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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.

1. Introduction

Euphorbia lagascae Spreng., (Euphorbiaceae) (hereafter abbreviated EPHLA in this paper), is a drought-tolerant native of southern Spain. Its seeds contain about 45–50% oil, of which 60–65% is a specific C_{18} 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

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

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

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