Growing euphorbia as a drought-tolerant source of expoxidized fatty acids

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Summary

This publication summarizes crop management recommendations for euphorbia, a new drought-tolerant industrial crop. Euphorbia produces a unique seed oil that is in demand by paint and plastic manufacturers.

Introduction

In the 1960s, researchers at USDA first recognized that *Euphorbia lagascae* (euphorbia) was a promising potential new industrial crop for dry regions in temperate zones because of the unique oils it produces in its seeds. Euphorbia is a drought-tolerant native of Spain. Its seed contains about 45%–50% oil, of which 60%–65% is vernolic acid, a C_{18} epoxidized fatty acid that is rarely found in nature.

Figure 1. Euphorbia plants grow in wide rows in midsummer 2009 near Medford, Oregon.

Credit: Richard Roseberg, © Oregon State University

Chemical companies have interest in vernolic acid because it has unusual and useful properties. Vernolic acid is a plant-based source of drying solvent used to make alkyd resin (oil-based) paints, and in manufacturing other chemicals and plastic products. Organic chemists have not been able to precisely reproduce its structure and properties by chemically altering petroleum or common seed oils. If this crop were more widely grown, it would provide a drought-tolerant source of these unique fatty acids, thus producing a valuable industrial raw material while also conserving irrigation water that could be used in other crops, such as food crops.

This publication describes the history of euphorbia, including problems that prevented adaptation as a viable crop in the past. Most of this article will summarize years of research at multiple locations describing the plant and how it grows, as well as several crop management practices that have been shown to improve crop health and seed yield. These guidelines will help farmers grow this crop successfully and improve chances for commercial success.

Crop development history

For many years, two main problems hindered both the breeding and agronomic research needed to develop euphorbia as a crop. First, euphorbia exhibits indeterminate flowering, meaning it produces flowers and then seeds over a long period of time. Thus, a single plant can have flowers, immature seedpods, mature seedpods and "shattered" seedpods along its branches all at the same time. Second, wild euphorbia has a violent seed-shattering habit. This means that as seedpods approach maturity and start to dry down, they explode (shatter), sending the seeds into the air and onto the ground where they cannot be harvested. No wild accessions of euphorbia contain a nonshattering trait.

However, in the early 1990s, researchers in Spain developed chemically induced mutants that resisted shattering for several weeks as the plants approached maturity, allowing harvest of most seeds before they fell on the ground. These nonshattering seed lines were transferred to Oregon State University and formed the basis for research conducted at the Southern Oregon Research and Extension Center and the Klamath Basin Research and Extension Center starting in 1995 (Figure 1). Between 1998 and 2012, this euphorbia was also tested at locations in Canada (Ontario), England, Germany and in Oregon (Benton and Sherman counties).

This seed originally consisted of four numbered mutant lines, but after several years of testing, it was clear the agronomic and seed quality differences between these four lines were minimal. Today, we consider this nonshattering euphorbia seed to be one cultivar for all practical purposes. It still has the indeterminate flowering characteristic, and after more than 10 generations, it has retained the nonshattering seedpod characteristic. Under cultivation, oil content in mature seed is consistently between 48%–52%. For more details on euphorbia's history, unique properties, crop status, current competitors and likely uses by industry, please see the references and resources listed below.

General crop growth characteristics, environments and yield potential

Euphorbia seed germinates readily in disturbed soil. Best seeding success occurs when seed is drilled to a depth of one-quarter to one-half inch. Seeding into tilled, bare soil has been successful, but limited testing with no-till drilling was also successful at these depths. Broadcasting seed onto the soil surface was not successful. Seedlings have a distinctive purplish-red color — this is normal (Figure 2). In the vegetative phase it turns to a grayish-green color. Late in the season, the main stems sometime change to a purplish-red color again, especially if the weather turns cold with freezing temperatures at night before harvest occurs (Figure 3).

As a native of central Spain, euphorbia shows great tolerance to drought and heat, surviving without significant summer rainfall and enduring daytime high temperatures routinely above 100°F. Observations at multiple locations confirm that euphorbia prefers a long, warm growing season and very dry conditions, especially during seed maturation. Euphorbia will grow in more humid climates, but tests in England, Germany, Ontario (Canada) and Oregon's Willamette Valley (USA) have not been successful. Diseases, lack of vigor and weed competition are more apparent under these conditions.

Pollen transfer and outcrossing are very limited. Euphorbia is highly self-fertile with pollination occurring inside protective tissues before insects can access the floral organs. This also severely limits pollen dispersal by wind. This characteristic helps explain why these seed lines have retained their nonshattering characteristic for more than 10 generations. Immature seedpods are the same grayish-green color as the plant, before turning tan or light brown as seed approaches maturity (Figure 4). Under cool/wet late-summer conditions, euphorbia tends to continue vegetative growth, and its seed capsules remain green, hindering dry-down and reducing the ultimate yield of mature brown seed.

Figure 2. Germinating euphorbia seedlings are purple. Later, the stems and leaves turn a grayish-green color.

Credit: Richard Roseberg, © Oregon State University

Figure 3. Near harvesttime, the stems often change from brown to purple, especially after a freeze event.

Credit: Richard Roseberg, © Oregon State University

When immature, the individual seeds within the seedpods are white. They then turn light brown and eventually a dark brown (almost black) at full maturity. The seed oil content of mature seeds is not affected by how the crop is grown or what level of moisture, temperature or nutrient stress it experiences. However, if seedpods do not mature, the seed oil content in the immature white seeds will be reduced dramatically, and those seeds will also have a low germination rate if saved for replanting. Otherwise, mature euphorbia seeds seem to readily germinate even after 10 years in storage at room temperature. Because of the high oil content, the seed is soft and easily crushed or damaged during harvest, seed cleaning and storage/handling processes.

Figure 4. Euphorbia seedpods gradually change color from green to brown in late summer on live branches still containing green leaves. (Photo taken near Klamath Falls, Oregon, 2012).

Credit: Richard Roseberg, © Oregon State University

Euphorbia produces its seed in capsules that have three chambers (one seed/chamber). During the harvest process, these capsules will separate into one of three forms:

- Whole pods occur when the capsule containing the three seeds remains intact.
- Partial pods occur when the three chambers have separated from one another but the individual seeds are still retained within each chamber.

- Good seed occurs when clean individual seeds have separated completely from all remnants of the original capsules or pods (Figure 5).

Once seed capsules separate into these three forms during harvest and cleaning, it is very difficult to further separate clean seed from the whole-pod and partial-pod capsule material because euphorbia seeds are very soft and easily damaged due to the high oil content. The 1,000-seed weight of good seed ranges from 10.5g–12.5g (0.37–0.44 ounce) but usually is approximately 11.6g (0.41 ounce).

Figure 5. During threshing at harvest, euphorbia seedpods break up into either good seed (GS), partial pods (PP) or whole pods (WP).

Credit: Richard Roseberg, © Oregon State University

The proportion of good seed, partial pods and whole pods at harvest varies with crop maturity and late-summer weather with more good seed and fewer whole pods if the crop can fully mature under warm dry conditions in late August and through September.

When plants can grow to full maturity and dry down naturally, the seed yield proportions are approximately 75% good seed, 20% partial pods and 5% whole pods. If the season length is shorter (or cooler), and the late-summer weather is also cooler and/or wetter, the proportions will be more like 50% good seed, 30% partial pods and 20% whole pods.

Weediness, weed control and safety concerns

Introducing a nonnative species like euphorbia into a new environment can raise concerns about escape and weediness in subsequent crops and neighboring lands. It is true that several other species within the *Euphorbia* genus are serious weeds in the Western U.S., especially in areas of limited moisture. These weeds include: leafy spurge (*E. esula*); prostrate spurge (*E. humistrata*); spotted spurge (*E. maculata*); and nodding spurge (*E. nutans*). Fortunately, researchers have shown that *E. lagascae* is susceptible to several common preplant incorporated, preemergence and postemergence broadleaf herbicides and thus is less likely to become a weed problem in subsequent crops if these herbicides are used.

On the other hand, research has shown that euphorbia is tolerant of several herbicides. In summary, euphorbia was tolerant of trifluralin, benefin and ethalfluralin applied preplant incorporated and pendimethalin applied preemergence. Germination was prevented or severely reduced by diuron or EPTC applied preplant incorporated or preemergence. Based on vegetative damage, it was tolerant of clopyralid, bentazon, alachlor, acifluorfen, sethoxydim, metsulfuron, imazapyr, imazethapyr, imazamox, ethofumesate and chloridazon applied postemergence. Euphorbia was significantly damaged or killed by postemergence applications of bromoxynil, DCPA, dicamba, 2,4-D, picloram and oxyfluorfen, although in some cases the degree of damage was dependent on herbicide rate. In a few cases (including metsulfuron, imazapyr, imazethapyr, imazamox and ethofumesate), herbicides severely reduced the seed yield without causing severe vegetative damage.

Although no herbicides are currently registered for use on euphorbia, this tolerance information could be used as the basis for further testing leading to herbicide registration. Such research and registration are necessary before herbicides can be legally and confidently incorporated into a weed control program for euphorbia.

Regarding crop rotation and persistence, euphorbia plants occasionally will regrow from the base in the fall after harvest if soil moisture is present and temperature is relatively warm. This has always been a temporary effect, and euphorbia does not appear to persist or spread in or near fields where it has been grown, especially where cold temperatures consistently drop below about 20°F during the winter after harvest.

Due to the presence of latex and other potentially irritating compounds in the stems and leaves, it is important to exercise safety precautions during harvest and processing operations, such as minimizing crop dust inhalation and reducing skin-contact exposure time.

Management factors affecting euphorbia crop growth and yield

Euphorbia seed yields have ranged from 100–1,700 lb/acre in over two dozen site-years of testing at multiple sites (mostly in semiarid Southern Oregon). These large yield variations are a function of weather and several crop management factors, as discussed below. However, given good management, seed yields are usually between 500–1,000 lb/acre. Because of these seasonal variations, yields shown in the figures below are expressed as relative yield, or percent of maximum yield measured at each location in a given year (with 100% representing the maximum yield for a given year and location).

Seeding date

Seeding early in the spring almost always results in higher yields, especially when grown without irrigation (Figure 6). Euphorbia seedlings are fairly cold-tolerant and can be seeded as much as a month before the last typical spring frost date. Seeding under early spring conditions seems to improve germination and seedling survival, probably due to good soil moisture as well as cooler temperatures. Delaying seeding date until late May or early June can cut the final yield in half (or more), although the yield reduction is less under higher irrigation rates.

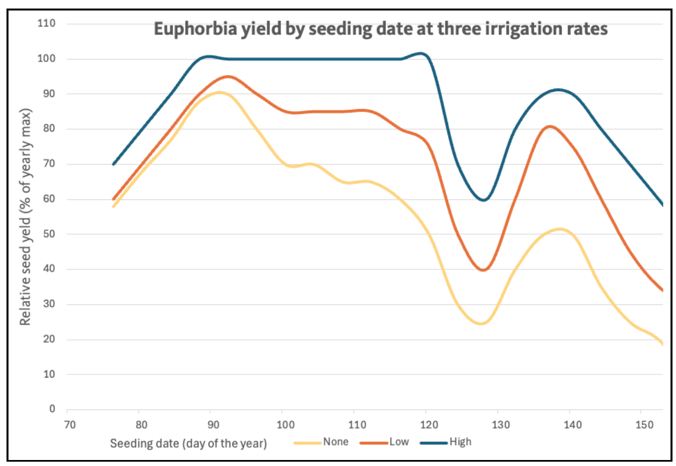

Figure 6. Euphorbia seed yield for various spring seeding dates as a function of irrigation rate. "Low" irrigation =~ 3 inches during season. "High" irrigation =~ 12 inches during season.

Credit: © Oregon State University

Although irrigation or timely late-spring rains can improve the results for later plantings, the additional moisture can also result in too much weed pressure. Testing at multiple locations and years in Oregon's Rogue Valley and Klamath Basin have shown that seeding around the first of May (calendar days 120–130) typically results in lower yields compared to earlier or later seeding dates, but the reason for this "yield dip" is not understood.

Euphorbia benefits from a long, warm growing season, and it is especially important to have warm, dry weather during the seedpod formation and seed maturation stages to maximize seed maturity and crop dry-down by harvest time. Overall, it appears that euphorbia requires at least 2,000 growing degree days (50°F minimum) to reach full maturity. Growers should adjust seeding time in a particular location to accumulate 2,500 growing degree days or more to improve seed yield and increase the likelihood of reaching full maturity.

Irrigation

Euphorbia is very drought-tolerant. It grows and produces reasonable seed yields even when grown without irrigation. However, applying some irrigation during the first half of the summer will increase plant size and final seed yield. In a warm, dry climate like Southern Oregon (less than 3 inches of rain during the growing season), applying 10–12 inches of irrigation typically increases final seed yield by 50%–100% compared to applying 2–3 inches of irrigation (Figure 6, “High” vs. “Low” treatments). Applying this range of irrigation (3–12 inches) is especially helpful if seeding occurs later than about May 1 (calendar day 120).

Applying irrigation above about 50% of a location’s potential evapotranspiration (or above about half the amount normally applied to alfalfa) does not increase yield and can cause an increase in plant disease and weed pressure. In all cases, irrigation water should be cut off by mid-August, otherwise euphorbia will continue to remain green and growing, which results in seedpods not maturing and also making harvest threshing more difficult.

Plant spacing/density

Euphorbia’s growth habit can vary dramatically depending on plant spacing (Figure 7). When planted in narrow rows at high seeding rates, it grows more upright with few side branches. When planted in wide rows at low seeding rates, it grows into a broader, “bushier” plant with many side branches by late summer.

Generally, growing euphorbia in narrow rows (6–12 inches apart) produces higher seed yields than wider row spacing, but euphorbia’s ability to branch out can sometimes result in high yields even when grown in wide rows (up to 36 inches) if weed control is good and the season is long enough to allow maximum side-branching (Figure 8). Yield is usually best when plants are more equidistant from each other. This means if euphorbia is grown in widely spaced rows, a high seeding rate within each row will not increase yield compared to a more moderate seeding rate.

Figure 7. Research on row spacing showed euphorbia adapts to varied plant populations, but narrow rows often produce somewhat higher seed yields. (Photo taken in the early summer near Medford, Oregon, 2008.)

Credit: Richard Roseberg, © Oregon State University

Regardless of row spacing, seeding rates between 15–30 seeds/ft^2 produce the best yield. At lower seeding rates, there are usually not enough plants to branch out and fill in the area (unless rows are very narrow). Under these conditions, the canopy remains incomplete, potential photosynthetic production is lost, and secondary issues such as poorer weed competition can also result.

At higher seeding rates, the plants tend to crowd each other out and usually don't produce additional branches and seedpods. With a typical 1,000-seed weight = 11.6g (0.41 ounce), a seeding rate of 15–20 seeds/ft^2 equates to planting about 17–22 lb/acre of seed.

Harvested seed types

If growers intend to save some harvested seed for future planting, they must decide whether to keep the good seed, the partial pods, or the whole pods, or to send those seed types to market for oil extraction.

The oil content of good seed is much higher than partial pods or whole pods since good seed does not have the attached pod capsule structures, thus it may be tempting to keep partial pods or whole pods for planting while sending the higher-quality good seed for extraction and sale. However, the germination and emergence rate of whole pods is consistently 25%–50% less than partial pods or good seed, leading to fewer plants unless whole pod seeding rate is dramatically increased.

Fewer plants with uneven spacing usually results in lower yield, although widely spaced plants can make up some of the difference by branching out and adding some additional seedpods given a long-enough growing season. Good seed usually has better germination than partial pods, but the difference between good seed and partial pods is far smaller than their differences with whole pods. Thus, the choice to market or replant good seed vs. partial pods is mainly dependent on market and price issues.

For equal seeding rates, starting with good seed always results in higher seed yield at harvest compared to partial pods and whole pods regardless of seeding date, although the difference between good seed and partial pods is small except for the latest seeding dates (Figure 9).

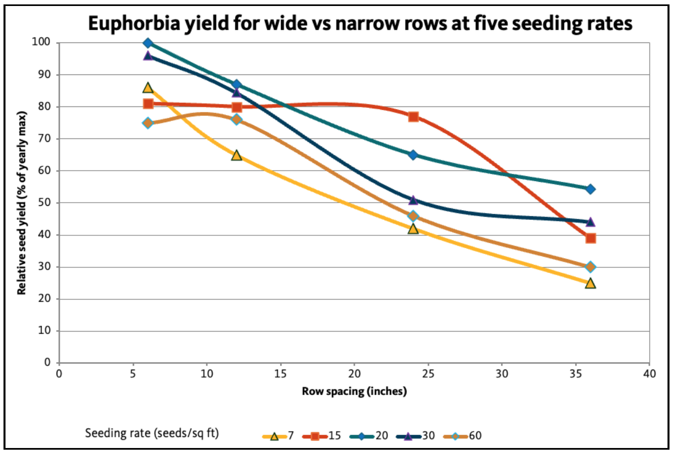

Figure 8. Euphorbia seed yield when grown at 6- to 36-inch row spacings at seeding rates ranging from 7–60 seeds per square foot.

Credit: © Oregon State University

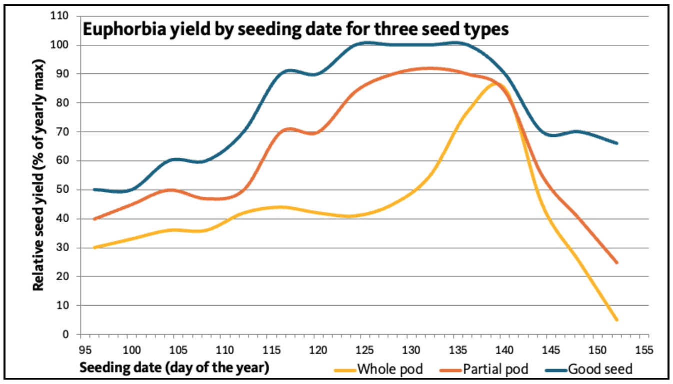

Figure 9. Euphorbia seed yield for various spring seeding dates as a function of seed type planted.

Credit: © Oregon State University

Starting with whole pods consistently results in the lowest yield, but there seems to be a time window in mid-May where yield reduction due to starting with whole pods is not large compared to earlier and later seeding dates. This phenomenon was consistently observed over multiple years, but the reason for this whole pod "yield peak" is not understood.

Nitrogen management

Euphorbia does not use much nitrogen. Whether tested in sandy loam soils with low (<1%) or moderately high (4%) organic matter, seed yield and oil content have not varied regardless of fertilizer nitrogen applied at rates ranging from 0–120 lb N/acre. However, plants grown without added N seem to mature slightly sooner.

Figure 10. Seedpods are fully mature and stems and leaves are fully dried-down. Plants in this state are fully ready for direct-combine harvest.

Credit: Richard Roseberg, © Oregon State University

Figure 11. Seedpods are nearly mature but stems and leaves are too green for direct-combine harvest. Swathing and field-drying plants in this state would improve the harvest process and increase retained seed yield.

Credit: Richard Roseberg, © Oregon State University

Harvest method (swathing vs. direct combine)

If plants naturally dry down and turn brown with mostly mature (light brown) seedpods by early fall (mid–late September), they are often dry enough to be harvested in one step with a standard combine harvester (direct-combined) (Figure 10). Under these conditions, some latex is still present in the stems but not enough to “gum up” the combine.

Once plants are mature, waiting too long under hot/dry conditions can result in highly brittle seedpods and stems and thus increase losses due to shattering before or during the combining process. When this occurs, the seedpod at the base of each primary branch is usually the first to mature and shatter, leaving an empty “spike” where the seedpod used to be (Figure 12).

Figure 12. Euphorbia’s indeterminate flowering can result in a range of seedpod maturity along the length of each branch, from fully mature or shattering seedpods at the base (right) to flowers or immature seedpods at the tip (left).

Credit: Richard Roseberg, © Oregon State University

If the crop is not harvested, seedpods will begin to shatter over time, starting at the base of each branch and proceeding outward, with seedpods near the ends of each branch being the last to mature and shatter. Once these shattered spikes start to appear, it is time to take immediate action to harvest before too many seedpods are lost to shattering.

If the crop's stems or seedpods are too green for proper threshing with a combine when weather starts to turn cooler, growers can first cut the plants (swathing), followed by 3–10 days of air-drying in the field, and then thresh the crop with a combine. This procedure is often used in other crops that need to be harvested in a somewhat green state, such as grass seed, vegetable seed, oil seeds like canola, etc. Trying to direct-combine euphorbia when stems and seedpods are still green will result in poor seed threshing and the latex in green stems can also "gum up" the combine (Figure 11).

For euphorbia, neither swathing nor direct-combining is automatically the better method in all cases. If the crop is mature and has dried-down well (nearly all brown plants and at least 75% light brown seedpods), then direct-combining will result in a higher retained seed yield with slightly higher oil content. However, if plants and pods are still partially to mostly green, swathing will allow more uniform drying and complete threshing, and thus a higher final seed yield (with similar oil content) than directly combining green plants.

There seems to be a trade-off point where the added step of swathing can result in higher shattering losses of fully mature seedpods while also improving threshing and retention of slightly immature seedpods. Due to this risk, it is usually preferable to directly combine euphorbia unless the crop does not naturally mature and dry-down.

Once the weather turns cool and/or more humid in the fall, euphorbia resists drying down further. However, if the weather remains dry while several subfreezing nights occur, the crop dry-down will be accelerated. Under these conditions, "frost-kill" can substitute for swathing in terms of accelerating the crop dry-down prior to combining.

The proportion of good seed, partial pods and whole pods at harvest is not affected by harvest method *per se*, it is mainly affected by crop maturity and late-summer weather. But weather and maturity play into the harvest method decision for other reasons, as described above. Thus, the decision regarding whether to swath before combining is mainly based on crop maturity and forecasted weather.

Other concerns

As noted above, euphorbia seems more susceptible to disease and grows with less vigor in humid climates. Insect damage has not been apparent in research fields, but if euphorbia becomes more widely grown, it is reasonable to assume that insect issues may arise as they have in other crops. Crop lodging has not been a problem, even when grown in windy areas, except when excessive irrigation was applied for research purposes.

Because this crop has not yet been commercialized, seed production and sales channels do not currently exist. Starting from current research seed stocks, a seed increase program could increase available seed supply fairly rapidly, but regeneration of the current nonshattering seed supplies cannot be delayed forever since seed viability gradually decreases over time.

The mutant seed lines were transferred from Spanish researchers to Oregon State University in the mid-1990s without conditions. Many publications by the Spanish researchers, by OSU researchers and collaborations with others suggest that intellectual property rights and royalties are not enforceable unless new research creates and documents additional genetic improvements.

Summary of recommendations

Because euphorbia is a new crop and not commercially grown yet, it is hard to predict how well it will do in all climates and soil conditions. However, keeping these recommendations in mind will greatly increase the chances of growing a successful crop.

1. Euphorbia germinates and grows best when seeded in early spring, as early as one month before the last frost, but can produce good seed yields from later spring plantings if a low level of irrigation is possible.
2. It grows well in various soil types under hot and dry summer conditions and does not seem to benefit from nitrogen fertilization.
3. Euphorbia can be grown in narrow or wide rows, as the plant will compensate for seed yield by producing more or less side branches with seedpods depending on the amount of space between plants.
4. Narrower rows generally produce higher yields but seeding rates of between 15–30 seeds/ft^2 nearly always produce the best yield, regardless of row spacing. If seed is limited and/or costly, adjusting row spacing and seeding rate to drop seeds in a more equidistant pattern will improve yield.
5. Good seed germinates slightly better than partial pods and results in slightly higher yield regardless of seeding date. Starting with whole pods will almost always result in fewer plants and lower yield, but this deficiency can be mostly overcome by increasing seeding rate if whole pods are chosen as the starting material (due to cost or availability).
6. Regardless of seeding date, irrigating more than about 50% of potential evapotranspiration (more than about 50% of normal alfalfa irrigation) is not helpful and may increase problems such as diseases and weed competition.
7. Irrigation must be stopped by mid-August to promote seedpod maturity and dry down by harvest time in late September or early October.
8. Euphorbia can be direct-combined if the plant and seedpods are mostly or completely brown at harvest, and such seeds will have high oil content.
9. If plants and/or seedpods are still partially green by mid–late September, euphorbia can be swathed, air-dried in the field and then successfully combined, collecting a high percentage of mature or nearly mature seeds.

References

Kleiman, R., C.R. Smith and S.G. Yates. 1965. Search for new industrial oils. XII. Fifty-eight Euphorbiaceae oils, including one rich in vernolic acid. *J. Am. Oil Chem. Soc.* 42:169-172.

Pascual, M.J., and E. Correal. 1992. Mutation studies of an oilseed spurge rich in vernolic acid. *Crop Sci.* 32:95-98.

Pascual-Villalobos, M.J., G. Robbelen and E. Correal. 1994. Production and evaluation of indehiscent mutant genotypes in *Euphorbia lagascae*. *Industrial Crops and Products.* 3:129-143.

Pascual-Villalobos, M.J. 1996. Mutagenesis in *Euphorbia lagascae*: Induction of novel variability for breeding purposes. p. 393-397 in *Proceedings of the IX Int. Conf. on Jojoba and its Uses and the III Int. Conf. New Crops and Products*, L.H. Princen and C. Rossi (eds.). Champaign, IL: J. Am. Oil Chem. Soc.

Roseberg, R.J. 1996. Underexploited temperate industrial and fiber crops. p. 60-84 in *Progress in New Crops*, J. Janick (ed.). Alexandria, Virginia: ASHS Press.

Roseberg, R.J. 1998. Planting date and herbicide effects on growth, seed yield, and oil yield of *Euphorbia lagascae*. p. 36 in *Annual Meeting Abstracts*, Association for the Advancement of Industrial Crops.

Roseberg, R.J., and R.A. Shuck. 2008. Agronomic Requirements of *Euphorbia lagascae*: A Potential New Drought-Tolerant Crop for Semi-Arid Oregon: 2008 (https://agsci.oregonstate.edu/sites/agscid7/files/assets/euphorbia_2008_report_final_0.pdf). *Klamath Basin Research & Extension Center Annual Research Report.*

Roseberg, R.J., and R.A. Shuck. 2009. Agronomic Requirements of *Euphorbia lagascae*: A Potential New Drought-Tolerant Crop for Semi-Arid Oregon: 2009 Results (https://agsci.oregonstate.edu/sites/agscid7/files/assets/euphorbia_2009_report_final_revised.pdf). *Klamath Basin Research & Extension Center Annual Research Report.*

Roseberg, R.J., and R.A. Bentley. 2010. Agronomic Requirements of *Euphorbia lagascae*: A Potential New Drought-Tolerant Crop for Semi-Arid Oregon: 2010 Results. (https://agsci.oregonstate.edu/sites/agscid7/files/assets/agronomic_requirements_of_euphorbia_lagascae_a_potential_new_drought-tolerant_crop_for_semi-arid_oregon_2010_results.pdf) *Klamath Basin Research & Extension Center Annual Research Report.*

Roseberg, R.J., and R.A. Bentley. 2011. Agronomic Requirements of *Euphorbia lagascae*: A Potential New Drought-Tolerant Crop for Semi-Arid Oregon: 2011 Results. (https://agsci.oregonstate.edu/sites/agscid7/files/assets/agronomic_requirements_of_euphorbia_lagascae_a_potential_new_drought-tolerant_crop_for_semi-arid_oregon_2011_results.pdf) *Klamath Basin Research & Extension Center Annual Research Report.*

Roseberg, R.J., and R.A. Bentley. 2012. Agronomic Requirements of *Euphorbia lagascae*: A Potential New Drought-Tolerant Crop for Semi-Arid Oregon: 2012 Results. (https://agsci.oregonstate.edu/sites/agscid7/files/kbrec/documents/pubs/euphorbia_2012_report_draft_2.pdf) *Klamath Basin Research & Extension Center Annual Research Report.*

Roseberg, R.J. 2016. Herbicide tolerance of *Euphorbia lagascae* Spreng., (Euphorbiaceae). *Industrial Crops and Products.* 90:56-64.

Trumbo, D.L. 1998. Epoxy oil from vernonia for paints and coatings. p. 18 in *Annual Meeting Abstracts*, Association for the Advancement of Industrial Crops.

Turley, D., M. Froment and S. Cook (eds.) 2000. *Development of Euphorbia lagascae as a new industrial oil crop.* European Community Concerted Action (FAIR-CT98/4460) Handbook. Wolverhampton, United Kingdom: ADAS Woodthorne.

Vogel, R., M.J. Pascual-Villalobos,and G. Robbelen. 1993. Seed oils for new chemical applications. 1. Vernolic acid produced by *Euphorbia lagascae*. *Agnew Botany* 67:31-41.

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