Agronomic Requirements of *Euphorbia lagascae:* A Potential New Drought-Tolerant Crop for Semi-Arid Oregon: 2010 Results.

Richard J. Roseberg and Rachel A. Bentley[1]

Background and Rationale

Euphorbia lagascae (Euphorbiaceae- 'spurge family') has been recognized as one of the more promising potential new industrial crops for the drier regions in the temperate zone (Roseberg, 1996). In the late 1950s and early 1960s the USDA analyzed many plant species in search of novel chemical compounds. They first recognized that *E. lagascae* was unique among the 58 euphorbs tested (and almost unique among all plants) in that the seed oil contained high levels of a C_{18} epoxy fatty acid (EFA) known as vernolic acid (12,13 epoxy-cis-9-octadecenoic acid) (Kleiman et al., 1965). *E. lagascae* (hereafter simply called 'euphorbia') is a drought-tolerant native of Spain whose seed contains about 45%-50% oil, of which 60%-65% is vernolic acid (Kleiman et al., 1965; Vogel et al., 1993). Vernolic acid is an EFA of great interest to the paint and coating industry as a drying solvent in alkyd resin paints, a plasticizer or additive in

[1] Associate Professor and Faculty Research Assistant, respectively, Klamath Basin Research & Extension Center, Klamath Falls, OR.

polyvinyl chloride (PVC) resins (Riser et al., 1962; Carlson et al., 1981; Carlson and Chang, 1985; Perdue et al., 1986). Paints formulated with vernolic acid emit very low levels of volatile organic compounds (VOC) and thus using such paints would greatly reduce the VOC air pollution that now occurs with volatilization of alkyd resins in conventional paints (Brownback and Glaser, 1992; Anon, 1993). The Clean Air Act amendments of 1990 required the reduction of VOC pollutants, and regulations in California have been implemented earlier with greater effect upon the paint industry.

After initially discovering euphorbia's valuable and nearly unique seed oil, the major problem that hindered both breeding and agronomic research needed to develop euphorbia as a crop has been its violent seed shattering habit, combined with its indeterminate flowering and seed habit, making it difficult both to harvest and to measure seed yield. No wild accessions of euphorbia contain a non-shattering trait (Vogel et al., 1993; Pascual-Villalobos et al., 1994). However, in the early-1990s, chemically induced, non-shattering mutants were developed in Spain (Pascual and Correal, 1992; Pascual-Villalobos et al., 1994; Pascual-Villalobos, 1996). These non-shattering seeds were transferred to Oregon State University in the mid-1990s and formed the basis for research conducted at the Southern Oregon Research & Extension Center (SOREC) and the Klamath Basin Research & Extension Center (KBREC) on a sporadic basis starting in 1995.

For more details on euphorbia's unique properties, crop status, current competitors, and likely uses in industry please refer to a more detailed discussion, including additional references, in our earlier reports (Roseberg and Shuck, 2008 and 2009).

Goal of Current Studies

Due to euphorbia's apparent drought tolerance, the potential of growing euphorbia under minimal irrigation on less-productive soils could help reduce water use conflicts in the Klamath Basin and other areas of the arid and semi-arid western US. Thus, given both the potential of euphorbia as a drought-tolerant crop, and the encouraging data from previous studies at SOREC in Medford, OR, we decided to proceed with additional, more detailed agronomic studies over multiple years, beginning in 2008 (Roseberg and Shuck, 2008 and 2009).

The objective of this series of studies was to examine euphorbia's response to crop management practices such as seeding date, irrigation rate, nitrogen fertilization, plant density, seeding rate, and seed type in semi-arid southern Oregon locations. In 2010, these studies were duplicated in both the Rogue Valley and in the Klamath Basin to compare responses in two dramatically different climates (grown at SOREC near Medford, OR and at KBREC near Klamath Falls, OR). Some of the 2010 studies were also grown at an additional site in the Klamath Basin (the JWTR Forest Nursery near Hildebrand, OR, hereafter called the 'Tree Farm' site). This additional site had a reliable source of well water for irrigation, which was important because in 2010 the irrigation water deliveries at KBREC were questionable at the time these trials were seeded. Using the Tree Farm site also allowed us to compare results in a different soil type and a slightly different Klamath Basin microclimate.

Materials and Methods Summary

Studies were conducted at KBREC (Poe fine sandy loam), SOREC (Central Point sandy loam) and the Tree Farm (Fordney loamy fine sand). At each location three separate types of experiments were seeded: I) Row spacing response; II) Seed type response; III) Seeding rate response. At KBREC and SOREC, there were three irrigation treatments ('high', 'low', and 'none') and two seeding dates at each location. At the Tree Farm, there was only one seeding date and one irrigation rate ('low'). After initial irrigation of all plots to encourage uniform germination, irrigation rates at each location were decided based on the Kimberly-Penman evapotranspiration calculated by the nearest US Bureau of Reclamation Agricultural Meteorological (AgriMet) automated weather station located at KBREC, at SOREC, and near the Tree Farm at the Lorella, OR station (US Bureau of Reclamation, 2010). Irrigation was applied at rates approximately equal to 50% of calculated evapotranspiration in the 'high' treatment and 25% of evapotranspiration in the 'low' treatment. After emergence, irrigation was not applied to the 'none' treatment except for unusual cases when some additional moisture was needed to allow mechanical weed control.

Kincaid Plot Drill

In each trial the euphorbia seed was drilled using a tractor mounted modified Kincaid (Kincaid Equipment Mfg.) plot drill. During the growing season weeds were controlled by mechanical and manual cultivation. No fertilizer was applied to any of the trials. All plots were harvested with a Hege (Hans-Ulrich Hege) plot combine with a 4.5-ft-wide header. Some plots was re-threshed a second time with the Hege plot combine after a period of air-drying in the field (several days to several weeks after initial harvest). This was done where some seed was not properly threshed during the first harvest because it was immature or the pod moisture was too

high to properly separate from the stems, by manually pitchforking the dried piles of already-combined euphorbia into the Hege. Harvested seed was cleaned using a Clipper seed cleaner. During the harvest process, euphorbia seed will separate into one of three forms. The intact capsule (called 'whole pods' or WP) consists of three sections, with each section containing an individual seed. 'Partial pods' (PP) consist of individual seeds that are still retained in the individual chambers, but the chambers have separated from one another, while 'good seed' (GS) indicates clean individual seeds that have separated completely from all remnants of the original capsules or pods. After cleaning, the percentage of GS, PP, and WP were calculated. After the seed was cleaned, good seeds were analyzed for oil content by the USDA-ARS-NCAUR lab in Peoria, IL, and oil yield per acre was calculated after correcting for the weighted proportion of good seed within the partial pods and whole pods.

All measured parameters were analyzed statistically using SAS® for Windows, Release 9.1 (SAS Institute, Inc.) software. Analysis of variance was calculated according to the appropriate individual experiment's design. Treatment significance was based on the F test at the P=0.05 level. If this analysis indicated significant treatment effects, least significant difference (LSD) values were calculated based on the student's *t* test at the 5% level.

Summary of Problems at SOREC

Before proceeding to a detailed discussion of materials, methods, and results for each experiment and site, it should be explained why there is no data for the SOREC site. The trial at SOREC grew very well throughout the season; the plants were healthy and vigorous. For some unexplained reason, the vast majority of the plants didn't develop any seed until very late in the season and thus never matured. An unusually large number of plants exhibited a 'mob-head' deformity consisting of sometimes flattened stems and a small cluster of flowers with very few seedheads concentrated at one point on the plant, very unlike the normally observed 'branchy' growth habit and widely dispersed seed set throughout a normal plant. Even the more normal looking plants had fewer-than-expected number of flowers, and the few seeds that formed matured very late. In the previous 10 seasons of growing euphorbia at KBREC or SOREC, we have observed an individual euphorbia plant with the 'mob-head' morphology only on rare occasions, with a few individuals widely scattered across a field. The low number of flowers and thus seedpods in 2010 was also unusual.

Normal Plant

Mob-Head

This 'mob-head' growth habit in euphorbia has been mentioned in the literature (Pascual-Villalobos, 1996). Our observations in 2010 were discussed with the world expert on euphorbia, but several potential explanations (effects of late seeding, spring moisture, rototilling between rows causing some root pruning, relatively cool summer temperatures, etc.) were not conclusive (Maria Pascual-Villalobos, pers. comm., 2010). The 2010 trials at SOREC were seeded later than normal due to a cool, wet spring, and wet conditions continued during emergence and early vegetative growth phase. We controlled weeds between the rows with a walk-behind rototiller, whereas we normally are able to use a tractor-mounted knife cultivator with some hand-weeding, which are less disruptive to the soil and roots near the surface. How these or other factors may have resulted in the observed growth habit is unknown. In contrast, the two Klamath Basin trials grew more normally, using the same seed and seeding procedures, although they also tended to mature later than in our previous studies here. Perhaps more than one factor contributed to the unusual growth habit observed at SOREC in 2010.

Because there were very few mature plants or seedpods by autumn, we did not harvest the SOREC trials, and therefore results from that location will not be discussed further.

I. Row Spacing Trials

Materials and Methods

KBREC

This study was set up as a split-split plot design with three replications. Irrigation rate was the main plot, seeding date was the sub-plot, and row spacing was the sub- sub-plot. The two seeding dates were May 6 and June 1. There were three different row spacings (12 inches, 24 inches, and 36 inches between rows) with constant number of seeds per foot of row, resulting in areal seeding rates of 60 seeds/ft^2, 30 seeds/ft^2, and 20 seeds/ft^2, respectively. All plots were seeded with clean 'good seed' saved from the 2009 harvest.

Total precipitation from May through October was 2.06 inches, with 1.56 inches falling from May through the end of August (Table 1), when the growth of most plants slowed noticeably and most plants gradually began to mature and dry down. For the first seeding date, a total of 11.87 inches of irrigation was applied on 12 dates in the 'high' irrigation treatment during the growing season, 7.44 inches of irrigation was applied on 8 dates in the 'low' treatment, and 3.51 inches of irrigation was applied over 5 applications in the 'none' treatment. Irrigation was only applied to the 'none' treatment a single time soon after each seeding date (to simulate a timely spring rain and to encourage uniform germination), and on later dates only when required to assist with mechanical weed control. Areas seeded on June 1 received one less irrigation (0.72 inches) than those seeded on May 6. The calculated Kimberly-Penman evapotranspiration from May 6-31 was 4.15 inches, was 7.21 inches for June, 9.81 inches for July, and 7.87 inches for August.

As described in the Materials and Methods Summary section above, the first seeding date in the 'high' irrigation treatment was combined twice (October 15 and November 21). The second seeding date in the 'high' treatment was combined once, on November 3. In the 'low irrigation treatment, both seeding dates were combined once, on November 4. The first seeding

date in the 'none' irrigation treatment was combined on October 21, and the second seeding date was combined on November 3. All of these harvest dates were later than normal, probably due to the relatively late seeding dates necessary in 2010 due to the wet spring.

Tree Farm

This study was laid out with the same row spacing treatments and seeded using the same equipment and seed as the KBREC study. However, since there was only one seeding date and one irrigation rate ('low'), this trial was a randomized complete block design with three replications. Plots were seeded on May 21. A total of 6.90 inches of irrigation was applied on 10 dates during the growing season (from seeding through August), in addition to 1.75 inches of rain. Calculated Kimberly-Penman evapotranspiration from seeding through August was 25.8 inches. All plots in this trial were combined twice, on September 17 and October 19.

Results and Discussion

KBREC

Overall, seed yields for most treatment combinations were lower than in some previous experiments, but yields were fairly good in some cases. There was no significant difference in total seed yield between seeding dates or row spacings, however, observed differences in yield were significant for irrigation rate response ($P = 0.05$) (Table 2).Yields decreased as irrigation rate decreased. In the 'high' irrigation treatment, the first seeding date was combined twice, as described above. The second cutting increased the total seed yield by over 20%, indicating this process may be an effective strategy in situations where a large number of seed pods don't thresh properly without a period of field drying after cutting. Yields in the 'low' and 'none' irrigation treatments were much lower than yields in the 'high' treatment.

There was no significant difference in seed oil content between seeding dates or row spacing, however, observed differences in seed oil content were significant for irrigation rate response. Seed oil percentages generally decreased as irrigation rate decreased. The second combining of the first seeding date in the 'high' irrigation treatment had lower seed oil percentages than the first cutting.

Differences in observed oil yield for irrigation rate and row spacing were significant. Similar to the pattern observed for seed yield, oil yields were highest in the 'high' irrigation treatment, and they decreased as irrigation rate decreased. The second combining of the first seeding date in the 'high' treatment added proportionally somewhat less to the total oil yield than it did to the seed yield due to the lower oil content in seed resulting from the second combining operation. The 36 inch row spacing had the lowest total oil yields, whereas both the 12 inch and 24 inch spacings each had the highest oil yield in certain cases.

The percent whole pods measurement is an indication of the maturity and/or relative indehiscence of the plants at time of harvest. There was no significant difference in percent whole pods for seeding date or row spacing, but there was a significant difference in percent whole pods between irrigation rates. The 'low' irrigation treatment typically had the highest

percent whole pods, suggesting that a low level of irrigation may have encouraged more non-shattering pod types to form (compared to 'high' or 'none'). Environmental influence of moisture and/or temperature at the time of pod formation on ultimate seed shattering habit has been observed at times in our previous trials (especially for fall-seeded trials at SOREC). This connection between environment during pod formation and seed shattering was described in more detail by Pascual-Villalobos, et al. (1994).

The final stand count measurement is an indication of how well the seed germinated and how well the seedlings persisted into healthy plants as of early summer. In this trial, because the number of seeds per lineal foot of row was constant in all treatments, one would expect the stand counts to be uniform unless seeding date, row spacing, or irrigation rate affected germination and seedling vigor. Stand counts were only significant for seeding date. In every case, the stand count was significantly higher for the earlier seeding date, suggesting that cooler temperatures or improved moisture clearly benefited germination and early season vigor. Likewise, there was a trend for decreased irrigation to result in a lower stand count, but this irrigation effect was not statistically significant.

Plant heights differences were statistically significant for irrigation rate and seeding date. Plants became shorter as irrigation rate decreased in almost every case. Interestingly, the second seeding date had taller plants than the first for both the 'high' and 'none' irrigation treatments, but heights were more uniform for the 'low' treatment.

In this experiment, there were situations where germination was reasonable, yet ultimate seed yield was very low or even zero (stand count vs. seed yield columns, Table 2). In some cases, such as the May 6 seeding date in the 'none' irrigation treatment, the plants generally remained very small during the season and set very few harvestable seed pods (see height column). Also, in the 'none' irrigation treatment, plants did not seem to persist to harvest as well as they had in previous years. Even a low level of irrigation seemed to improve persistence, number of seed pods, and amount of harvestable seed.

Because these seeding dates were delayed until later than our desired dates by wet spring conditions, it was also observed that a larger-than-normal number of plants did not mature and dry down well by the time they had to be combined. This may have also contributed to the relatively low seed yields in the 'low' and 'none' irrigation treatments even where a good number of plants were still alive at harvest, as well as the need to re-combine some plants from the 'high' irrigation treatment a second time to collect the large number of immature seed pods that did not thresh well when combined directly the first time.

Tree Farm

There were enough seed pods that were not fully mature by harvest time so that we re-combined all plots a second time at the Tree Farm even though these were grown under the 'low' irrigation regime (whereas the only plots needing to be re-combined at KBREC were in the 'high' irrigation treatment). Yields were fairly high compared to some past experiments, perhaps due to the contribution of the second combining (thus presumably capturing nearly all the available seed). The second combining increased total seed yields by about 2/3 at the Tree Farm (Table 3).

Differences due to row spacing were not significantly different for any of the measured parameters (Table 3). Despite this lack of statistical significance, some consistent patterns were observed. Seed and oil yield tended to decrease as row spacing increased, whereas percent whole pods, stand count, and plant height all tended to increase as row spacing got wider. Interestingly, seed oil content also seemed to increase as row spacing got wider (only for the second combining). In this trial, it appeared that wider row spacing resulted in plants that were taller and had more intact pods than those in narrow rows, but that narrower rows resulted in a higher yield simply due to a greater number of plants per acre.

II. Seed Type Trials

Materials and Methods

KBREC

Euphorbia seed is produced in capsules (also called seed pods) that normally contain three seeds each (Vogel et al., 1993; Verdolini et al., 2004). Each individual seed is contained within a separate, small chamber or section. Thus, the intact capsule (called 'whole pods' or WP) consist of three sections, with each section containing an individual seed. During the harvest process, euphorbia seed will thresh out into one of three forms: 'whole pods', 'partial pods' or PP (seed still retained in the individual chambers that have separated from one another), and 'good seed' or GS (clean individual seeds that have separated completely from all remnants of the original capsules or pods). During post-harvest seed cleaning, the seed is typically separated (by size) into these three forms. Past analysis has shown that 'partial pods' contain approximately 48.1% 'good seed' by weight, and that 'whole pods 'contain approximately 43.4% 'good seed' by weight.

Good Seed, Partial Pods, and Whole Pods

Once seeds separate into these three forms during harvest and cleaning, it would be difficult to further separate seed from their pods because euphorbia seed is very soft (due to the high oil content) and easily damaged. Thus, it would be useful to know if PP or WP could be seeded directly, and whether they suffer any loss of germination vigor, crop growth, or ultimate yield compared to using GS. The 2010 study was a more detailed examination of earlier results that suggested that different seed types did produce different results (Roseberg and Shuck, 2009).

In 2010, the three seed types were grown under three irrigation regimes and two seeding dates to evaluate their response to these management variables. This study was set up as a split-split plot design with six replications. Irrigation rate was the main plot, seeding date was the sub-plot, and seed type was the sub-sub-plot. Irrigation amount, number of applications, and precipitation amount were the same as in the row spacing trial described above (Table 1). The two seeding dates were also the same (May 6 and June 1). Calculated Kimberly-Penman evapotranspiration during the season, harvest dates and methods were also the same.

The three different seed types (GS, PP, and WP) were seeded at a rate of 30 seeds/ft^2, which equaled 28.8 lb/ac for GS, 59.9 lb/ac for PP, and 66.3 lb/ac for WP. Row spacing was 24 inch in all cases.

Tree Farm

This study was laid out with the same seed type treatments and seeded using the same equipment and seed supply as the KBREC study. However, since there was only one seeding date (May 21) and one irrigation rate ('low'), this trial was a randomized complete block design with six replications. Plots were seeded on May 21. Irrigation amount, number of applications, precipitation amount, and calculated Kimberly-Penman evapotranspiration were the same as in the Tree Farm row spacing trial described above. All plots in this trial were combined twice, on September 17 and October 19.

Results and Discussion

KBREC

Overall, seed yields were lower than in some previous experiments. There were significant differences in seed yield due to irrigation rate and seed type, but the differences were not significant for seeding date (P = 0.05) (Table 4). There was also a significant interaction between irrigation rate and seed type, indicating that response to irrigation was not the same for all seed types. Yields were by far the highest in the 'high' irrigation treatment. As in the row spacing study above, the first seeding date was combined twice in the 'high' irrigation treatment only. The second combining increased the total seed yield by more than 1/3. Seed yield was highest from GS and lowest from WP in almost every case.

There was no significant difference in seed oil content for any of the treatments. Differences in observed oil yields were significant for all treatments, and followed the same patterns observed for seed yield, except that seeding date differences were also statistically

significant for oil yield. Oil yields were generally highest in the 'high' irrigation treatment, for the first seeding date, and for GS compared to the other irrigation rate, seeding date, and seed types.

There was no significant difference in percent whole pods for any of the treatments. Stand counts were only significant for irrigation rate and seeding date. The 'high' irrigation treatment had the highest stand counts for both seeding dates, while the 'none' irrigation treatment had very low stand counts o the second seeding date. The first seeding date had consistently higher stand counts for the 'high' and 'none' irrigation treatments, but not for the 'low' treatment where the pattern was reversed (leading to the significant irrigation rate by seeding date interaction). Plant height differences were significant for irrigation rate and seed type. Good seed consistently resulted in taller plants. Height also tended to increase as irrigation rate decreased in some cases, but the patterns were not consistent, as evidenced by the significant irrigation rate by seeding date and irrigation rate by seed type interactions.

Tree Farm

Differences in seed yield due to seed type were statistically significant (P = 0.05) (Table 5). Yield tended to be higher for GS, and was significantly lower for WP than for either GS or PP. Unlike at KBREC, all plots were harvested twice. As was true in the row spacing trial at the tree farm, the second combining increased total seed yields by about 2/3. Seed oil content was only significant for the second cutting, where the WP had a higher percent seed oil than the PP or GS. Despite this, oil yield followed the same pattern as seed yield, with WP resulting in lower oil yield for both combinings as well as the total oil yield.

Differences in percent whole pods were significantly different only for the second combining, where seeding with WP resulted in significantly fewer whole pods at harvest than using either GS or PP for seed.

Differences in stand count were significantly different, with WP resulting in far fewer plants than either GS or PP. Differences in plant height were also significant, with WP resulting in significantly shorter plants than either GS or PP. this pattern was also observed at KBREC, although plants were of more uniform height at the tree farm.

III. Seeding Rate Trials

Materials and Methods

KBREC

This study was set up as a split-split plot design with four replications. Irrigation rate was the main plot, seeding date was the sub-plot, and seeding rate was the sub-sub-plot. Irrigation amount, number of applications, and precipitation amount were the same as in the row spacing trial described above (Table 1). The two seeding dates were also the same (May 6 and June 1). Calculated Kimberly-Penman evapotranspiration during the season, harvest dates and methods were also the same. There were three different seeding rates ('high', 'medium', and 'low')

seeded at a rate of 30, 15, and 7.5 seeds/ft^2, respectively. Between-row spacing was 24 inches in all cases. All plots were seeded with clean 'good seed' saved from the 2009 harvest.

Tree Farm

This study was laid out with the same seeding rate treatments and seeded using the same equipment and seed supply as the KBREC study. However, since there was only one seeding date (May 21) and one irrigation rate ('low'), this trial was a randomized complete block design with four replications. Irrigation amount, number of applications, precipitation amount, and calculated Kimberly-Penman evapotranspiration were the same as in the Tree Farm row spacing trial described above. All plots in this trial were combined twice, on September 17 and October 19.

Results and Discussion

KBREC

Like the other 2010 trials, overall yields were lower than in previous years' studies. There were significant differences in seed yield due to irrigation rate and seeding date, but differences due to seeding rate were not significant (P = 0.05) (Table 6). Yields were by far the highest in the 'high' irrigation treatment. In the 'high' treatment, the first seeding date was combined twice, and the second combining increased the total seed yield by over 1/3. For the 'high' and 'low' irrigation treatments, the May 6 seeding date generally had higher yields, but in the 'none' irrigation treatment the June 1 seeding date had a higher yield (though all yields were low in the 'low' and 'none' treatments). Thus it is not surprising that there was a significant irrigation rate by seeding date interaction for yield. Although the results were not significant, seed yields tended to increase as seeding rate decreased in many cases.

There were significant differences in seed oil percentage for irrigation rate only. The 'none' irrigation treatment had the highest seed oil percentage. Although differences between seeding dates were not significant, the later seeding dates tended to have higher oil content. Added to the irrigation rate results, it appeared that moisture stress tended to increase seed oil content somewhat. Oil yield differences were significant for irrigation rate only, but they followed the same pattern as seed yield. Oil yields were by far the highest for the 'high' irrigation treatment. For the 'high' irrigation treatment, the second cutting increased total oil yield by about 1/3.

Differences between percent whole pods were only significant for irrigation rate. Whole pod percent was highest for the 'low' irrigation rate, and lowest for the 'none' irrigation treatment. This result was similar to that of the row spacing trial described above, suggesting that a low level of irrigation may have encouraged more non-shattering pod types to form (compared to 'high' or 'none'). Environmental influence of moisture and/or temperature at the time of pod formation on ultimate seed shattering habit has been observed at times in our previous trials (especially for fall-seeded trials at SOREC). This connection between

environment during pod formation and seed shattering was described in more detail by Pascual-Villalobos, et al. (1994).

Differences in stand counts were statistically significant for irrigation rate, seeding rate, and seeding rate, as were the two-way interactions between these treatments. Given the nature of this trail, one would expect the stand count to be consistently higher where the seeding rate was higher, and vice versa, but this was not consistently true except for in the 'high' irrigation treatment. In the 'low' and 'none' treatments, sometimes the high seeding rate resulted in the highest stand count, and sometime the medium seeding rate had the highest stand counts. The lowest seeding rate never produced the highest stand count, although it did ultimately result in the highest seed yield in two of the six irrigation rate by seeding date treatment combinations (the late seeding date for both 'low' and 'none' irrigation). Overall, the 'high' irrigation treatment had the highest stand counts, but the 'low' and 'none' treatments were more similar to each other.

Differences in plant height were significant for all measured parameters, as were their interactions, making it difficult to observe consistent patterns among treatment responses. In general, low stand counts tended to correlate with tall plants, suggesting that less densely spaced plants tend to branch out and grow taller than plants that grew in a denser stand. Where differences were significant, the June 1 seeding date resulted in taller plants than the May 6 seeding date, which may be more related to the number of mature plants rather than the seeding date *per se*.

Tree Farm

Yield for this trial was similar to the other two trials conducted at the Tree Farm site for the same seeding rate (30 seeds/ft^2). Yields at the tree farm for this trail were higher than those at KBREC for the same irrigation treatment ('low'). Differences between seeding rates were significant for seed yield, oil yield, and stand counts (Table 7). Seed yields were higher for the 'high' seeding rate than for other two rates. By combining the plots a second time, we were able to increase the total seed yields by 40-68%, suggesting that a large number of seeds were not mature enough for proper threshing during the first (direct) combining, but still accounted for a significant proportion of the total seed and oil yield (despite the slightly lower oil yield for seeds resulting from the second combine operation) if they could be recovered via drying and a second combining operation. Oil yield followed the same pattern as seed yield. Stand counts were highest for the 'high' seeding rate, and decreased as seeding rate decreased, although the difference between the medium and low seeding rate was not significant.

Differences between seeding rates were not significant for seed oil percent, percent whole pods, or plant height. All stand counts were moderate compared to some plots in the KBREC trial, so it is not surprising that all the tree farm plants had room to branch out and grow taller with less competition than was observed in denser stands at KBREC.

Conclusions

Euphorbia is very flexible, and can adapt to many different growing conditions and management practices. This series of experiments confirm that euphorbia is able to survive and produce a harvestable seed yield under completely non-irrigated conditions, but that seed yield is greatly enhanced by some irrigation. In 2010, seeding date did not seem to have much of an effect on most factors we measured, including seed yield. Although the results were not significant, closer row spacing tended to yield higher than wider spacing. At times in the past, euphorbia has produced greater seed yields at narrow row spacing (thus higher number of seeds/ft^2), and at other times seed yield was increased at wider row spacing; a condition resulting in larger, branchier plants.

Due to this variable row spacing response in the past, in 2010 we began testing euphorbia under a range of seeds/ft^2, yet constant row width, to see whether seed density within a row or row spacing *per se* are the factors that contribute to these differences in growth habit and yield. Higher seeding rates typically resulted in higher stand density, but not necessarily higher seed yields. Up to a point, euphorbia seems to compensate for lower stand density by growing taller and with more branches (producing more seeds per plant), so that seed yield is not necessarily closely correlated to seeding rate or early season stand density (until plant populations became very low).

These studies showed that yields are greatly increased by seeding ‘good seed’, rather than ‘partial pods’ or ‘whole pods’. It is not clear whether seed germination is actually lower for seeds retained in partial pods or whole pods, or of the pods themselves somehow inhibit germination, either physically (through delayed or reduced moisture imbibition prior to germination) or due to some allelopathic effect of the seed pod on euphorbia seed germination.

Because some plots remained greener than normal at time of harvest and did not thresh well, we experimented this year with running these less-mature plots through the combine two times. Seed yield increased from 1/3 to 2/3 when combined plants were allowed to dry in the field and then re-combined. Seed oil content was typically 3-6% lower for seed from the second combining, but this process still added significantly to the total recoverable oil yield. It would be interesting to try this procedure again using multiple irrigation rates to see if seed yield could be increased under different irrigation rates and growing season conditions.

In nearly every case, the Tree Farm had higher seed yields and seed oil percent than the comparable treatments in the KBREC trials. Evaluating earlier seeding dates in combination with irrigation treatments would be helpful at the Tree Farm site in order to better understand the limits of seeding date and irrigation response for euphorbia seed production on that type of soil.

Acknowledgement

Seed oil analysis for this research was generously provided by the USDA-ARS-National Center for Agricultural Utilization Research (Peoria, Illinois).

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Table 1. 2010 Precipitation & irrigation for euphorbia irrigation rate x seeding date & seed type x irrigation rate trials. Klamath Basin Research & Extension Center, Klamath Falls, OR.

		"High" Block		"Low" Block		"None" Block	
Month	Precipitation (inch)	Irrigation (inch)	Irrigation Applications	Irrigation (inch)	Irrigation Applications	Irrigation (inch)	Irrigation Applications
May	0.66	0.72	1	0.72	1	0.72	1
June	0.52	4.57	5	3.71	4	1.57	2
July	0.15	2.72	3	1.58	2	1.22	2
August	0.23	3.86	3	1.43	1	0.00	0
September	0.05	0.00	0	0.00	0	0.00	0
October	0.45	0.00	0	0.00	0	0.00	0
Total	**2.06**	**11.87**	**12**	**7.44**	**8**	**3.51**	**5**

Table 2. 2010 Euphorbia response to irrigation rate, seeding date, & row spacing.
Klamath Basin Research & Extension Center, Klamath Falls, OR.

			Seed Yield (lb/ac)			Oil Content %		Oil Yield (lb/ac)			Percent Whole Pods			Final	Plant
Irrigation Rate	Seeding Date	Row Spacing	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	Over-all	Stand (per 3 ft)	Height (inch)
High	May 6	12 inch	331	91	453	46.4	44.4	158	40	212	17.1	21.0	18.7	65.3	18.3
		24 inch	368	124	492	47.4	44.0	174	54	228	18.1	24.1	19.5	80.0	18.7
		36 inch	334	114	447	47.3	45.5	160	52	211	16.4	24.5	18.5	73.3	15.7
	June 1	12 inch	501	na	501	48.6	na	243	na	243	16.3	na	16.3	36.7	27.0
		24 inch	295	na	295	48.0	na	141	na	141	17.2	na	17.2	31.7	29.3
		36 inch	315	na	315	46.2	na	145	na	145	20.3	na	20.3	21.0	28.0
Low	May 6	12 inch	77	na	77	44.8	na	34	na	34	23.0	na	23.0	44.7	11.3
		24 inch	142	na	142	44.8	na	63	na	63	27.2	na	27.2	57.3	11.7
		36 inch	79	na	79	42.5	na	34	na	34	20.1	na	20.1	80.3	11.7
	June 1	12 inch	129	na	129	46.6	na	60	na	60	32.3	na	32.3	12.7	11.3
		24 inch	59	na	59	32.9	na	19	na	19	22.5	na	22.5	14.3	11.7
		36 inch	0	na	0	na	na	na	na	na	na	na	na	12.0	10.7
None	May 6	12 inch	0	na	0	na	na	na	na	na	na	na	na	41.7	6.3
		24 inch	0	na	0	na	na	na	na	na	na	na	na	62.3	9.0
		36 inch	0	na	0	na	na	na	na	na	na	na	na	68.3	6.7
	June 1	12 inch	33	na	33	49.5	na	16	na	16	14.2	na	14.2	24.0	10.0
		24 inch	100	na	100	46.6	na	47	na	47	25.9	na	25.9	17.7	14.7
		36 inch	0	na	0	na	na	na	na	na	na	na	na	22.0	11.0
Mean			154	109	172	46.0	44.5	72	48	80	20.2	23.0	20.6	42.5	14.6
***P* (Irrigation Rate)**			**<0.001**	**na**	**0.001**	**0.006**	**na**	**<0.001**	**na**	**<0.001**	**0.019**	**na**	**0.034**	**0.193**	**<0.001**
LSD (0.05)- Irrigation Rate			112	na	138	1.6	na	56	na	68	1.21	na	0.9	NSD	2.8
CV Irrigation Rate (%)			38.8	na	48.6	3.6	na	39.6	na	48	24	na	23.2	48.2	20.9
***P* (Seeding Date)**			**0.791**	**na**	**0.294**	**0.120**	**na**	**0.832**	**na**	**0.341**	**0.285**	**na**	**0.775**	**<0.001**	**<0.001**
LSD (0.05)- Seeding Date			NSD	na	NSD	NSD	na	NSD	na	NSD	NSD	na	NSD	12.1	1.8
CV Seeding Date (%)			44.5	na	56.4	13.0	na	50.7	na	60	25	na	24.1	42.8	18.9
***P* (Row Spacing)**			**0.079**	**0.191**	**0.123**	**0.404**	**0.784**	**0.050**	**0.215**	**0.083**	**0.400**	**0.326**	**0.417**	**0.236**	**0.109**
LSD (0.05)- Row Spacing			NSD	NSD	NSD	NSD	NSD	14	NSD	NSD	NSD	NSD	NSD	NSD	NSD
CV Row Spacing (%)			38.5	25.0	35.6	5.1	4.2	38.2	27.0	35.7	22.5	11.9	21.9	36.2	19.7
***P* (Irrig. Rate X Seeding Date Interaction)**			**0.350**	**na**	**0.146**	**0.073**	**na**	**0.426**	**na**	**0.185**	**0.376**	**na**	**0.156**	**0.652**	**0.003**
***P* (Irrig. Rate X Row Spacing Interaction)**			**0.123**	**na**	**0.157**	**0.773**	**na**	**0.090**	**na**	**0.122**	**0.229**	**na**	**0.205**	**0.460**	**0.655**
***P* (Seeding Date X Row Spacing Interaction)**			**0.058**	**na**	**0.046**	**0.466**	**na**	**0.045**	**na**	**0.037**	**0.709**	**na**	**0.779**	**0.026**	**0.760**
***P* (Irrig. Rate X Seeding Date X Row Spacing Interaction)**			**0.093**	**na**	**0.079**	**na**	**na**	**0.075**	**na**	**0.067**	**na**	**na**	**na**	**0.882**	**0.881**

Table 3. 2010 Euphorbia response to row spacing at the Tree Farm site.
Klamath Basin Research & Exension Center, Klamath Falls, OR.

	Seed Yield (lb/ac)			Oil Content %		Oil Yield (lb/ac)			Percent Whole Pods			Final	Plant
Row Spacing	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	Over-all	Stand (per 3 ft)	Height (inch)
12 inch	391	262	653	49.7	43.0	194	112	306	10.0	19.0	13.6	28.7	22.0
24 inch	295	204	499	49.9	46.6	147	95	242	12.4	19.8	15.4	30.3	22.7
36 inch	256	178	434	49.8	48.6	127	86	213	14.5	19.2	16.2	32.7	25.7
Mean	314	215	528	49.8	46.0	156	98	254	12.3	19.3	15.1	30.6	23.4
***P* Value**	**0.090**	**0.363**	**0.177**	**0.904**	**0.090**	**0.090**	**0.509**	**0.188**	**0.285**	**0.892**	**0.489**	**0.946**	**0.175**
LSD (0.05)	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD
CV %	17.7	30.2	22.2	1.2	5.0	17.5	26.0	20.0	23.6	11.5	16.2	47.9	8.6

Table 4. 2010 Euphorbia response to irrigation rate, seeding date, & seed type.
Klamath Basin Research & Extension Center, Klamath Falls, OR.

			Seed Yield (lb/ac)			Oil Content %		Oil Yield (lb/ac)			Percent Whole Pods			Final	Plant
Irrigation Rate	Seeding Date	Seed Type	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	Over-all	Stand (per 3 ft)	Height (inch)
High	May 6	Good	320	104	424	46.2	43.3	148	45	193	19.2	25.0	20.6	63.3	18
		Partial Pod	160	79	255	47.0	41.8	76	33	122	19.5	27.6	22.4	55.8	12
		Whole Pod	122	49	170	46.2	45.3	56	22	78	18.0	18.8	17.7	67.3	9
	June 1	Good	324	na	324	47.3	na	154	na	154	17.7	na	17.7	38.0	17
		Partial Pod	149	na	149	46.7	na	70	na	70	21.2	na	21.2	28.8	10
		Whole Pod	32	na	32	39.7	na	12	na	12	20.8	na	20.8	37.7	8
Low	May 6	Good	30	na	30	45.6	na	14	na	14	22.6	na	22.6	12.7	19
		Partial Pod	17	na	17	45.6	na	8	na	8	24.2	na	24.2	10.2	10
		Whole Pod	11	na	11	46.0	na	5	na	5	20.6	na	20.6	15.2	9
	June 1	Good	11	na	11	45.0	na	5	na	5	23.2	na	23.2	28.5	27
		Partial Pod	43	na	43	44.0	na	19	na	19	16.3	na	16.3	18.8	11
		Whole Pod	6	na	6	44.9	na	3	na	3	19.1	na	19.1	26.8	14
None	May 6	Good	25	na	25	46.2	na	12	na	12	16.0	na	16.0	17.0	27
		Partial Pod	13	na	13	38.1	na	5	na	5	13.4	na	13.4	22.7	11
		Whole Pod	23	na	23	44.2	na	10	na	10	11.8	na	11.8	14.2	14
	June 1	Good	54	na	54	46.9	na	26	na	26	24.4	na	24.4	4.2	22
		Partial Pod	14	na	14	44.3	na	6	na	6	18.8	na	18.8	4.5	12
		Whole Pod	7	na	7	46.5	na	3	na	3	22.9	na	22.9	3.2	15
Mean			79	77	93	45.5	43.5	37	33	43	19.3	23.8	19.6	26.0	15
***P* (Irrigation Rate)**			**<0.001**	**na**	**<0.001**	**0.295**	**na**	**<0.001**	**na**	**<0.001**	**0.705**	**na**	**0.630**	**<0.001**	**<0.001**
LSD (0.05)- Irrigation Rate			81	na	103	NSD	na	38	na	50.6	NSD	na	NSD	6.0	1.5
CV Irrigation Rate (%)			105.3	na	109.5	4.6	na	107.2	na	127.9	24.5	na	39.5	44.0	13.5
***P* (Seeding Date)**			**0.497**	**na**	**0.055**	**0.624**	**na**	**0.556**	**na**	**0.014**	**0.436**	**na**	**0.339**	**<0.001**	**0.083**
LSD (0.05)- Seeding Date			NSD	na	NSD	NSD	na		na	12	NSD	na	NSD	3.2	NSD
CV Seeding Date (%)			99.5	na	100.8	8.2	na	105.7	na	60.2	17.6	na	20.5	30.0	14.2
***P* (Seed Type)**			**<0.001**	**0.043**	**<0.001**	**0.353**	**0.318**	**<0.001**	**0.035**	**<0.001**	**0.706**	**0.040**	**0.617**	**0.233**	**<0.001**
LSD (0.05)- Seed Type			42	43	50	NSD	NSD	19	17	11	NSD	6.7	NSD	NSD	5
CV Seed Type (%)			55.2	36.9	56.3	5.6	7.0	56.4	33.8	52.5	19.5	18.7	20.0	42.0	11.9
***P* (Irrig. Rate X Seeding Date Interaction)**			**0.483**	**na**	**0.020**	**0.682**	**na**	**0.515**	**na**	**0.002**	**0.005**	**na**	**0.013**	**<0.001**	**<0.001**
***P* (Irrig. Rate X Seed Type Interaction)**			**<0.001**	**na**	**<0.001**	**0.029**	**na**	**<0.001**	**na**	**<0.001**	**0.156**	**na**	**0.146**	**0.164**	**<0.001**
***P* (Seeding Date X Seed Type Interaction)**			**0.253**	**na**	**0.853**	**0.046**	**na**	**0.220**	**na**	**0.509**	**0.532**	**na**	**0.220**	**0.660**	**0.263**
***P* (Irrig. Rate X Seeding Date X Seed Type Interaction)**			**0.275**	**na**	**0.695**	**0.270**	**na**	**0.254**	**na**	**0.375**	**0.264**	**na**	**0.404**	**0.945**	**<0.001**

Table 5. 2010 Euphorbia response to seed type at the Tree Farm site.
Klamath Basin Research & Extension Center, Klamath Falls, OR.

	Seed Yield (lb/ac)			Oil Content %		Oil Yield (lb/ac)			Percent Whole Pods			Final	Plant
Seed Type	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	Over-all	Stand (per 3 ft)	Height (inch)
Good Seed	315	213	528	49.4	45.0	156	96	252	10.7	19.1	14.2	26.8	22.3
Partial Pod	271	211	482	49.3	44.1	133	93	227	11.8	20.0	15.3	25.3	21.5
Whole Pod	107	82	189	49.8	47.6	53	39	92	11.2	15.5	13.0	9.5	20.2
Mean	231	169	400	49.5	45.6	114	76	190	11.2	18.2	14.2	20.6	21.3
***P* value**	**<0.001**	**<0.001**	**<0.001**	**0.334**	**0.031**	**<0.001**	**<0.001**	**<0.001**	**0.646**	**0.041**	**0.206**	**<0.001**	**0.004**
LSD (0.05)	26	49	62	NSD	2.6	13.3	20.3	27	NSD	3.6	NSD	5.3	1.1
CV (%)	8.8	22.5	12.1	1.3	4.4	9.0	20.7	11.2	17.5	15.3	14.7	20.1	3.9

Table 6. 2010 Euphorbia response to irrigation rate, seeding date, & seeding rate.
Klamath Basin Research & Extension Center, Klamath Falls, OR.

			Seed Yield (lb/ac)			Oil Content %		Oil Yield (lb/ac)			Percent Whole Pods			Final	Plant
Irrigation Rate	Seeding Date	Seeding Rate	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	Over-all	Stand (per 3 ft)	Height (inch)
High	May 6	High	280	94	374	46.1	43.7	131	42	172	19.7	24.5	20.9	53.5	18.0
		Medium	235	90	325	46.2	42.4	109	38	147	20.9	24.6	21.9	39.5	18.2
		Low	375	161	536	47.2	44.5	177	71	248	24.4	26.5	25.0	15.2	19.0
	June 1	High	263	na	263	46.8	na	123	na	123	19.5	na	19.5	37.8	16.5
		Medium	365	na	365	47.0	na	173	na	173	19.1	na	19.1	12.5	28.0
		Low	194	na	194	47.4	na	92	na	92	20.9	na	20.9	4.8	27.8
Low	May 6	High	50	na	50	45.6	na	23	na	23	22.6	na	22.6	10.5	18.0
		Medium	81	na	81	45.0	na	36	na	36	30.6	na	30.6	24.8	9.5
		Low	52	na	52	45.0	na	23	na	23	29.1	na	29.1	14.2	12.0
	June 1	High	7	na	7	45.9	na	3	na	3	25.4	na	25.4	26.2	27.0
		Medium	40	na	40	45.1	na	18	na	18	26.8	na	26.8	11.8	10.0
		Low	78	na	78	46.5	na	36	na	36	25.9	na	25.9	6.2	11.5
None	May 6	High	11	na	11	45.9	na	5	na	5	14.2	na	14.2	17.8	27.2
		Medium	72	na	72	46.7	na	33	na	33	19.6	na	19.6	36.0	10.0
		Low	43	na	43	47.6	na	20	na	20	22.0	na	22.0	23.0	9.2
	June 1	High	82	na	82	46.9	na	38	na	38	24.4	na	24.4	4.0	20.2
		Medium	101	na	101	48.6	na	49	na	49	13.8	na	13.8	12.2	16.8
		Low	139	na	139	48.1	na	67	na	67	14.1	na	14.1	11.8	16.2
Mean			148	113	169	46.6	43.5	69	49	78	21.5	25.1	21.7	20.1	17.5
***P* (Irrigation Rate)**			**<0.001**	**na**	**<0.001**	**0.006**	**na**	**<0.001**	**na**	**<0.001**	**<0.001**	**na**	**<0.001**	**<0.001**	**<0.001**
LSD (0.05)- Irrigation Rate			116.0	na	143.0	1.0	na	55.0	na	66.0	2.0	na	3.0	3.4	1.0
CV Irrigation Rate (%)			35.9	na	34.9	2.1	na	36.7	na	35	12.1	na	11.4	23.6	7.8
***P* (Seeding Date)**			**0.233**	**na**	**0.032**	**0.390**	**na**	**0.189**	**na**	**0.070**	**0.778**	**na**	**0.511**	**<0.001**	**<0.001**
LSD (0.05)- Seeding Date			NSD	na	23.2	NSD	na	NSD	na	11	NSD	na	NSD	4.0	0.8
CV Seeding Date (%)			20.1	na	22.3	3.4	na	21.1	na	23.1	9.9	na	10.0	37.5	9.1
***P* (Seeding Rate)**			**0.646**	**0.265**	**0.661**	**0.065**	**0.596**	**0.645**	**0.225**	**0.658**	**0.895**	**0.642**	**0.919**	**<0.001**	**<0.001**
LSD (0.05)- Seeding Rate			NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	5.0	1.2
CV Seeding Rate (%)			64.7	42.4	66.6	2.7	4.4	66.4	41.6	67.9	22.1	6.9	21.5	42.9	11.8
***P* (Irrig. Rate X Seeding Date Interaction)**			**0.005**	**na**	**<0.001**	**0.648**	**na**	**0.007**	**na**	**<0.001**	**0.290**	**na**	**0.133**	**0.009**	**0.012**
***P* (Irrig. Rate X Seeding Rate Interaction)**			**0.992**	**na**	**0.996**	**0.650**	**na**	**0.994**	**na**	**0.995**	**0.875**	**na**	**0.895**	**<0.001**	**<0.001**
***P* (Seeding Date X Seeding Rate Interaction)**			**0.894**	**na**	**0.798**	**0.999**	**na**	**0.893**	**na**	**0.801**	**0.053**	**na**	**0.055**	**0.006**	**<0.001**
***P* (Irrig. Rate X Seeding Date X Seeding Rate Interaction)**			**0.138**	**na**	**0.135**	**0.415**	**na**	**0.152**	**na**	**0.141**	**0.402**	**na**	**0.356**	**0.151**	**<0.001**

Table 7. 2010 Euphorbia response to seeding rate at the Tree Farm site.
Klamath Basin Research & Extension Center, Klamath Falls, OR.

Seeding Rate	Seed Yield (lb/ac)			Oil Content %		Oil Yield (lb/ac)			Percent Whole Pods			Final Stand (per 3 ft)	Plant Height (inch)
	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	1st Cut	2nd Cut	Total	1st Cut	2nd Cut	Over-all		
High	322	219	541	49.8	46.7	160.2	102	262	10.7	20.0	14.5	28.2	22.5
Medium	108	43	151	49.5	44.2	53.4	19	73	8.5	13.9	9.9	14.5	20.5
Low	112	48	160	49.4	45.7	55.4	22	78	9.0	14.1	10.6	10.0	21.0
Mean	181	104	284	49.5	45.5	90	48	138	9.4	16.0	11.7	17.6	21.3
***P* value**	**<0.001**	**<0.001**	**<0.001**	**0.524**	**0.461**	**<0.001**	**<0.001**	**<0.001**	**0.660**	**0.101**	**0.186**	**<0.001**	**0.430**
LSD (0.05)	68	26	80	NSD	NSD	33	10	40	NSD	NSD	NSD	4.8	NSD
CV %	21.8	14.6	16.2	1.0	5.9	21.4	12.6	16.9	36.7	23.3	28.2	15.9	9.9