Herbicide tolerance of *Euphorbia lagascae* Spreng., (Euphorbiaceae)

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Abstract

Euphorbia lagascae Spreng., (Euphorbiaceae), (abbreviated EPHLA), has good potential to become an important crop and source of epoxy fatty acids in semi-arid regions. Crop yield is enhanced with good weed control, and this study examined EPHLA's tolerance to several pre-plant incorporated (PPI), pre-emergence (PRE), and post-emergence (POST) herbicides, as well as seed and oil production factors. Preliminary tests were done in a greenhouse, and more involved studies were done in the field. The most promising PPI and PRE herbicides included benefin, ethalfluralin, trifluralin, and pendimethalin. Chloridazon and DCPA also gave reasonably good results, but rate and timing may be important when using these herbicides. Diuron and EPTC injured EPHLA and were poor herbicide candidates for EPHLA. The most promising POST herbicides included clopyralid, alachlor, acifluorfen, and chloridazon, to which EPHLA exhibited very good tolerance and very good to excellent yields. Oxyfluorfen and bromoxynil caused significant vegetative injury, but EPHLA produced good to excellent yields, suggesting that the herbicide injury was temporary. Bentazon and DCPA caused a moderately low degree of injury to EPHLA, which responded with a somewhat decreased seed yield, indicating that the

effect of rate and timing may be important for these herbicides. Several POST herbicides, including metsulfuron, imazapyr, imazethapyr, imazamox, ethofumesate, and dicamba, caused a low degree of visible injury to the EPHLA, but EPHLA seed yield was very low, suggesting that these herbicides injured EPHLA's reproductive processes. Picloram and 2,4-D caused severe damage or death to EPHLA. Because several PPI, PRE, and POST herbicides caused severe damage to EPHLA, they could be useful if EPHLA escaped cultivation to become a weed problem.

Keywords: *Euphorbia lagascae*, Herbicide, Seed yield, Oilseed, Vernolic acid, Oregon, Weeds.

1. Introduction

Euphorbia lagascae Spreng., (Euphorbiaceae) (hereafter abbreviated EPHLA in this paper), is a drought-tolerant native of southern Spain. Its seeds contain about 45 to 50% oil, of which 60 to 65% is a specific C₁₈ epoxy fatty acid (EFA) known as vernolic acid (Kleiman et al., 1965; Vogel et al., 1993). Vernolic acid is produced by very few plants in nature, and of those, only EPHLA, *Vernonia galamensis* (Cass.) Less., (Asteraceae), and *Stokesia laevis* (Hill) Greene (Asteraceae), appear to have the potential to be domesticated for commercial agricultural production (Earle, 1970; Kleiman, 1990).

Early on, it was recognized that vernolic acid would be useful in the paint and coating industry as a drying solvent in alkyd resin paints and as a plasticizer or additive in polyvinyl chloride (PVC) resins (Carlson et al., 1981; Carlson and Chang, 1985). Coatings

made with vernolic acid can greatly reduce volatile organic compound (VOC) emissions during drying that now occur with typical alkyd resins in conventional paints (Brownback and Glaser, 1992), thus reducing air pollution related to these VOCs.

Historically, EFA compounds have been made by chemically epoxidizing common oils such as soybean, rapeseed, linseed, and petroleum-derived oils (Carlson and Chang, 1985; Dierig and Thompson, 1993). However, such compounds are random mixtures of EFA chemical structures, with the epoxide group appearing on various carbon atoms in the chain, and thus may not perform as well as the more uniform EFA structure of EPHLA's vernolic acid for some applications (Trumbo, 1998; Turley et al., 2000). More details about EPHLA's significance as a potential crop plant, its unique properties, crop status, current competitors, and likely uses in industry were described in our earlier reports (Roseberg, 1996; Roseberg and Shuck, 2009).

Despite the large benefits that could result from domestication of EPHLA as a crop, its development has been limited historically due to the seed-shattering trait that exists in all known wild populations. This, combined with the plant's indeterminate flowering and seed production pattern, ensures that only a small fraction of the potential seed yield is mature and harvestable at any given time for wild types. In the 1990s, synthetically mutagenized seeds that produce plants with a non-shattering seed habit were successfully developed (Pascual-Villalobos et al., 1994). This non-shattering trait has been inherited in subsequent generations, allowing field research on EPHLA's agronomic crop requirements to occur using seed descended from this original mutagenized seed source.

We have studied various aspects of EPHLA crop management between 1995 and 2012 in years when funding allowed. These studies were conducted primarily at the Southern Oregon Research and Extension Center (SOREC), near Medford, Oregon, or at the Klamath Basin Research and Extension Center (KBREC), near Klamath Falls, Oregon, both agricultural research stations operated by Oregon State University in SW Oregon. A production problem common to all existing or potential crops is weed competition and control. Our studies have suggested that once established, EPHLA competes well against many weeds in this region's semi-arid climate, but that weed competition can be severe for several weeks following germination. If planted in the spring, EPHLA's germination coincides with that of many highly competitive summer weeds, and if not controlled, these weeds could readily overwhelm the young EPHLA planting. However, it is also true that planting EPHLA in the fall can lead to weed problems if its growth is slowed by cool temperatures at the same time that seasonal rains promote weed seed germination. While EPHLA would normally be grown as an annual crop, probably in rotation with other crops, it can at times regrow from the base after it is cut for harvest. If it could be managed in this way as a short-term perennial, it may be able to obtain an advantage over newly germinating weeds.

The objective of this study was to identify and evaluate herbicides that could prove useful in commercial cultivation of EPHLA. Because EPHLA is a new introduction to North America, and thus a potential weed, herbicides that could control escapes of this plant were also noted.

2. Materials and Methods

2.1 Herbicide Selection

To simplify future registration, all herbicides we tested were already registered in the USA for another crop at the time of these studies. Full chemical names of herbicides described herein can be found in “Common and Chemical Names of Herbicides Approved by the Weed Science Society of America” (Ransom et al., 2010).

The herbicides tested in this study were selected in one of four ways:

1) A search of the literature identified a preliminary evaluation of several herbicides for EPHLA as a crop in Spain (Vogel et al., 1993).

2) Known tolerance (or lack thereof) by weeds in the same genus or family was used to select possible candidates for weed control in an EPHLA crop (or for control of EPHLA escapes).

3) Some herbicides that were widely used to control common broadleaf weeds in the SW Oregon region were also considered as potentially useful in EPHLA crop cultivation.

4) Recommendations from chemical company scientists were used to select herbicides that may have selective weed control in EPHLA crop cultivation.

2.2 Locations and crop management common to all studies

The herbicide studies described in this paper were done at the Southern Oregon Research and Extension Center (SOREC) located between Medford and Jacksonville, Oregon, USA (42° 21' N, 122° 55' W). The soil is a Central Point sandy loam (coarse-loamy, mixed, mesic, Pachic Haploxeroll).

The general sequence of these experiments was to first test EPHLA tolerance to a wide range of PPI, PRE, or POST herbicides in greenhouse flats, followed by more detailed and more highly replicated field tests of the more likely herbicide candidates, which also included some lay-by herbicides (herbicides applied after crop emergence to prevent emergence of later-germinating weeds). Initial herbicide rates were chosen to be near the minimum that could be expected to provide an observable level of weed control, which ranged from the low to middle of rates registered for other crops. In some cases, rates suggested by chemical company scientists were used. Though some greenhouse studies were replicated to allow statistical analysis, they were not intended to be carried through seed harvest, but the later field experiments were continued through harvest to evaluate herbicide effects on EPHLA seed yield and seed oil content.

For the PPI treatments, the soil was sprayed and roto-tilled to a depth of about 75 mm in the field or mixed thoroughly in a rotating drum in the greenhouse before seeding. The PRE herbicides were sprayed after planting but before emergence. POST spray treatments were applied after EPHLA emergence to control emerged weeds. Lay-by treatments were applied following EPHLA emergence and after existing weeds had been controlled by cultivation to prevent later cycles of weed emergence. In each study described in this

102 paper, herbicides were applied in water solutions, using compressed air at 260 kPa pressure through a four-nozzle boom (Spraying
103 Systems TEEJET 8003 nozzles spaced 510 mm apart). The boom was mounted on a bicycle-wheel-frame sprayer and pushed by hand
104 at 3.2 km hr⁻¹ to apply 390 L ha⁻¹.

105
106 Crop tolerance was rated relative to a hand-weeded treatment, with a rating of zero indicating no visible injury, and a 100 indicating
107 crop death. Intermediate ratings were based on tissue necrosis, stunting, and vigor. The effectiveness of the herbicides against specific
108 weed species is fairly well known, and thus was not separately rated. However, weed infestation observed in the un-weeded control
109 plots was compared to the herbicide-treated plots to verify that apparent EPHLA herbicide tolerance, where EPHLA was not injured,
110 was occurring in the presence of visible herbicide activity on weeds.

111
112 Irrigation was applied with standard droplet sprayer nozzles for the greenhouse studies and through hand-line impact sprinklers for the
113 field studies. Irrigation was applied as needed to activate PRE herbicides and to keep enough available water in the root zone to allow
114 vigorous vegetative growth. However, care was taken to avoid applying excess irrigation that could affect herbicide mobility, and thus
115 its activity in the root zone. EPHLA is a drought-tolerant plant in its native habitat, so excess irrigation was avoided to minimize the
116 chance of disease or other non-herbicidal factors inhibiting growth and vigor that would confound the results. Based on previous
117 experience with EPHLA, irrigation was applied at about half the potential evapotranspiration rate (PE_T), which resulted in soil

moisture that generally remained within the 50% to 100% depletion range for plant available water. While this limited irrigation would cause moisture stress for many crop plants, EPHLA grows satisfactorily even under such low irrigation rates.

2.3 Statistical analysis.

Each replicated study was designed and analyzed as a randomized complete block. Data were subjected to analysis of variance using SAS statistical software (SAS, 2008). When a significant ($P < 0.05$) treatment effect occurred, the least significant difference value was calculated to compare treatment means.

2.4 PPI and PRE herbicides

2.4.1 Greenhouse tests.

After preliminary screening tests in 1998, the first three replicated tests of PPI and PRE herbicides were conducted using greenhouse flats in 1999. Some herbicides were included in all three tests, with increasing rates in each successive test (resulting in a “low”, “medium”, and “high” rate test of these herbicides). For each treatment, 100 EPHLA seeds were seeded by hand at about 6 mm depth in a 0.46 m by 0.91 m greenhouse flat, filled with field soil. This round of testing was meant to separate potentially useful herbicides from those that clearly inhibited EPHLA germination and emergence. Thus, each treatment was replicated only twice to allow statistical comparison only if large treatment differences occurred. PPI herbicides were sprayed and mixed into the soil just prior to

seeding, whereas PRE herbicides were sprayed onto the surface soon after seeding with the boom sprayer. EPHLA tolerance to PPI and PRE herbicides was measured on several dates by counting the number of emerged EPHLA plants, but only the final emergence number for each rate test is reported herein.

2.4.2 Field Test.

Based on the greenhouse test results, several promising PPI and PRE herbicides were evaluated in the field in 2000. Each treatment plot was replicated four times. Individual plots were 13.7 m long, containing 4 rows spaced 0.51 m apart. EPHLA seed was seeded on 22 March using a Planet Jr. single row drill, set to place the seed at 6 to 12 mm depth, and about 80 seeds m⁻¹ of row. PPI herbicides were roto-tilled into the soil the day before seeding, while PRE herbicides were applied through the boom sprayer the day after seeding.

Crop tolerance was measured by evaluating crop injury 3 and 7 weeks after treatment, and EPHLA was harvested at maturity in late August using a Hege 125C plot combine. Seed yield and 1000 seed weights were measured directly, and oil content was measured on cleaned samples using nuclear magnetic resonance techniques on an Oxford 4000 NMR Analyzer (Oxford Analytical Instruments, Ltd., Eynsham, Oxon, United Kingdom), using known EPHLA standard seed samples for calibration. Oil yield was calculated using seed yield and oil content values.

2.5 *POST herbicides*

2.5.1 Greenhouse tests.

EPHLA has slow initial growth and a long vegetative phase, so it was expected that PPI and PRE herbicides would not typically provide enough control of weeds for the entire growing season. Because of the large number of potential POST herbicides, and the lack of published observations with EPHLA, two rounds of un-replicated screening tests were conducted in greenhouse flats to provide preliminary information before proceeding to more involved, replicated testing in the field. These preliminary POST tests were seeded in greenhouse flats and managed similar to the PPI/PRE tests, except sufficient seeds were planted to produce a dense stand of seedlings.

2.5.2 Field Test 1.

Based on the results from the greenhouse tests, promising POST herbicides were then tested in the field in 2005 and 2012. In 2005 (Field Test 1), treatments were replicated twice. Individual plots were 9.1 m long, containing 4 rows spaced 0.61 m apart. EPHLA seed was seeded on 18 March using a Planet Jr. single row drill, set to place the seed at 6 to 12 mm depth, and about 80 seeds m⁻¹ of row. POST herbicides were sprayed over the crop on 9 June, when the EPHLA plants were between 150 and 250 mm tall, using the boom sprayer. Weeds were removed by hand from the control treatments and plots receiving DCPA, which is normally used as a lay-

169 by herbicide. Crop tolerance was measured 2 and 4 weeks following herbicide application. In addition, effects of herbicides on crop
170 maturity and seed shattering were measured on 16 August, approximately one week before harvest. This was done by randomly
171 selecting several individual branches from each plot, counting the number of individual seed pods on each branch, and designating
172 them as either green, brown, or shattered.

173

174 At maturity, plots were harvested on 24 August using a Hege 125C research plot combine. In some plots a significant number of
175 immature or partially mature seeds appeared to remain on the plants after combining. Thus, crop residue was left in the field for two
176 weeks to completely dry and then was combined again. Seed yield, 1000 seed weight, oil content, and oil yield were measured or
177 calculated for both combine runs. EPHLA sometimes can regrow during the fall and winter after harvest, so managing EPHLA as a
178 perennial was considered. To determine how herbicide use might affect this approach, post-harvest regrowth was rated on 28
179 September, five weeks after combine harvest.

180

181 2.5.3 Field Test 2.

182 The field study of POST herbicides was repeated in 2012, although two herbicides that caused significant EPHLA damage with
183 minimal seed yield in Field Test 1 were not included in Field Test 2. Treatments were replicated four times in Field Test 2. Individual
184 plots were 6.1 m long, containing 4 rows spaced 0.51 m apart. EPHLA seed was seeded on 6 April using a Planet Jr. single row drill,
185 set to place the seed at 6 to 12 mm depth, and about 80 seeds m⁻¹ of row. POST herbicides were sprayed over the crop on 14 June,

186 when the EPHLA plants were about 300 mm tall, using the boom sprayer. Weeds were removed by hand from the control treatments
187 and plots receiving DCPA, which is normally used as a lay-by herbicide. Crop tolerance was measured 9 and 36 days after herbicide
188 application. In addition, effects of herbicides on crop maturity and seed shattering were measured on 30 August, approximately one
189 week before harvest. This was done in the same way as the previous field POST herbicide study, by randomly selecting several
190 individual branches from each plot, counting the number of individual seed pods on each branch, and designating them as either green,
191 brown, or shattered.

192

193 At maturity, plots were harvested on 5 September using a Hege 125C plot combine. Essentially all the seed threshed out well during
194 the first combine run so that a second combine operation was not necessary. Seed yield, 1000 seed weight, oil content, and oil yield
195 were measured or calculated. Unlike the previous field study, there was little fall regrowth from any of the plots in this study.

196

197 **3. Results and Discussion**

198

199 *3.1 PPI and PRE herbicides*

200

201 3.1.1 Greenhouse tests.

In almost every case, herbicides either severely reduced EPHLA emergence (diuron and EPTC) at all herbicide rates tested, or had little effect on emergence at any of the tested rates (Table 1). Due to EPHLA's obvious lack of tolerance to diuron and EPTC at the low and moderate rates, they were not included in the high rate test, and were dropped from further consideration. EPHLA emergence was not hindered by chloridazon at the low and moderate rates compared to the control, but it was not evaluated at a higher rate. Compared with some of the herbicides tested, chloridazon caused some visible injury, but not enough to disqualify it from further consideration. In contrast, chloridazon did not injure EPHLA in the earlier test in Spain, while providing good weed control and good seed yield (Vogel et al., 1993). EPHLA emergence was not hindered by any of the dinitroaniline herbicides (trifluralin, pendimethalin, ethalfluralin, or benefin) when compared to the control treatment or to each other. Pendimethalin was not included in the first two tests, but was tested at three rates both PPI and PRE in the third experiment, where EPHLA emergence was similar to the control treatment for all six cases.

Thus the initial greenhouse flat tests of EPHLA emergence when treated with PPI and PRE herbicides suggested that benefin, ethalfluralin, trifluralin, and pendimethalin were excellent candidates for continued testing, while chloridazon and DCPA had good potential.

3.1.2 Field Test.

218 The most promising PPI and PRE herbicides from the greenhouse experiments were evaluated in the field at multiple rates. Overall,
219 the EPHLA crop tolerance was good, as visible injury observed both three and seven weeks after seeding was very low for all
220 herbicides and rates tested (Table 2). Pendimethalin tended to cause more injury than the other herbicides, but even its response was
221 considered acceptable. EPHLA injury from pendimethalin applied both PRE and PPI was significantly greater at the high rate than the
222 low rate measured 7 weeks after seeding, and this difference was more pronounced than it had been after 3 weeks. Pendimethalin
223 applied PPI tended to cause somewhat greater injury to EPHLA than the same rate applied PRE, but the difference only significant for
224 the low rate 3 weeks after seeding.

225
226 Compared to other crop management trials of EPHLA we have done over the years, seed yields in this test were excellent for all
227 treatments and no significant differences were observed, although a trend for decrease in yield was observed for EPHLA treated with
228 pendimethalin PRE. Likewise, seed oil contents were very good for all treatments, with no significant differences between treatments,
229 but there was a tendency for a slight decrease in oil content for the pendimethalin treatments compared to all others. Oil yield is a
230 function of both seed yield and seed oil content, so it was not surprising that oil yield was similar for all treatments, although EPHLA
231 treated with pendimethalin PRE tended to have a slightly lower oil yield than the other treatments.

232
233 The 1000 seed weights for three of the four pendimethalin treatments were significantly lower than five of the six benefin,
234 ethalfluralin, and trifluralin treatments. In all cases the 1000 seed weight was similar to or greater than typically observed values for

indehiscent mutants, which tend to be larger than seeds from dehiscent wild types (Pascual-Villalobos et al., 1993). This indicates that very healthy, mature seeds were produced in this experiment. The results for trifluralin also confirmed previous testing in Spain, where trifluralin did not injure the crop (Vogel et al., 1993).

3.2 POST Herbicides

3.2.1 Greenhouse Tests.

Damage to EPHLA by the POST herbicides in the two rounds of un-replicated screening tests in the greenhouse varied greatly, resulting in a group of potentially useful herbicides that were carried forward for more detailed field testing.

3.2.2 Field Test 1.

The two field experiments more completely compared the effects of various POST herbicides on EPHLA growth and seed production than the greenhouse tests did. In these two field studies, seed yields were in the 200 – 300 kg ha⁻¹ range, more similar to yields observed in other crop management studies we have conducted over the years. In the first field study, 20 POST herbicide treatments (including two rates of some herbicides) were evaluated for their effects on crop growth and injury, seed yield and size, seed oil content, and oil yield (Table 3).

252 Crop injury was significant and unacceptable for bromoxynil, 2,4-D, and picloram. Visible injury from oxyfluorfen was not as severe,
253 but still was more than desirable for routine crop production. At 14 and 29 days after treatment, EPHLA appeared to tolerate the other
254 herbicides well, as there was little or no visible crop injury.

255

256 EPHLA treated with dicamba exhibited the greatest delay in maturity, displaying many green pods with relatively few shattered or
257 brown pods. EPHLA treated with imazethapyr, alachlor at the high rate, and DCPA also had relatively more green pods and fewer
258 shattered pods, but they also had an appreciable number of brown pods. Herbicide treatments that resulted in a relatively high
259 proportion of brown pods with few shattered pods included clopyralid, bentazon, imazapyr at the low rate, imazamox, and
260 ethofumesate. If all else is equal, a crop with a high percentage of brown, mature seed pods and few shattered pods is most desirable.

261

262 EPHLA began to regrow after harvest in some plots, despite the lack of irrigation and minimal rain. The potential to manage this crop
263 as a short-term perennial would improve management options, so plants were allowed to regrow for one month after harvest to
264 measure this effect. EPHLA had no regrowth in the 2,4-D treatments, but regrowth was slow and/or sporadic for several other
265 herbicides. EPHLA that had consistently good regrowth, suggesting seed production may be possible the following year, included
266 plants treated with metsulfuron, imazapyr (low rate), ethofumesate, and dicamba.

267

268 Not too surprisingly, in many cases there was a strong connection between visible herbicide injury and eventual seed yield, oil
269 content, and oil yield. Thus, where injury was minimal, seed yield and related parameters were usually very good to excellent, i.e., for
270 the clopyralid, alachlor, acifluorfen, and chloridazon treatments. Conversely, where herbicide injury was severe, seed production and
271 quality were usually also adversely affected, i.e., 2,4-D and picloram. In an intermediate situation, EPHLA treated with bentazon and
272 DCPA exhibited a fairly low injury, but also produced a somewhat decreased seed yield.

273
274 However, the connection between visible injury and eventual seed yield was not always obvious. Oxyfluorfen and bromoxynil caused
275 a moderate to high degree of injury, but EPHLA produced a fairly good to excellent yield and seed quality (especially for the lower
276 rate of each herbicide). In these cases, EPHLA was apparently able to recover from the initial herbicide injury and, in a presumably
277 less competitive environment, created enough new leaf area and seed pods to produce fairly good to very good yields by harvest.

278
279 In contrast, several herbicides, including metsulfuron, imazapyr, imazethapyr, imazamox, ethofumesate, and dicamba, caused
280 moderately low to very low visible injury, but EPHLA produced very low seed yield and/or seed oil content. Thus, these herbicides
281 were not overly phytotoxic to the plant, but clearly interfered with some portion of its reproductive cycle, resulting in a stand of
282 reasonably healthy-looking plants that produced very few seed pods.

283

Because some plots appeared to have a large number of un-threshed seed pods after the first combine operation, threshed material was allowed to dry in the field for two weeks before a second threshing with the plot combine, as described above. Although seed yield, seed oil content, and 1000 seed weights were measured on seeds harvested in this second combine operation, the values were very low and did not contribute much to the total seed and oil yield (data not shown). Thus, only total seed yield and oil yield values are shown in Table 3. The seed oil content and 1000 seed weight values in Table 3 refer only to the mature seed harvested during the first combine operation.

3.2.3 Field Test 2.

In the second field study of POST herbicides, 18 treatments (including two rates of some herbicides) were evaluated for their effects on crop growth and injury, seed yield and size, seed oil content, and oil yield (Table 4).

Similar to the first field test, visible crop injury was significant for bromoxynil, especially at the higher rate. Initial injury from oxyfluorfen was also significant, but plants improved dramatically by the second evaluation date. There was somewhat more damage from acifluorfen than in the first field study, but symptoms improved with time for this treatment as well. Damage from ethofumesate and dicamba was low initially, but appeared to worsen by the second evaluation date. At both 9 and 36 days after treatment, EPHLA appeared to tolerate the other herbicides very well, as there was little or no visible crop injury.

301

302 Similar to the first field test, EPHLA treated with dicamba exhibited the greatest delay in maturity, displaying many green pods with
303 relatively few shattered or brown pods. Also similar to the first field test, EPHLA treated with imazethapyr, alachlor at the high rate,
304 and DCPA also had relatively more green pods and fewer shattered pods, but they also had an appreciable number of brown pods.
305 Herbicide treatments that resulted in a relatively high proportion of brown pods with few shattered pods included clopyralid, bentazon,
306 imazapyr, imazamox, and ethofumesate. These responses were similar to those in the first field study. If all else is equal, a crop with a
307 high percentage of brown, mature seed pods and few shattered pods is most desirable. Unlike the first field test, there was very little
308 EPHLA regrowth after harvest. Utilizing potential regrowth as a management option for subsequent year's seed production requires
309 further study to understand what conditions encourage this crop behavior. Also unlike the first field test, the seed pods threshed well
310 the first time for all herbicide treatments in the second field test, avoiding the need for an extended drying period and second combine
311 operation.

312

313 As in the first field study, there was often a strong connection between visible herbicide injury and eventual seed yield, oil content,
314 and oil yield. Thus, where injury was minimal, seed yield and related parameters were usually very good to excellent, i.e., for the
315 clopyralid, alachlor, and chloridazon treatments. Conversely, where herbicide injury was severe, seed production and quality were
316 usually also adversely affected, i.e., the high rate of bromoxynil. In an intermediate situation, EPHLA treated with bentazon and
317 DCPA exhibited little or no visible injury, but also produced an intermediate seed yield, similar to results in the first field test.

318

319 As in the first field test, oxyfluorfen caused a moderate to high degree of injury (especially on the first injury rating date), but EPHLA
320 produced a fairly good to excellent yield and seed quality. The response to acifluorfen was similar to that of oxyfluorfen in this second
321 field test, with moderate initial injury improving over time and a moderately good final seed yield. In these cases, EPHLA was
322 apparently able to recover from the initial herbicide injury and, in a presumably less competitive environment, created enough new
323 leaf area and seed pods to produce fairly good to very good yields by harvest. In contrast, injury from dicamba and ethofumesate
324 seemed to get worse over time, and this effect was more pronounced in the second field test than it had been in the first. However,
325 both herbicides resulted in low seed yields in both tests. Similar to the first field test, the response to bromoxynil was more of a dose-
326 response relationship, with the higher rate causing more visible injury and eventual lower yield.

327

328 Similar to the results from the first field test, several herbicides, including metsulfuron, imazapyr, imazethapyr, and imazamox caused
329 low visible injury, but EPHLA produced very low seed yield and/or seed oil content. Thus, these herbicides were not overly
330 phytotoxic to the plant, but clearly interfered with some portion of its reproductive cycle, which resulted in a stand of reasonably
331 healthy-looking plants that produced very few seed pods.

332

333 There were significant differences in 1000 seed weight which generally followed the pattern observed in the first field study. Seed
334 weights were highest for the alachlor treatment, and lowest for imazapyr. Unlike the first field test, seed weights were also

significantly lower than the other treatments for metsulfuron and dicamba. As discussed above for seed yield, imazapyr and metsulfuron clearly interfered with the crop's reproductive cycle.

In earlier studies in Spain, neither chloridazon nor bentazon caused visible injury to EPHLA, and seed yield was good for both treatments (Vogel et al., 1993). In our second field test, seed yield following bentazon treatment was significantly lower than the untreated control, and tended to be lower than the chloridazon treatment, a similar pattern to that observed in the first field test (Tables 3 and 4). Unlike the first field test, seed oil content was essentially identical for these three treatments. The results from these two field studies might suggest that bentazon is slightly more injurious than was evident from the study in Spain, but probably not enough to exclude bentazon from future consideration without additional data to confirm these trends.

3.3 New Crop weed control implications

Introduction of a new crop species, especially one that is as hardy and drought tolerant as EPHLA, creates the potential for the plant to escape as a weed. Several PPI, PRE, and POST herbicides evaluated in this study were quite toxic to EPHLA, and apparently would be good candidates for controlling any unwanted escapes from cultivation. Other herbicides not evaluated in these studies may also be useful in controlling potential EPHLA escapes. Several weeds common in the western USA are in the Euphorbiaceae family, and

several herbicides are registered to control such weeds in certain cropping circumstances. If EPHLA is grown commercially, future researchers may wish to evaluate these compounds as control agents for EPHLA to limit the potential risk of EPHLA escaping as a weed.

4. Conclusions

Euphorbia lagascae has good potential to become an important crop source of epoxy fatty acids in semi-arid regions. Crop yield is enhanced with good weed control, and EPHLA exhibited good tolerance and seed yield when treated with some of the herbicides we tested. The most promising PPI and PRE herbicides included benefin, ethalfluralin, and trifluralin. Pendimethalin also gave acceptable results but with slightly lower seed oil content and 1000 seed weight. The most promising POST herbicides included clopyralid, alachlor, acifluorfen, and chloridazon, to which EPHLA exhibited very good crop tolerance and produced very good to excellent yields. Oxyfluorfen initially caused significant vegetative injury, but EPHLA produced good to excellent yields, suggesting that the damaging effect on EPHLA was temporary and did not affect the reproductive processes. Injury and seed yield both seemed rate-dependent for the bromoxynil treatments, such that higher rates caused more injury and lower yield, although both were acceptable in certain cases. Bentazon and DCPA caused a low level of visible injury, but EPHLA treated with them produced a somewhat decreased seed yield, indicating that these herbicides could be useful if the effects of rate and timing were better understood. Metsulfuron, imazapyr, imazethapyr, imazamox, ethofumesate, and dicamba did not cause much vegetative injury (although injury

from dicamba and ethofumesate generally increased over time), but they all adversely affected EPHLA seed production in some way, resulting in very low yields even in the absence of obvious visible injury. Several of the PPI, PRE, and POST herbicides were highly toxic to EPHLA, and would be useful to help avoid a weed problem by killing escaped EPHLA plants.

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Table 1. EPHLA tolerance measured as percent emergence after treatment with herbicides at low, medium, and high rates applied preplant incorporated (PPI) and preemergence (PRE). 100 seeds planted for each greenhouse flat.

Herbicide	Timing	Rate (kg ha ⁻¹ a.i.)	Emergence ¹
<u>Low rate test</u>			
Benefin	PPI	1.12	76.0
Chloridazon	PRE	2.80	71.5
DCPA	PPI	6.72	79.5
DCPA	PRE	6.72	58.0
Diuron	PRE	1.68	20.5
EPTC	PPI	3.36	24.5
Ethalfuralin	PPI	0.56	86.0
Trifluralin	PPI	1.12	87.5
Control		na	78.5
Mean		--	64.7
Prob. > F		--	<0.001
LSD (0.05)		--	18.4
C.V. (%)		--	12.3
<u>Medium rate test</u>			
Benefin	PPI	2.24	72.0
Chloridazon	PRE	5.60	55.5
DCPA	PPI	13.44	48.0
Diuron	PRE	3.36	26.0
EPTC	PPI	6.72	0
Ethalfuralin	PPI	1.12	58.5
Trifluralin	PPI	2.24	67.5
Control		na	55.0
Mean	--	--	44.8
Prob. > F	--		0.003

473	LSD (0.05)	--		24.4
474	C.V. (%)	--		23.0
475				
476	<u>High rate test</u>			
477				
478	Benefin	PPI	4.48	64.5
479	DCPA	PPI	26.90	70.0
480	DCPA	PRE	26.90	75.5
481	Ethalfuralin	PPI	2.24	73.5
482	Trifluralin	PPI	4.48	64.0
483	Pendimethalin	PPI	1.12	74.5
484	Pendimethalin	PPI	2.24	79.0
485	Pendimethalin	PPI	4.48	80.5
486	Pendimethalin	PRE	1.12	79.5
487	Pendimethalin	PRE	2.24	75.0
488	Pendimethalin	PRE	4.48	79.0
489	Control		na	74.0
490				
491	Mean	---		73.2
492	Prob. > F	---		0.132
493	LSD (0.05)	---		NSD
494	C.V. (%)	---		10.2

¹ Emergence measured 34 days after planting (DAP) for low rates, 29 DAP for medium rates, and 28 DAP for high rate test.

Table 2. EPHLA injury, seed yield, oil content, and seed weight following treatment with preplant incorporated (PPI) and pre-emergence (PRE) herbicides in the field.

Herbicide	Timing	Rate (kg ha ⁻¹ a.i.)	Injury @ 3 wk (%)	Injury @ 7 wk (%)	Seed Yield (kg ha ⁻¹)	Seed oil content (%)	Oil Yield (kg ha ⁻¹)	1000 Seed Weight (g)
Benefin	PPI	1.12	1	0	1000	50.4	505	12.05
Benefin	PPI	2.24	1	0	1090	50.9	555	12.08
Ethalfuralin	PPI	1.12	2	0	1070	50.9	543	12.02
Ethalfuralin	PPI	2.24	5	2	1040	50.5	523	12.02
Trifluralin	PPI	1.12	2	0	1210	50.5	613	11.92
Trifluralin	PPI	2.24	5	8	1060	50.0	531	12.35
Pendimethalin	PPI	1.12	15	2	1040	49.3	512	11.26
Pendimethalin	PPI	2.24	18	10	1040	49.5	514	11.93
Pendimethalin	PRE	1.12	8	0	925	50.3	467	11.34
Pendimethalin	PRE	2.24	15	8	922	48.7	450	11.49
Control			0	0	1080	50.5	545	12.05
Mean	--	--	7	3	1040	50.1	522	11.85
Prob. > F	--	--	<0.001	0.002	0.423	0.254	0.328	0.008
LSD (0.05)	--	--	6	4	NSD	NSD	NSD	0.48
C.V. (%)	--	--	39.8	60.8	10.6	1.6	10.6	1.8

Table 3. Injury rating, evaluation of pod maturity, seed yield, seed oil content, oil yield, 1000 seed weight and post-harvest regrowth rating as affected by POST herbicide treatments (Field Test 1).

Herbicide	Rate (kg ha ⁻¹ a.i.)	Injury @ 14 days (%)	Injury @ 29 days (%)	Shattered Pods (%)	Brown Pods (%)	Green Pods (%)	Total Seed Yield (kg ha ⁻¹)	Seed Oil Content (%) (1 st run)	Total Oil Yield ¹ (kg ha ⁻¹)	1000 Seed Weight (g) (1 st run)	Post- harvest Regrowth Rating ²
Clopyralid	0.28	0	8	8.7	82.0	9.2	266	50.6	130	12.40	1.0
Oxyfluorfen	0.28	30	30	18.8	66.2	15.0	246	49.8	119	13.14	1.0
Oxyfluorfen	0.56	50	38	9.3	52.1	38.6	164	48.4	77	12.11	1.0
Bentazon	1.68	4	10	14.0	70.0	16.0	172	50.4	84	13.04	1.0
Alachlor	2.24	5	0	12.8	69.7	17.5	294	49.1	139	13.43	1.5
Alachlor	4.48	20	0	9.5	46.4	44.1	268	49.1	126	14.19	1.0
Metsulfuron	0.007	15	8	27.9	63.9	8.2	26	41.8	9	11.21	4.0
Acifluorfen	0.28	2	2	28.4	45.5	26.0	221	48.7	104	13.69	1.0
Imazapyr	0.14	10	2	16.2	75.5	8.3	20	45.9	8	12.57	4.5
Imazapyr	0.28	10	0	44.0	55.9	0.0	18	46.8	8	10.45	3.0
Imazethapyr	0.07	8	0	2.9	45.1	52.0	78	47.8	34	12.94	3.0
Imazamox	0.07	10	0	12.4	74.2	13.4	62	47.9	28	13.54	3.0
Ethofumesate	2.24	5	10	16.8	67.9	15.2	50	43.9	20	11.90	4.5
DCPA	6.72	5	0	2.9	54.9	42.2	141	45.8	61	13.30	1.5
Dicamba	0.56	18	15	15.6	12.7	71.7	33	43.8	13	11.20	4.0
Bromoxynil	0.28	60	70	51.6	13.8	34.6	125	48.6	59	13.51	1.5
Bromoxynil	0.56	75	92	20.5	66.1	13.4	65	48.0	31	15.38	1.0
2,4-D	1.12	80	90	* ³	* ³	* ³	38	49.8	19	12.24	0.0
Chloridazon	3.92	0	5	25.5	51.2	23.3	239	49.8	116	13.31	0.5
Picloram	0.56	35	55	36.1	26.7	37.3	39	49.3	17	14.53	1.5
Control	na	0	0	24.9	70.9	4.2	261	50.4	131	11.52	3.0
Mean	--	22	22	19.9	55.5	24.5	135	47.9	64	12.82	2.0
Prob. > F		0.001	0.001	0.070	0.004	0.001	0.001	0.007	0.001	0.112	0.001
LSD (0.05)	--	8	7	NSD	34.9	25.4	110	4.0	55	NSD	1.6
C.V. (%)		16.5	15.7	99.9	44.4	73.1	39.1	4.0	41.4	10.1	37.6

¹ Total oil yield calculated as (first run seed yield times first run oil content) plus (second run seed yield times second run oil content). Separate data for first and second runs not shown.

² Evaluation of post-harvest regrowth was done using a rating scale that ranged from 0 for very brown, dead plants to 5 for plants showing very green, vigorous regrowth of 200 to 400 mm tall.

*³ Plants within in the plot areas randomly sampled for pod maturity analysis in the 2,4-D treatment had only dead plants, thus no pod maturity readings were recorded for that treatment.

Table 4. Injury rating, evaluation of pod maturity, seed yield, seed oil content, oil yield, and 1000 seed weight as affected by POST herbicide treatments (Field Test 2).

Herbicide	Rate (kg ha ⁻¹ a.i.)	Injury @ 9 days (%)	Injury @ 36 days (%)	Shattered Pods (%)	Brown Pods (%)	Green Pods (%)	Seed Yield (kg ha ⁻¹)	Seed Oil Content (%)	Oil Yield (kg ha ⁻¹)	1000 Seed Weight (g)
Clopyralid	0.28	1	4	11.5	81.5	7.0	232	44.1	106	12.00
Oxyfluorfen	0.28	38	11	19.5	66.0	14.5	224	44.1	101	12.02
Oxyfluorfen	0.56	52	11	12.0	55.2	32.8	153	44.0	70	11.29
Bentazon	1.12	4	6	15.8	72.5	11.8	161	44.3	67	12.04
Bentazon	2.24	5	5	18.2	70.5	11.2	158	44.2	64	11.99
Alachlor	4.48	15	8	12.0	44.8	43.2	232	44.0	104	13.14
Metsulfuron	0.007	8	9	28.2	65.0	6.8	19	40.5	9	10.43
Acifluoren	0.28	18	9	30.2	47.0	22.8	200	44.1	94	12.28
Acifluorfen	0.56	29	15	21.8	48.0	30.2	196	44.0	88	12.22
Imazapyr	0.14	6	10	19.0	79.0	2.0	15	42.8	6	9.76
Imazethapyr	0.07	5	5	6.0	48.2	45.8	67	43.5	28	11.86
Imazamox	0.07	5	8	15.8	73.8	10.5	56	43.4	22	12.07
Ethofumesate	2.24	5	20	17.2	70.0	12.8	46	42.7	20	11.15
DCPA	6.72	0	0	5.2	55.0	39.8	128	43.4	53	12.20
Dicamba	0.56	10	26	18.2	16.8	65.0	22	42.6	7	10.45
Bromoxynil	0.28	21	12	52.8	18.8	28.5	112	44.0	53	12.25
Bromoxynil	0.56	50	41	26.8	56.2	17.0	60	44.0	27	12.25
Chloridazon	3.92	1	0	27.8	50.2	22.0	212	44.2	87	11.99
Control	na	0	0	27.8	68.8	3.5	229	44.3	109	11.31
Mean	--	14	10	20.3	57.2	22.5	133	43.6	59	11.72
Prob. > F	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	--	6	9	11.8	13.2	11.0	60	1.4	21	0.66
CV %	--	29.0	58.0	41.1	16.2	34.7	31.8	2.0	21.9	3.4