyris* is also more difficult than with oilseed. *Euphorbia lathyris* plants harvested and left in the field in early October were not dry enough for milling and hexane extraction by early November. Hence, added costs to dry and process *E. lathyris* will be reflected in the price of the rosin.

The implication that genetic improvement will greatly increase rosin content is not well

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Euphorbia, continued

founded. We have no germplasm on hand for *E. lathyris* to suggest that we can go much beyond 5 to 6 percent hexane extractables. Genetically based variance in the rosin fraction is quite low or nil in both the northern and southern California ecotypes. A recent worldwide search for new germplasm has not yet uncovered *E. lathyris* plants with significantly higher rosin contents. Rosin levels are characteristically low in other plant genera, and there may be physiologically determined upper limits for whole plant hydrocarbons. Thus, before plants such as *E. lathyris* can serve as sources of fuel hydrocarbons, more research must be done on factors limiting production of the triterpenoid component of the hexane extractable fraction.

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Co-author Cliff Low in large *Euphorbia lathyris* test plot, University of California, Davis.