Winter Annual Oilseed Crop Evaluation: 2009-2013

Canola, Camelina and Meadowfoam[1]

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This report summarizes results from tests of three different winter annual oilseed crops for individual sites from fall 2009 to spring 2013. Canola (Brassica *napus*, B. *juncea*) camelina (Camelina *sativa*), and meadowfoam (Limnanthese *alba)* were tested at research sites and famers fields in the central valley and Lassen County. There are no registered herbicides for camelina in California, so the tolerance of camelina to available herbicides was evaluated in Fresno County at one site. Varieties tested varied in part from year to year. There was a large amount of site and year variation in seed and oil yield for all species tested. Overall, canola was the highest yielding species and had the highest oil content, while meadowfoam had the lowest yields and oil content. Depending on rainfall and residual soil moistrue at planting, species varied by site and year in their response to supplemental spring irrigation, and to supplemental nitrogen fertilizer. One possible use for new oilseed crops is for biodiesel feedstocks, so the relative value of each type of oil for biodiesel is discussed. No signficant occurrence of insect pests or pathogens were observed in any of these trials, but brassica crops are reported to suffer from occassional outbreaks of insect pests or pathogens in California, and some images of potential pests and diseases are included.

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Introduction

Winter annual oilseeds include canola (Brassica *napa* and Brassica *juncea*), Camelina (Camelina *sativa*), and Meadowfoam (Limnanthes *alba*). Each are best planted in late fall or early winter, and in many locations in CA, may be grown on winter rainfall, or a combination of winter rainfall, stored or residual soil moisture, and limited irrigation if rainfall and residual soil water are limiting. Each species has different oil quality characteristics that make them variably suitable for biodiesel use or as feedstocks for other industrial uses including cosmetics and chemicals. Camelina and Meadowfoam are not used as edible oils in the US, but canola is. Oilseed meals from Canola and Camelina have important uses as livestock feeds.

During the period from fall 2009 to spring 2013, a series of trials evaluating three different oilseed species and varieties within these species were conducted. There were also trials evaluating crop response to differing rates of N fertilizer, and whether fall-planted crops would respond with increased yields to spring applied irrigation, especially in drier locations like western Fresno County. There were also some trials evaluating seeding rates for canola and differing planting dates in fall.

The majority trials of these were conducted at the UC Westside Research and Extension Center (WSREC) and the UC Davis campus. Other locations included Macarthur in Lassen County and Lockeford, in San Joaquin County. All trials were conducted using randomized complete block designs, usually with four replications. The varieties tested varied during these trials depended on which cooperating seed companies were willing to provide varieties. Over the course of the four years a representative sample of the varieties being offered for sale in California, or being developed for sale in California were tested. In the 2012-13 growing season, varieties from Australian canola breeding programs were tested for the first time.

Winter annual oilseed species were emphasized. In most of California where a Mediterranean to semi-arid climate predominates, many oilseed species in the family *Brassicaceae* are best planted in the fall and harvested in the mid to late spring. These species have the advantage of growing during the cooler part of the year when crop water use is less per unit dry matter than in summer, and can also take advantage of the winter rains that characterize the climate in most of the state. This is similar to the way wheat, barley and oats are treated and the seasons largely overlap. In locations like Macarthur, with cold winters and freezing temperatures, these same species are planted in spring and harvested in fall, similar to large areas of the rest of the United States with continental climates. Both exceptionally wet and cold, and dry and cold weather was experienced during the alternating years as these trials were conducted. Crop response varied significantly across years and sites, so results are reported for each year. Where general patterns were observed across years, these are highlighted and discussed after individual years are reported.

Canola

Canola is the third most important oilseed globally. It is produced principally in Canada, western Europe and Australia (FAOSTAT, 2012). Canola oil is widely used for both human consumption (Duff et al., 2006; Johnson and Fritsche, 2012) and biodiesel production, and seed meal is well suited for livestock feeding (Duff et al., 2006; Newkirk, 2009). Rapeseed (Br. *napus*) is the original source for canola, and has higher levels of erusic acid and glucosinolates, which are both anti-nutritional factors (Ebberlein et al., 1999; Chew, 1998; Fenwick, 1983). Glucosinolates in oilseed meals have reported uses as natural pesticides and may be valuable by-products of some varieties with pest control uses (Mora and Borek, 2010). Another canola type (Brassica *juncea*) is a related species also used for cooking and transportation fuels. Canola and rapseed are the primary feedstocks produced within the European Union for the manufacture of biodiesel. In the United States, canola production is centered predominantly in the Midwest and Northwestern states, but current demand for canola oil in the United States exceeds domestic production (USDA NASS, 2011). Although the crop has been evaluated in CA intermittently since the late 1970s, there is no canola production for oil in the state at the present time. Some canola is produced in the Imperial Valley for variety development purposes and seed increase.

Previous work in California

Paul Knowles at the University of California, Davis initiated evaluation of canola germplasm and related Brassica oilseed crops in the late 1970s and early 1980s (Knowles, 1980; Knowles et al., 1981; Knowles et al., 1983). Yields of between 1,000 to 2000 lb/ac were reported from these trials (Knowles et al., 1981), but the work ended with Knowles retirement. Since then, Thomas Kearney of UCCE, based in Yolo County, carried out a number of yield and variety evaluation trials over a multi-year period. Most recently, a trial was conducted in Yolo and Fresno Counties evaluating varieties, N response, and response to late season irrigation by Kaffka, Brittan and Hutmacher in 2006-07. They planted a number of commercial varieties, and evaluated the response of selected varieties to differing rates of fertilizer N, and supplemental irrigation in spring (approximately 6 ac in). Maximum yields were higher in Yolo than in Fresno County (Figure 1and 4), supplemental irrigation in Yolo County in spring resulted in a significant yield increase (Figure 2), and canola responded to increasing N rates linearly across the range of N levels applied (Figure 3), indicating that the crop's N demand was not satisfied at 150 lbs of N per acre that year.

Figure 1. Variety yields in Yolo County in 2006.

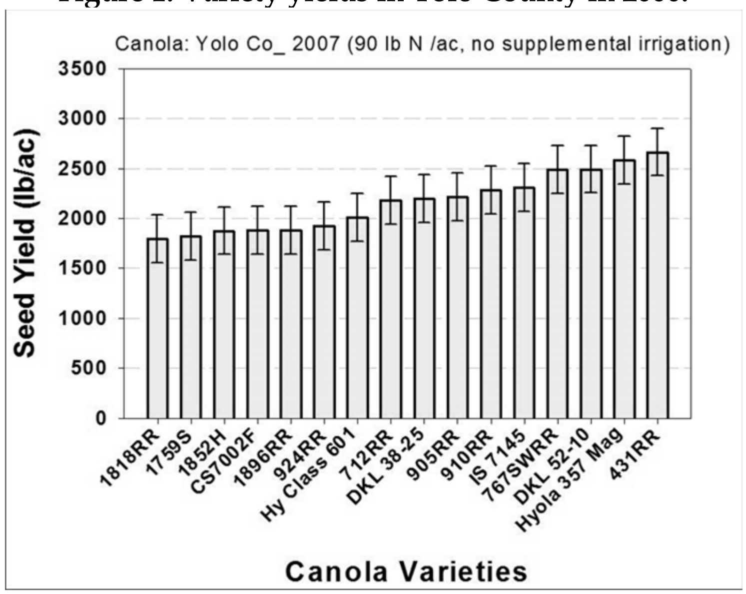


Figure 2. Supplemental irrigation effects in spring in Yolo County in 2007 (approximately 6 ac-in of water were applied).

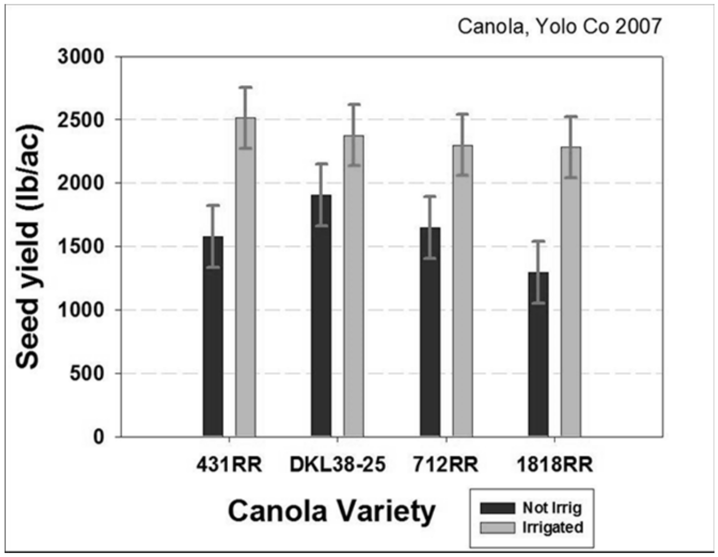


Figure 3. Nitrogen response of canola in Yolo County in 2007.

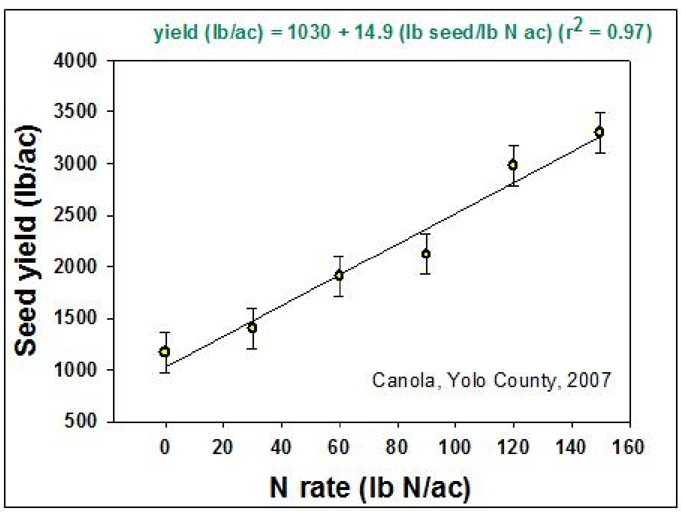
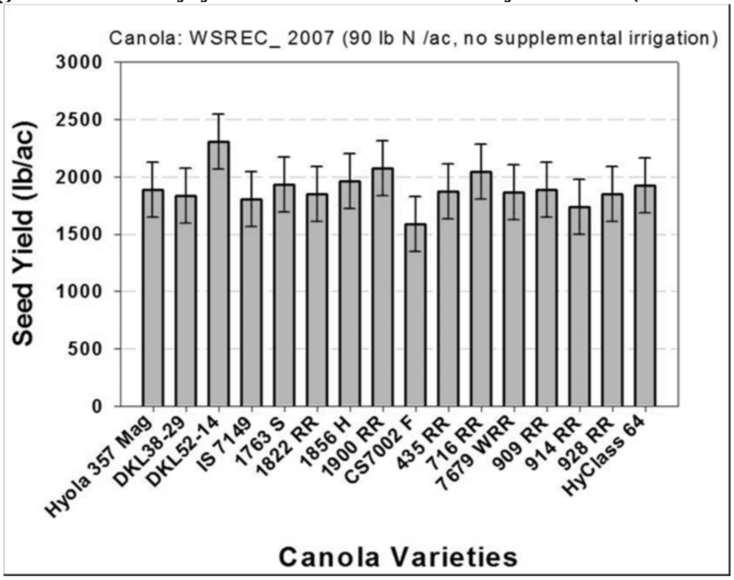


Figure 4. Variety yields in Fresno County in 2007 (WSREC).



Trials (2009-2013): Methods and Results

Central Valley sites (Davis, WSREC) 2009-2012.

2009-10 Trials.

Six canola cultivars from Viterra, Inc., a Canadian company, were tested in Davis at the UC Davis campus research farm and the UC Westside Research and Extension Center (WSREC)[5]. HJMOZ 9043, J07Z-01904 and J07Z-14246 were *B. juncea* entries (Indian mustard), and SP07-74527, SP-1Y 08-11116, SP-1Y 08-11126 were *B. napus* entries, the traditional canola. Varieties were chosen with the advice of Viterra. Soils on the Davis campus were primarily Yolo loams, and at the WSREC, primarily Panoche loams. Results are summarized in the figures reported here. All error bars in the figures are standard errors.

Seed yields were higher at WSREC overall than at Davis, with the *B. napus* entries reaching 2 tons per acre (Figure 5). The highest yields at WSREC were achieved with 160 lb of N per acre and exceeded 2.0 t/ac. At Davis, response was not linear and the largest yields were achieved at the larger rate of 240 lb N/ac (Figure 6). Supplemental irrigation (approximately 6 ac in) in spring had no effect on yield at either location. Both sites have excellent agricultural soils with high water holding contents.

While seed yields were greater at WSREC, the oil content of seed (reported as percent) was greater at Davis (Figure 8). Winter and spring temperatures in Davis are cooler than at WSREC

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[5] http://ucanr.org/sites/westsiderec/

and rain typically occurs later in spring, at least in most years (Appendix A). The oilseed crops in general mature later at Davis than at WSREC in western Fresno County, so seeds can accumulate a larger percentage of oil due to later maturity.

The *B. juncea* varieties were both lower yielding and had lower oil contents resulting in an overall lower total oil yield per acre (% oil x seed yield) at WSREC, while oil contents were similar across all varieties at Davis. This suggests that B. *juncea* varieties are slower to accumulate oil than traditional canola varieties. Temperature may be more important than soil moisture since supplemental irrigation in spring did not influence oil percent (Figure 10). Similarly, oil content was not influenced by N fertilizer level (Figurre 9). The protein content of the residual meal left after oil crushing and extraction is likely to be influenced by fertilizer N levels, but this was not tested in these trials. Oil yields by variety are reported in Figure 11Figure 11. Varieties influenced oil yield significantly, with the highest individual plot yields exceeding one ton of oil per acre and average yields close to 1800 lb/ac. This is nearly 250 gals of biodiesel equivalent per acre use a FAME process (Section 5).

Figure 5. Canola variety yields at WSREC and Davis in the 2009-10 growing season.

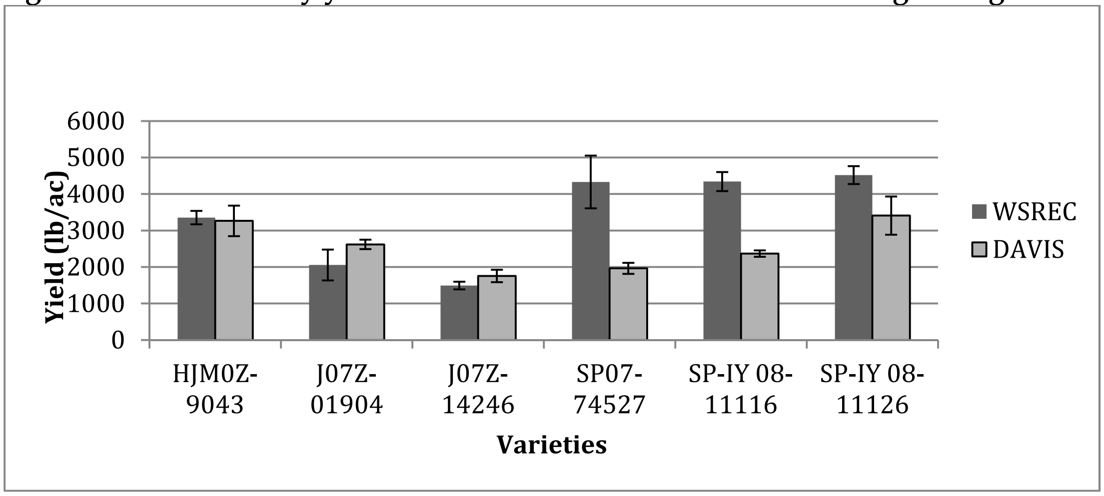


Figure 6. Canola response to N (cv: SP07) at WSREC and Davis in 2009-10.

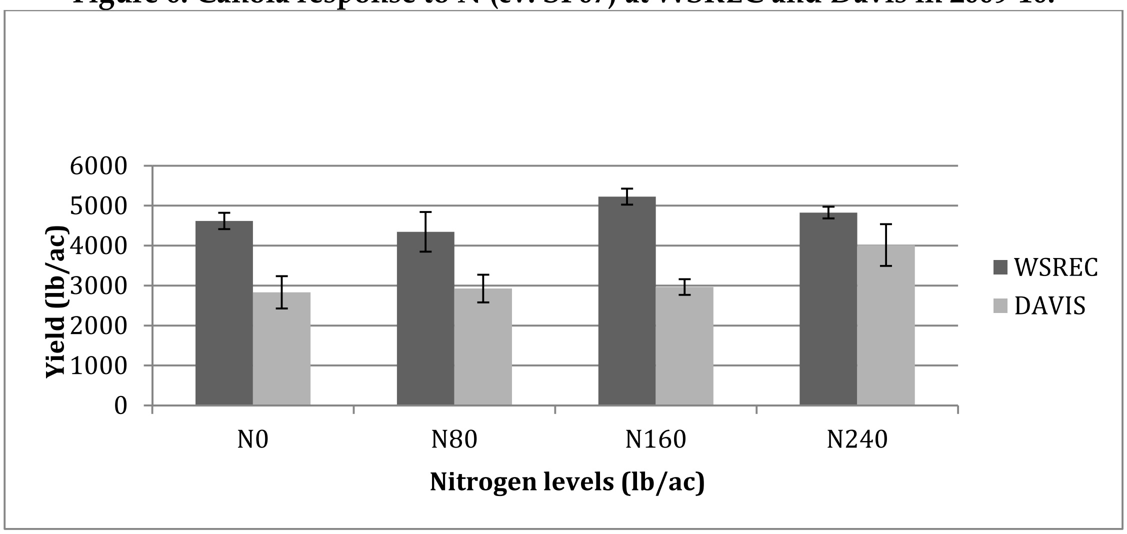


Figure 7. Canola response to supplemental spring irrigation plus rainfall (I) compared to treatments that were not irrigated in spring (NI) at WSREC and Davis in the 2009-10 growing season.

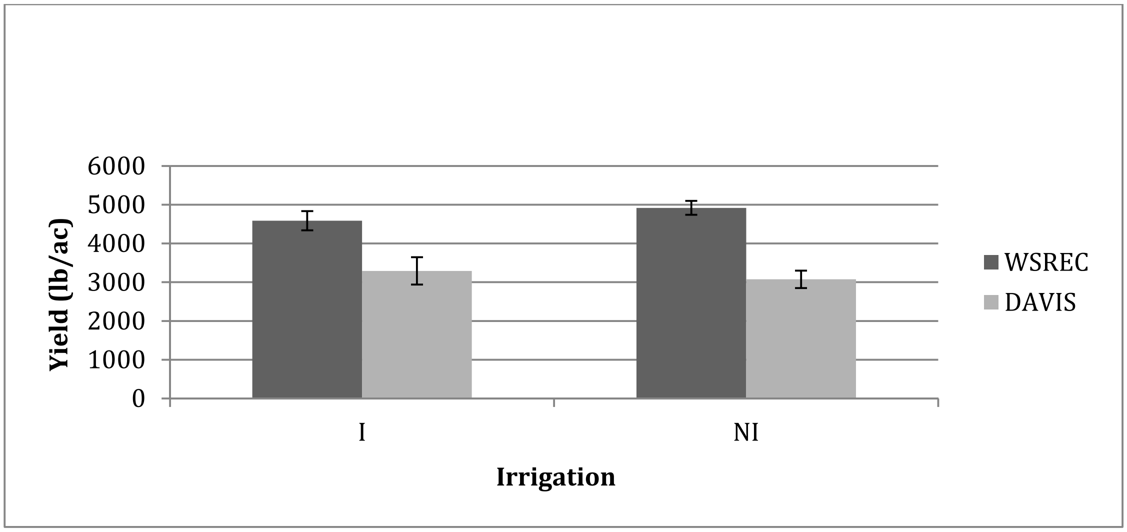


Figure 8. Canola seed oil contents by variety at WSREC and Davis in the 2009-10 growing season.

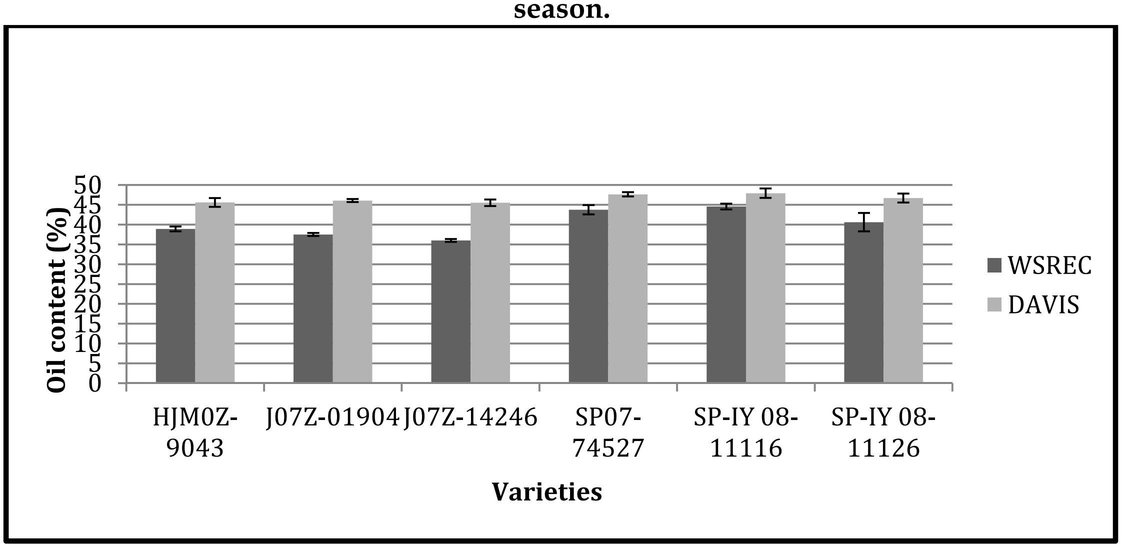


Figure 9. Canola oil content in response to N fertilizer in SP07 at WSREC and Davis in the 2009-10 growing season.

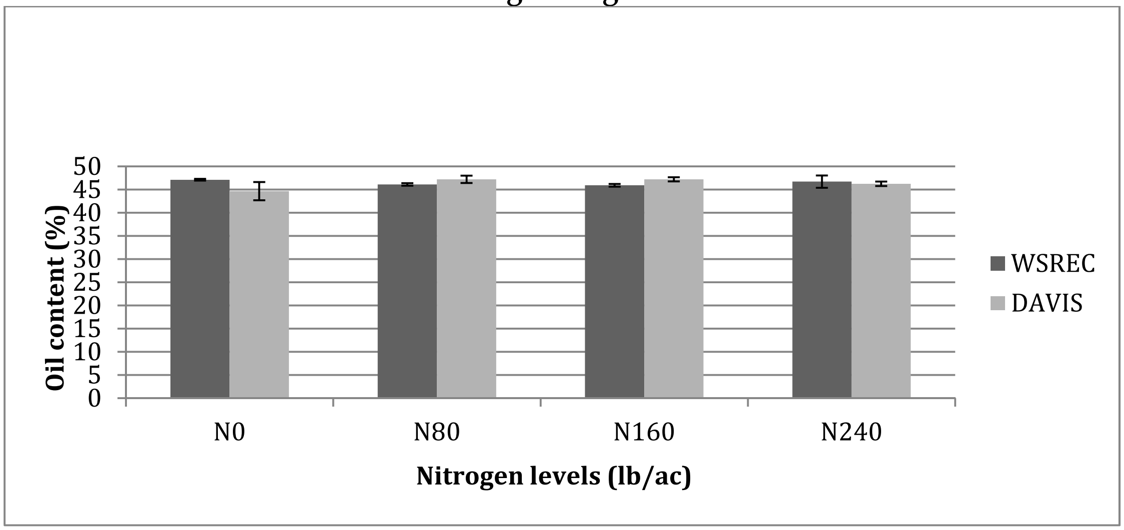


Figure 10. Canola oil content in response to supplemental spring irrigation in SP07 at WSREC and Davis in the 2009-10 growing season.

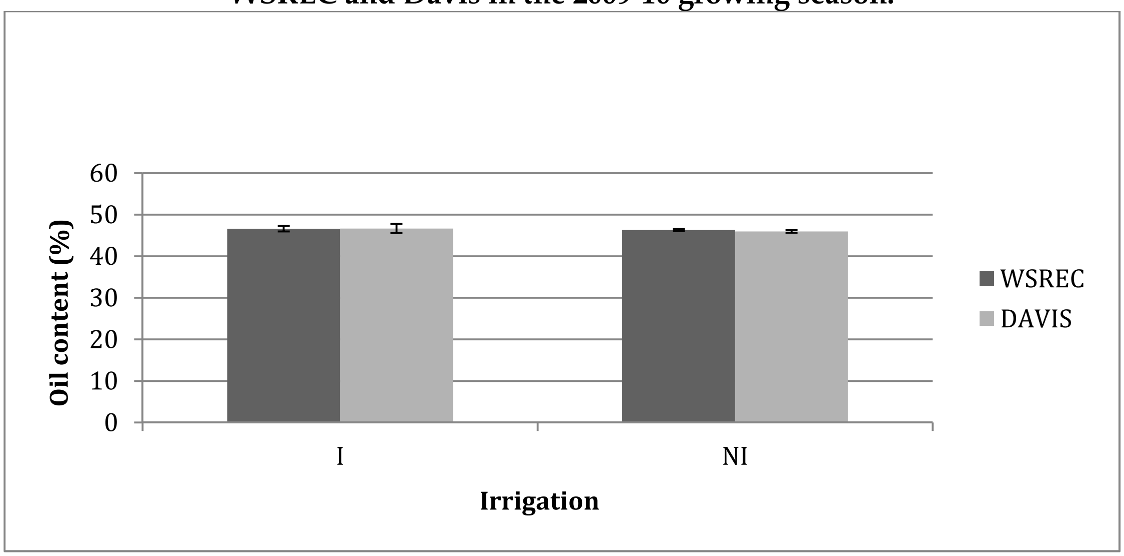
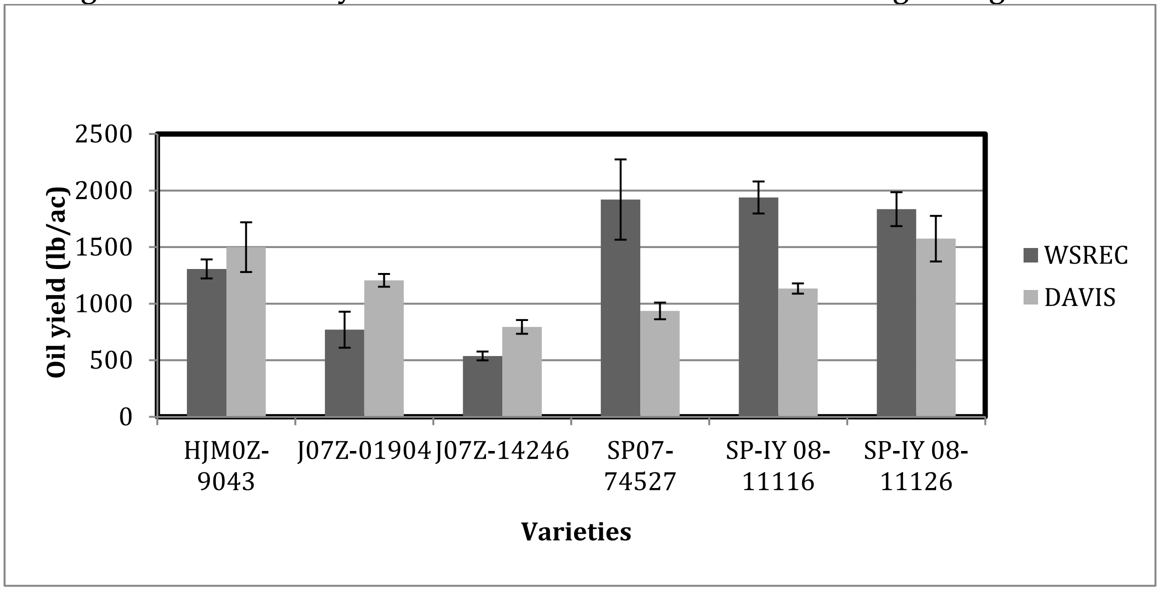


Figure 11. Canola oil yield at WSREC and Davis in the 2009-10 growing season.



2010-11 Trials.

A similar set of trials to 2009-10 were conducted at Davis and WSREC during the 2010-11 growing season. This was an exceptionally wet and cold year, especially at the Davis location, and results were significantly different between years, especially at Davis (Appendix A). In 2010-11, Cibus, Inc. submitted varieties for testing, as did Viterra. HJM1Z-0029 was a *B. juncea* variety, all others were *B. napus*. At Davis, significant rainfall occurred into June and there were a large number of freezing nights, especially in February. Freezing occurred in March and April as well. These factors combined to reduce crop yield at Davis much below those observed in all other years of the trials. Similarly, cold weather affected crop yield at WSREC, but not as much as at Davis. Precipitation levels were much less at WSREC as well (Appendix A). The combination of both cold temperatures in spring during flowering and seed development with wet soils was especially disadvantageous for canola, so responses at Davis were of interest primarily as an example of extreme weather effects.

Variety yields at WSREC were highly variable, but the best variety yields were similar to those observed in the previous year (Figure 12). N response was minimized due to lower overall yields (Figure 13). A single spring irrigation increased seed yield at WSREC by approximately 500/ac (Figure 14) but no supplemental irrigation was applied at Davis in spring due to constant spring rains. Seed oil contents were similar to the previous year at both locations with Davis resulting in higher oil contents than western Fresno County (Figure 15). N application did not affect oil content at either location (Figure 16). Similarly, oil yields were not affected by N application at WSREC (Figure 17), but supplemental irrigation in spring did improve oil yields modestly (Figure 18).

Figure 12. Canola variety yields (and s.e.) at Davis and WSREC in the 2010-11 growing season.

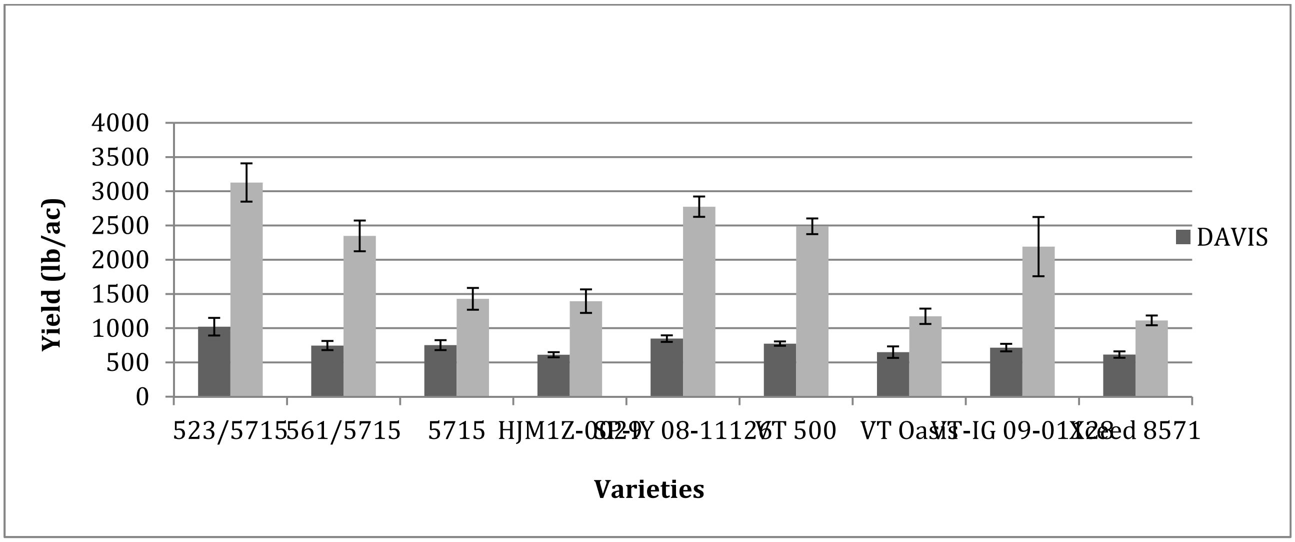


Figure 13. Canola yields (VT 500) in response to N fertilizer rates at Davis and WSREC in the 2010-11 growing season.

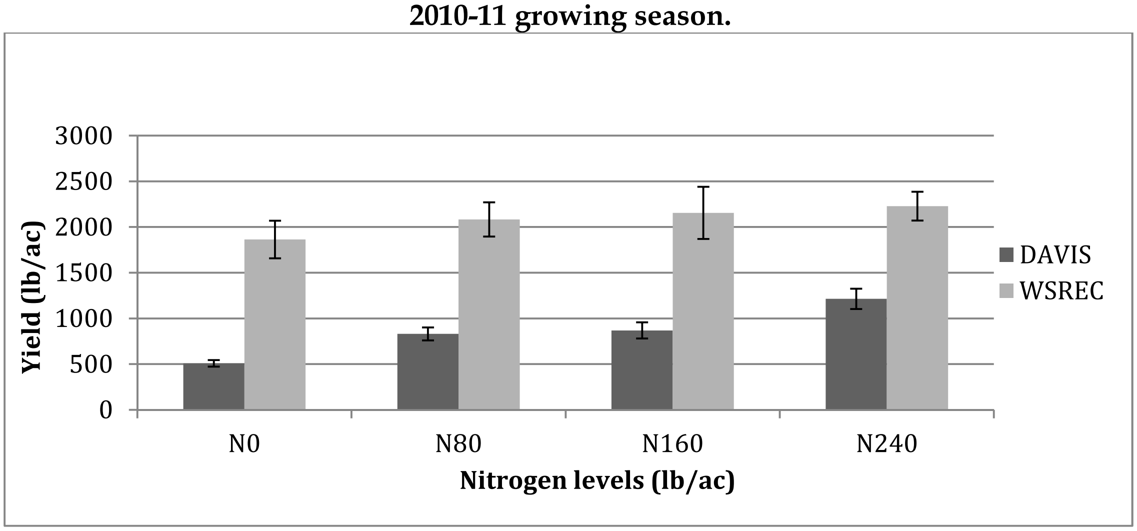


Figure 14. Canola yields (VT 500) in response to supplemental spring irrigation at WSREC in the 2010-11 growing season. There was no supplemental irrigation at Davis due to late season rainfall.

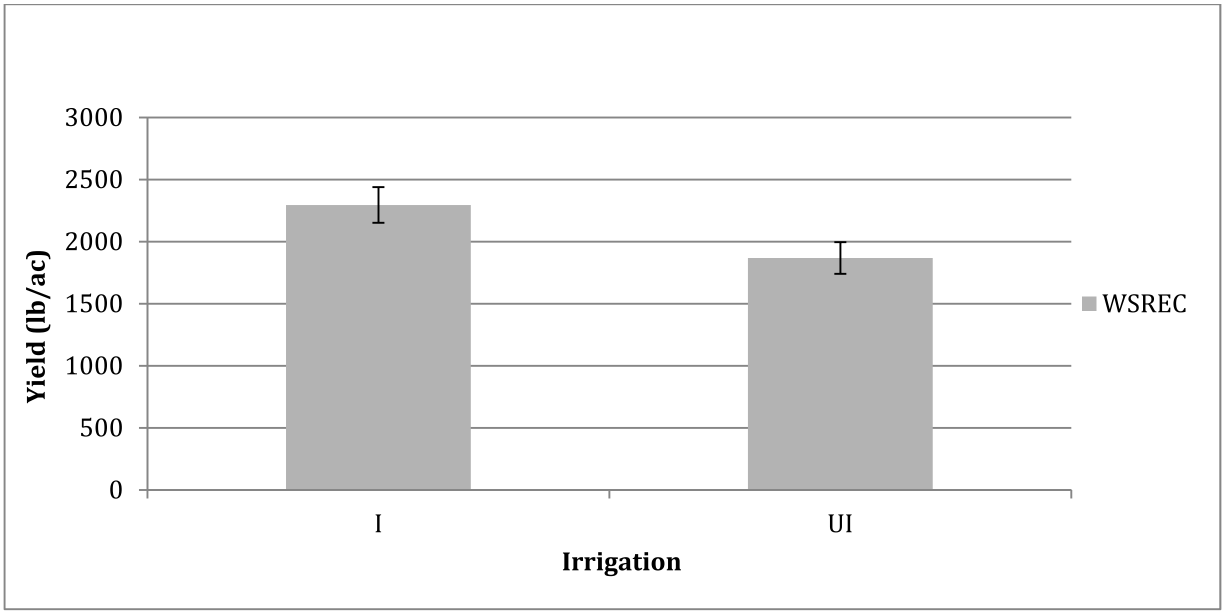


Figure 15. Canola oil content by variety at Davis and WSREC in the 2010-11 growing season.

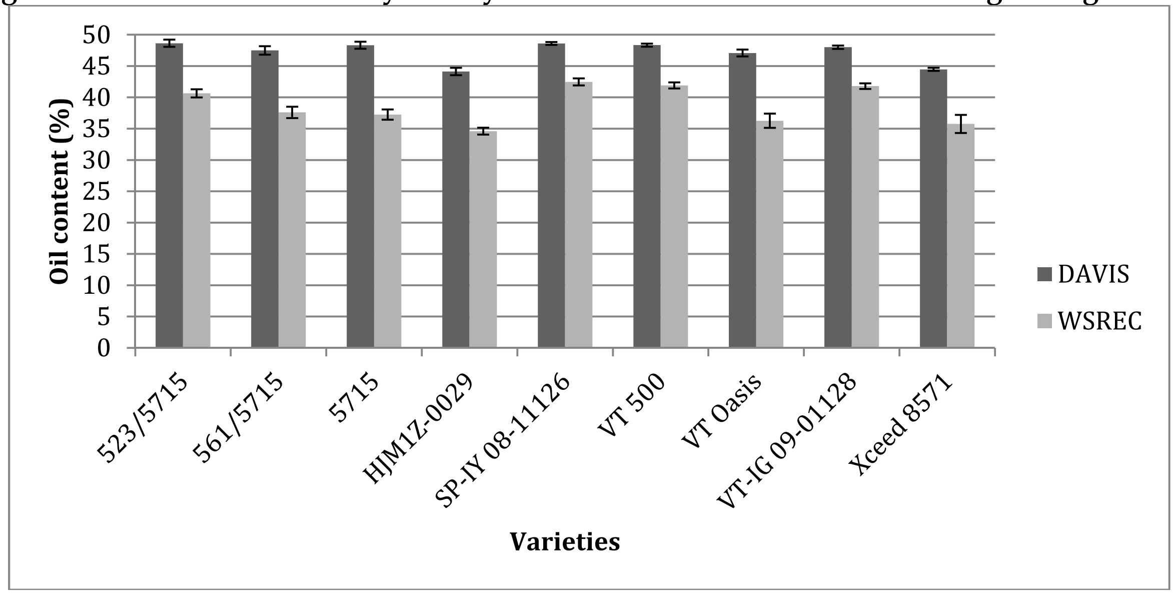


Figure 16. Canola oil content (VT 500) in response to N fertilizer rates at Davis and WSREC in the 2010-11 growing season.

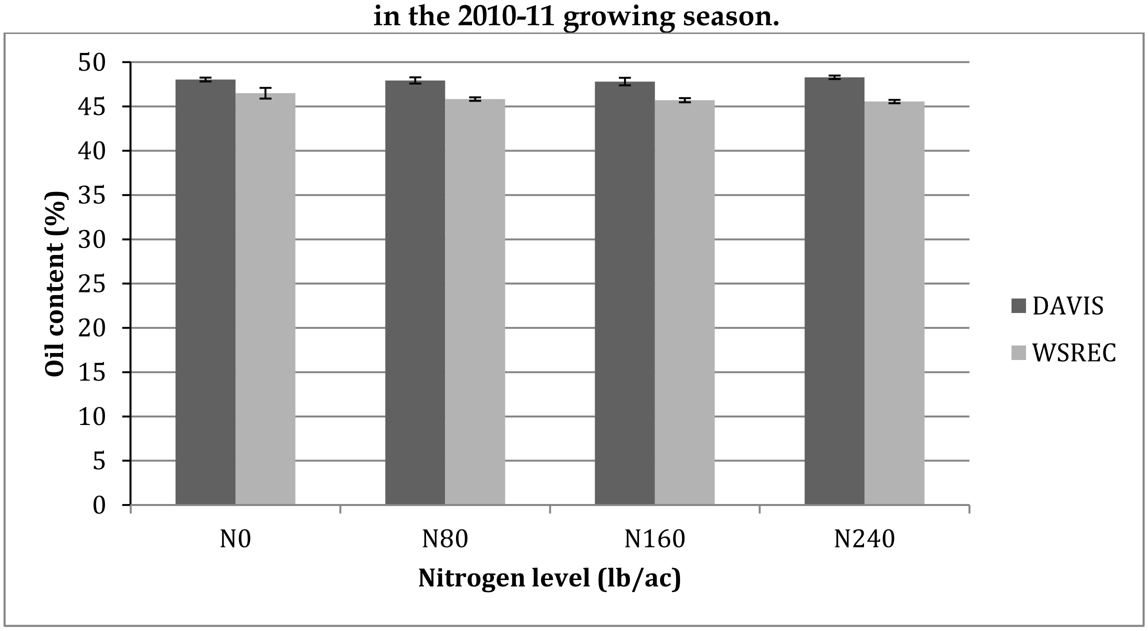


Figure 17. Canola oil yields (VT 500) in response to N fertilizer rates at Davis and WSREC in the 2010-11 growing season.

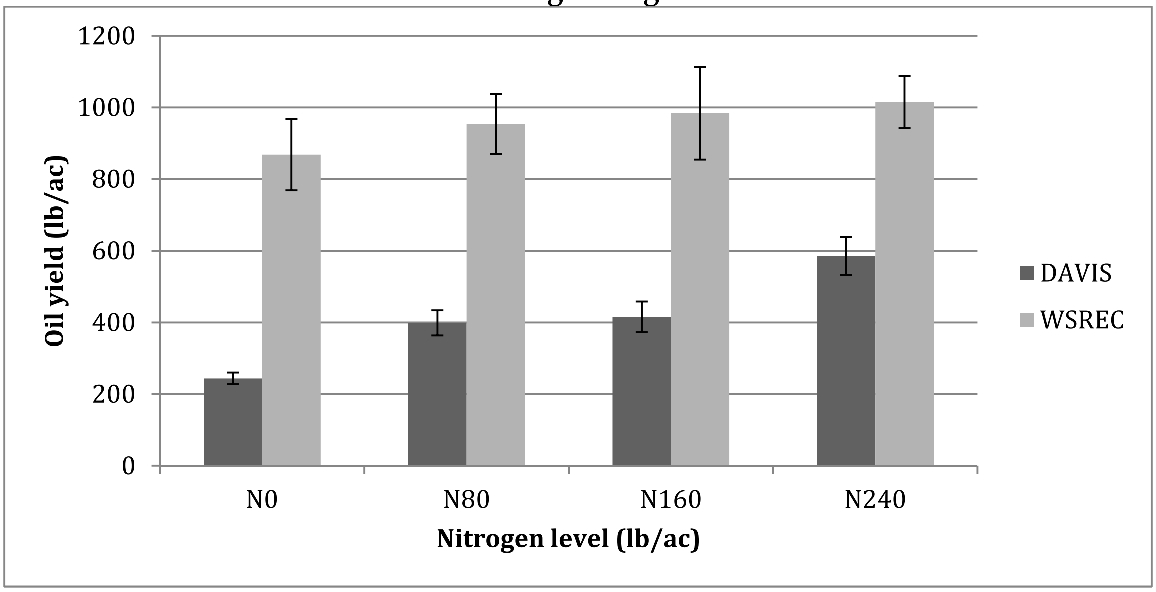
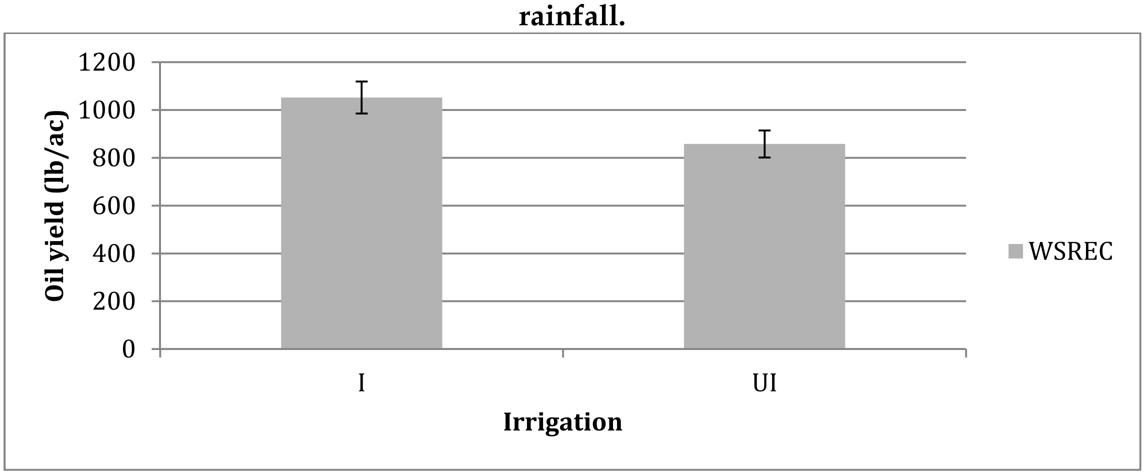


Figure 18. Canola yields (VT 500) in response to supplemental irrigation at WSREC in the 2010-11 growing season. There was no supplemental irrigation at Davis due to late season rainfall.



2011-12 Trials.

Fewer companies submitted varieties for testing in 2011. Viterra provided only one entry in 2011 in time for planting due to an apparent change in policy concerning patents that took the company some time to resolve. Kaiima, an Israeli company, provided three new varieties for testing. Two planting dates were compared, the last week of October and middle November. There were no significant differences between the planting dates. Optimum N fertilizer levels at Davis were between 160 and 200 lb N per acre. Lower levels of fertilizer N were required at WSREC (less than or equal to 160 lb/ac) where crop growth was more restricted. Late season irrigation increased canola yields at WSREC by approximately 400 lbs per acre. No response was observed at Davis with late season rains. Oil perecent varied from 35.2 to 44.1 % and averaged 38.3 % overall for both sites and all varieties.

Figure 19. Variety trial yields (lb/ac) in the 2011-12 growing season.

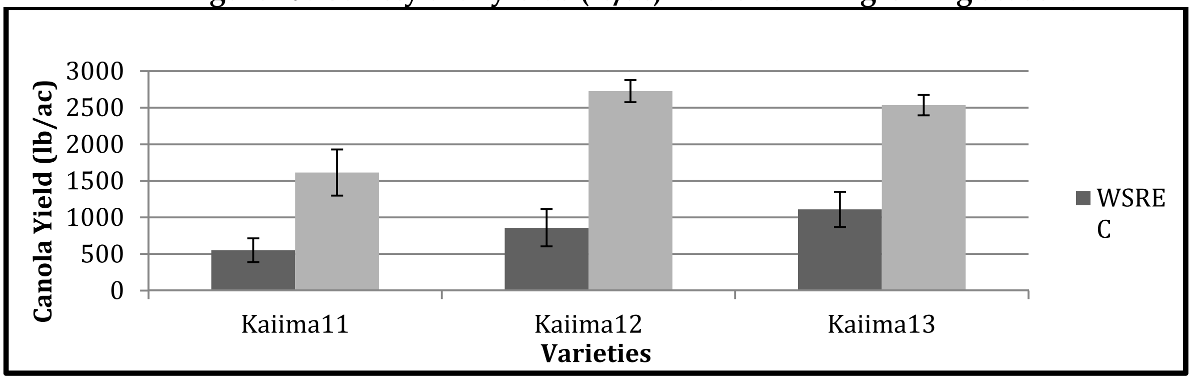


Figure 20. Variety trial yields (lb/ac) in the 2011-12 growing season.

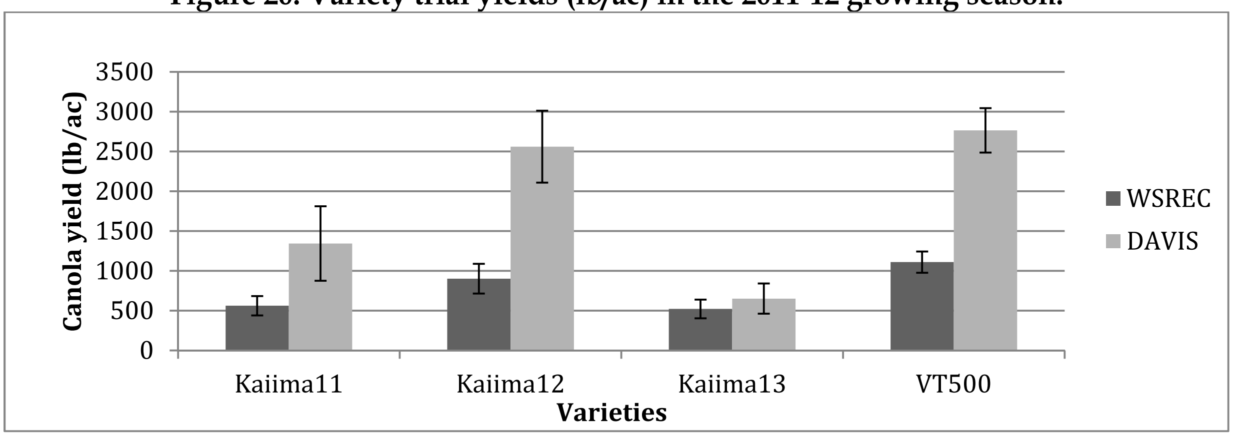


Figure 21. Canola response to N in the 2011-12 growing season. Damage from a residual herbicide appeared to have limited canola response at the WSREC location.

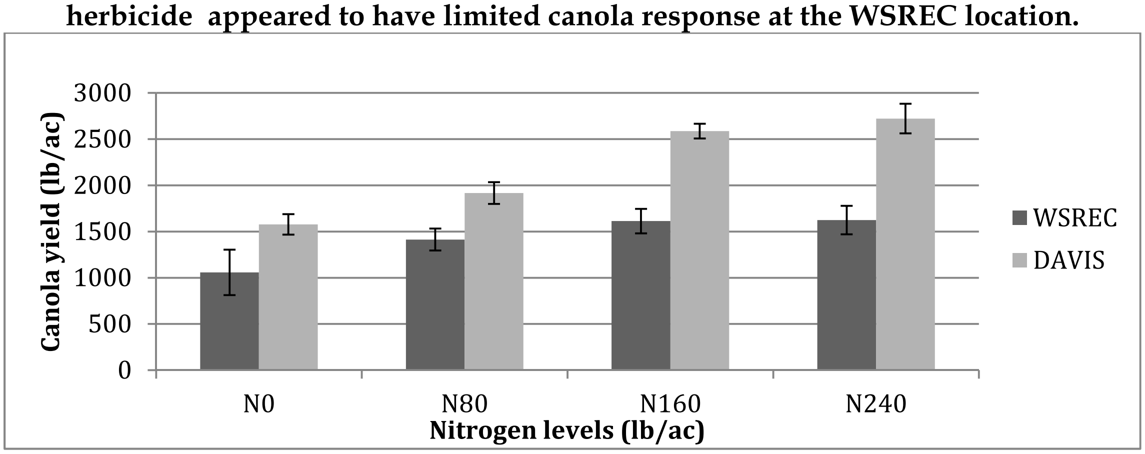
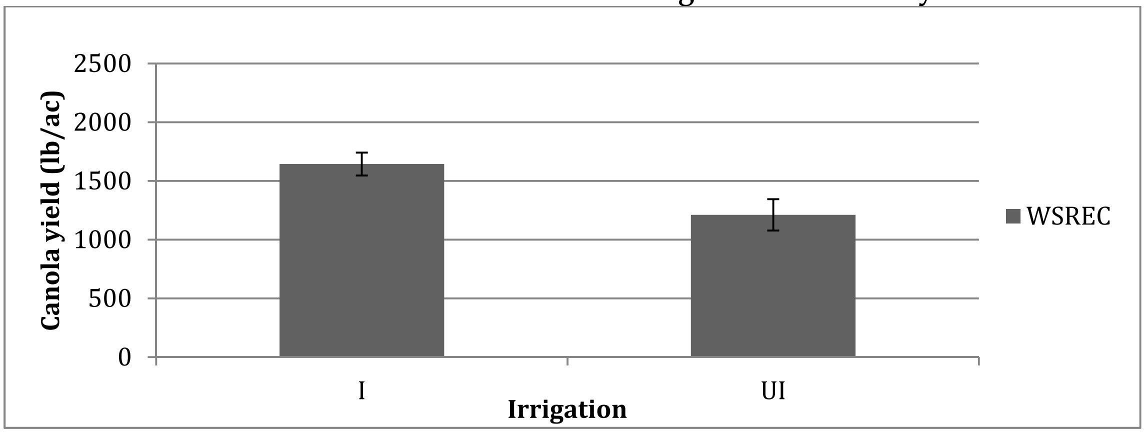


Figure 22. Canola response to late season irrigation at WSREC in the 2011-12 growing season. Late season rains at Davis made irrigation unnecessary.



Special planting date and seeding rate trials in 2010-11

At Davis and WSREC in 2010-11, different planting dates and seeding rates were evaluated. It was hypothesized that an earlier planting date might result in larger yields and earlier maturity, allowing for double cropping. The 2010-11 growing season was beset with above average rainfall throughout the growing season and lower than average temperatures. Much more rainfall fell at Davis than at WSREC and temperatures were also lower there on average. At Davis, in a cold and wet year, earlier planting resulted in better performance, though yields were smaller than in all the other years during which these trials were carried out. Similarly at WSREC, even 10 days earlier planning in fall 2010 resulted in larger yields. In this case yields were much larger than at Davis and similar to other years' results, suggesting that very high levels of rainfall and low temperatures at establishment will limit canola performance. Seeding rate responses varied, but there appleared to be no advantage for rates greater than 4 lbs per acre (Figure 23, 24).

Figure 23. Planting dates and seeding rate comparisons in Davis in the 2010-11 growing season.

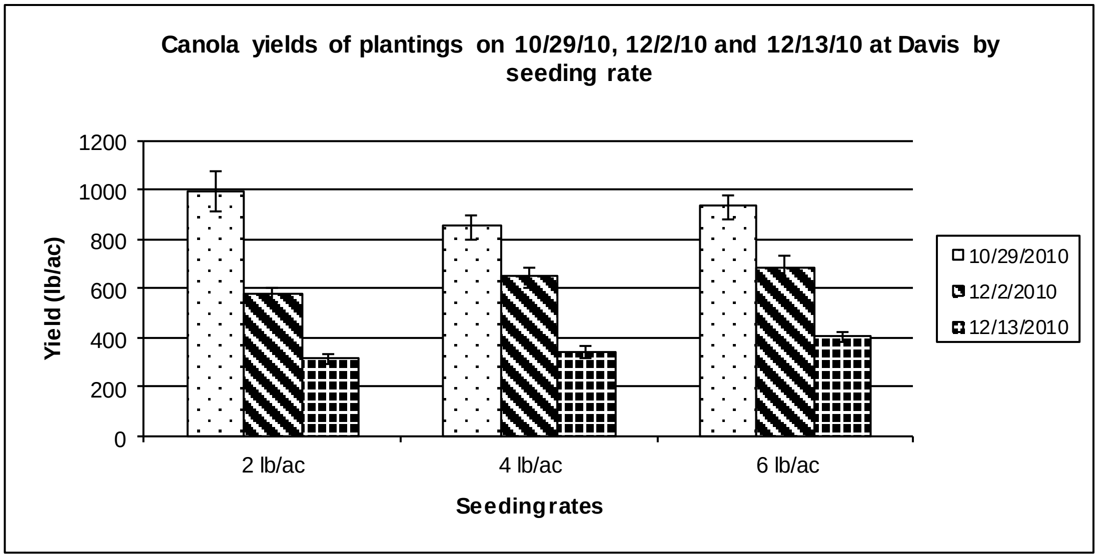
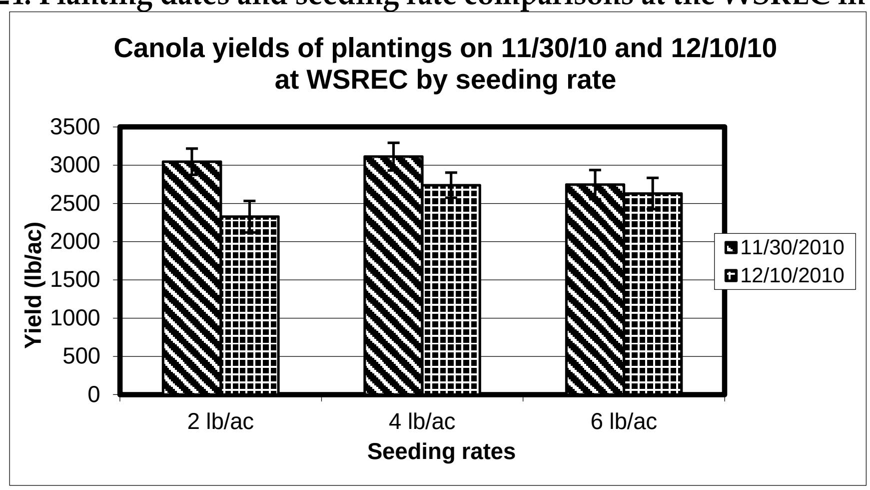


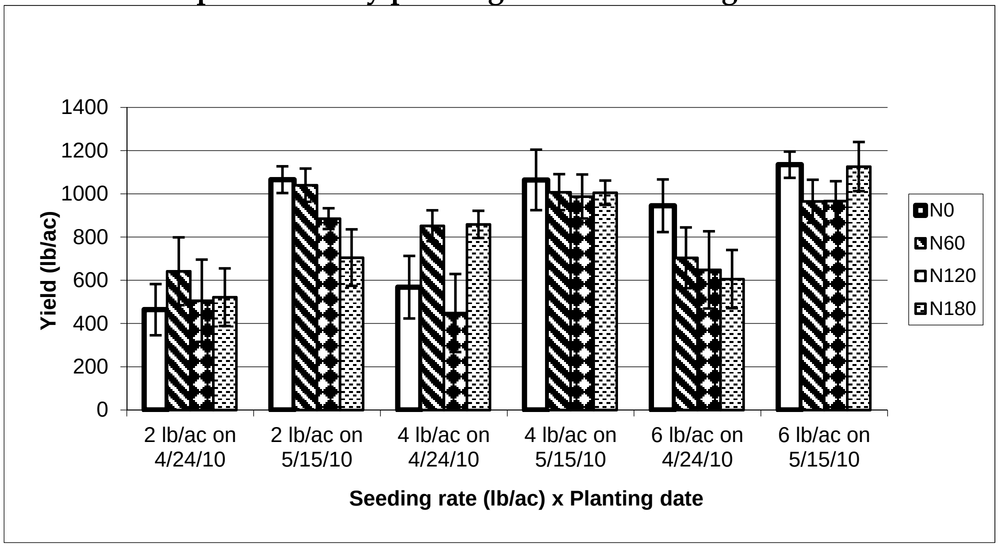
Figure 24. Planting dates and seeding rate comparisons at the WSREC in 2010-11.



Macarthur results (2010) (Dan Marcum-UCCE, Lassen County).

Macarthur is located in Lassen County and has a continental climate with freezing temperatures in winter and mild summers (Appendix A). Brassica oilseed crops are spring-planed annuals at this location. In 2010, two planting dates were compared and three seeding rates (Figure 25). Higher seeding rates were hypothesized to compensate for weed pressure and a short growing season at that location. Four different N rates were compared (0, 60, 120, and 180 lbs of N per acre). Plots were irrigated. Plots were hand-harvested. Yields were larger when planted in mid-May than in late April. Yields were higher at 4 and 6 lbs per acre rates than at 2 lb/ac rates, and there was no response to N above 60 lbs N per acre at the realtively low observed yield levels at this site.

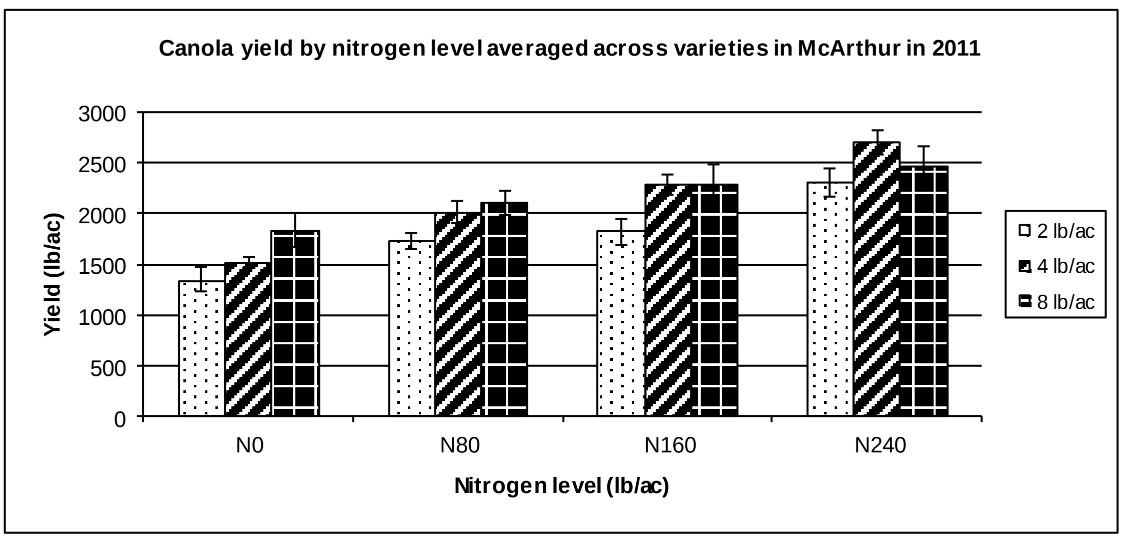
Figure 25. Canola response to N by planting date and seeding rate in Macarthur in 2010.



Macarthur (2011) (Dan Marcum-UCCE, Lassen County).

A similar set of trials was carried out in Macarthur in 2011, except that all plots were planted in mid-May, and the highest seeding rate was increased to 8 lbs per acre (Figure 26). Yields were significantly better. Higher yields influenced all crop responses. There was no difference in yield between 4 and 8 lb/ac planting rates, but higher rates were superior to 2 lb per acre rates at this location, as in 2010. At the 4 lb/ac seeding rate, yields increased linearly with N application up to 240 lb N/ac in this year.

Figure 26. Yield by seeding rate and N rate in Macarthur in 2011.



Discussion: Multi-year comparisons and general conclusions.

A large amount of variance was observed among the divers varieties tested during these trials, and in response to large differences in climate from year to year. In most years, canola yields in the lower Sacramento Valley location at Davis averaged 2.25 t/ac of seed, with high oil percentages on average greater than 46%. The best yielding varieties had yields greater than 3.0 t/ac (3,000 lb of seed) (Table 1). In two of three years, 3,000 lb/ac yields were reflective of the upper 10 to 20% of varieties tested. Overall, the oil percentage across sites and years was 43.5%, which is quite high. Assuming that superior varieties can be identified for Sacramento Valley locations, it is reasonable to assume that canola yields can reach that level in most years, except for unusually adverse years, such as the exceptionally wet and cold winter of 2010-11 in Davis. Overall, the diverse varieties tested here reflect the range of materials available from the industry at the current time.

Year to year weather variation affected the yield performance of canola significantly, while oil content was much less variable. Differences in location are also associated with temperature and precipitation differences and can be thought of as additional years of trials. The 2010-11 season also experienced a larger number of days in late winter with freezing temperatures compared to average weather patterns. This cold weather pattern also affected camelina and data for the number of exceptionally cold days in winter that year is reported in Table 6 below. In contrast to the Davis site, there was not sufficient cold weather to adversely affect canola yields to the same degree at WSREC in 2010-11. In 2011-12 at WSREC, yields were much lower than otherwise observed. Similar to results reported for Camelina below, MCPA herbicide residual damage is a likely explanation for low yields that year. WSREC yields for both canola and camelina in 2011-12 should be discounted in evaluating the overall results of these multi-year trials for that reason.

Overall, seed yields are larger on average at the WSREC than at Davis, though not consistently so, suggesting the milder winter temperatures there on average compared to Davis favorably affect yields, most likely by creating conditions favorable for seed formation. Seed oil content, however, tends to be lower on average at WSREC than at Davis. Temperatures rise more quickly in spring at WSREC than at Davis, limiting the length of time oil can accumulate in seeds compared to Davis.

These trials demonstrate that canola is likely to perform well at most Central Valley locations with reasonable agricultural soils. As a winter annual crop, it may be produced in higher rainfall regions with little to no irrigation, and in lower rainfall areas of the San Joaquin Valley, with no more than 1 acre foot of irrigation water per year, except under extremely dry or arid conditions. This makes it a promising alternative crop where irrigation water is limited.

When canola reaches yields equal to or greater than 1 t/ac, it requires a minimum of 150 lb N /ac unless soils at any given site have large amounts of N remaining from previous crops and fertilization practices.

Canola planted in spring and harvested in fall in Lassen County resulted in yields greater than 1t/ac in 2011. There have been fewer trials at this location, but good management practices including irrigation during summer should allow for commercially acceptable yields at that location as well.

Table 1. Canola variety trail yields (2009-12) at Davis.

Year	Number	Mean	Std. Dev.	Std. Err. Mean	Lower 5%	Upper 5%	
2009-10	24	2560	820	167	2220	2910	
2010-11	36	750	170	29	690	810	
2011-12	16	1830	1110	279	1240	2420	
Quantities							
Level	Minimum	10%	25%	Median	75%	90%	Maximum
2009-10	1472.2	1550	2120	2390	2890	3890	4740
2010-11	409.5	540	620	740	830	1000	1200
2011-12	207.1	440	710	1880	2850	3420	3500

Table 2. Canola variety trial yields (2009-13) at WSREC.

Year	Number	Mean	Std. Dev.	St. Err. Mean	Lower 5%	Upper 5%	
2009-10	24	3350	1390	283	2760	3930	
2010-11	36	2000	810	135	1730	2280	
2011-12	16	770	360	90	580	960	
2012-13	63	3020	940	136	1460	4630	
Quantities							
Level	Minimum	10%	25%	Median	75%	90%	Maximum
2009-10	1010	1320	1990	3620	4610	5030	5610
2010-11	960	980	1280	1930	2660	3100	3880
2011-12	270	310	430	810	1020	1380	1470
2012-13	850	1660	2420	3120	3450	4270	5280

Camelina

Camelina (*Camelina sativa*, sometimes called false flax) is also a member of the mustard family. In recent years it has received attention and is being produced in many of the Great Plains States and in the Pacific Northwest (Pavlista et al., 2012). In most locations where it is produced, it is treated as spring-summer annual, though winter hardy types also are reported to exist. Camelina originated in central Europe. Seeds and capsules of the crop have been found in archaeological excavations from the Bronze Age in Scandinavia. The crop was widely grown in Eastern Europe and Russia up to the early 1940s with some production lasting up to the 1950s, but has a much longer history of cultivation in Europe, reaching back perhaps 2000 years (Schultze-Motel, 1979). It is reported to be genetically diverse (Ghamkhar et al., 2010; Gerhinger et al., 2006). Under cultivation, plants can vary in height from a few inches to more than four feet due to both environmental and genetic influences. Seed weight varies and an average 1000-seed mass varies between 0.7 and 1.6 g. Oil content ranges from 28% to 42% (Putnam et al., 1993). In response to resurgent interest in oil crops for biofuel production, interest in camelina has grown in recent years. It is being grown as a feedstock for bio-jet fuels in the Northwestern states[6].

Previous work in California

To our knowledge, there has been no previous work in California apart from one demonstration trial conducted by Kaffka and Alonso in 2008 near Davis, California. They planted 5 commercially available camelina cultivars in mid-December and harvested the plots in late May 2009. Seed yields varied from 400 to 600 lb per acre. Oil content was not analyzed.

2009-10 Trials

Camelina was planted at both Davis and WSREC in early December 2009 but emergence was weak and irregular at Davis, so plots were abandoned. Using the same seed and equipment at WSREC, emergence was satisfactory. Poor stands at Davis were attributed to the tendency of soils at the research site to crust, planting at too great a depth, and camelina's lack of seedling vigor.

Yields at the WSREC were quite good in May 2010, with some varieties producing more than 2000 lb/ac in small plots (Figure 27). There was no response to N fertilizer in this trial (Figure 28). Seed oil content varied little among the varieties tested (Figure 29), with average oil content

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[6] http://www.newenergyworldnetwork.com/renewableenergynews/by_technology/biofuel_biomass/boeing-alaska-airlines-head-consortium-to-promote-aviation-biofuel-development.html

in seeds (36.8%) similar to others reported in the literature. Oil yields varied from 700 to approximately 1000 lbs per acre (Figure 30), which would result in 100 to 130 gal of biodiesel per acre using the FAME process. Oil content and oil yield did not respond to increasing fertilizer N levels (Figure 31, 32). Supplemental irrigation in spring also had no effect on oil content or oil yield in 2009-10 at WSREC (Figure 33, 34).

Figure 27. Camelina variety trial seed yields in 2009-10 at WSREC.

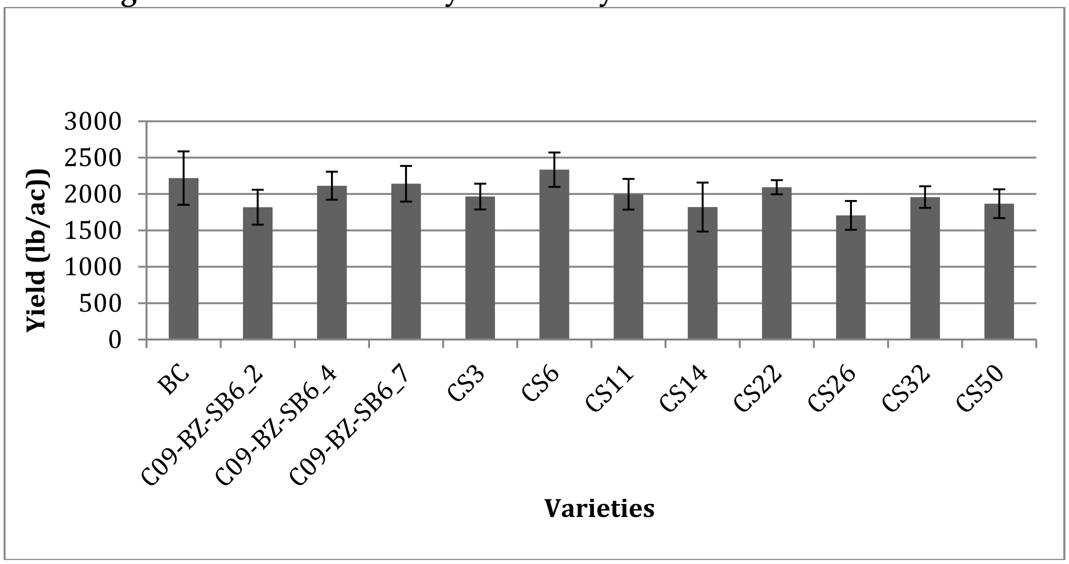


Figure 28. Camelina response to N in 2009-10. There was no significant response.

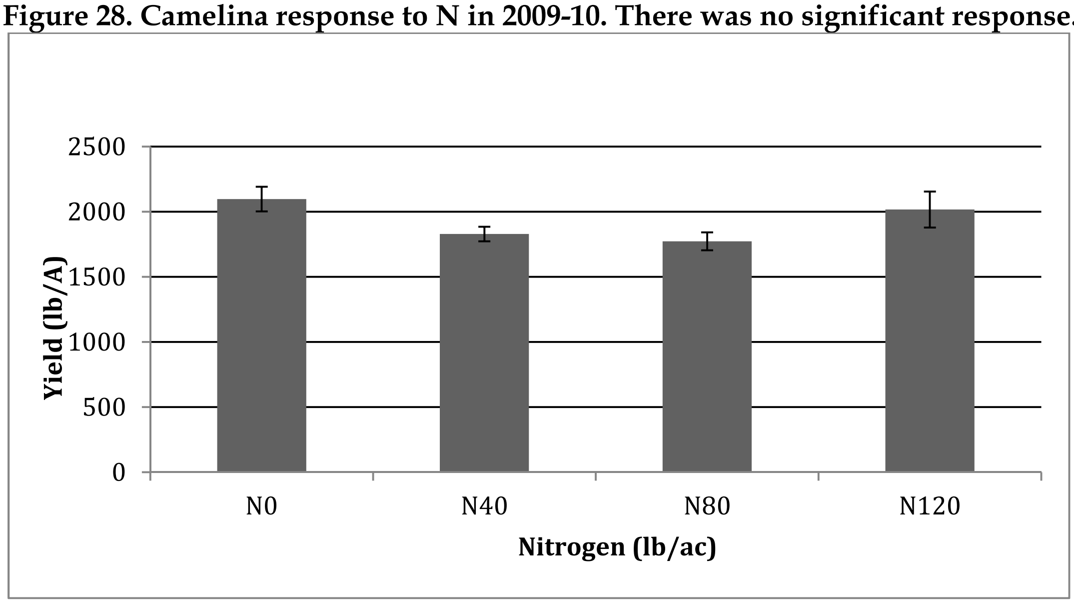


Figure 29. Oil content (%) of Camelina varieties at WSREC.

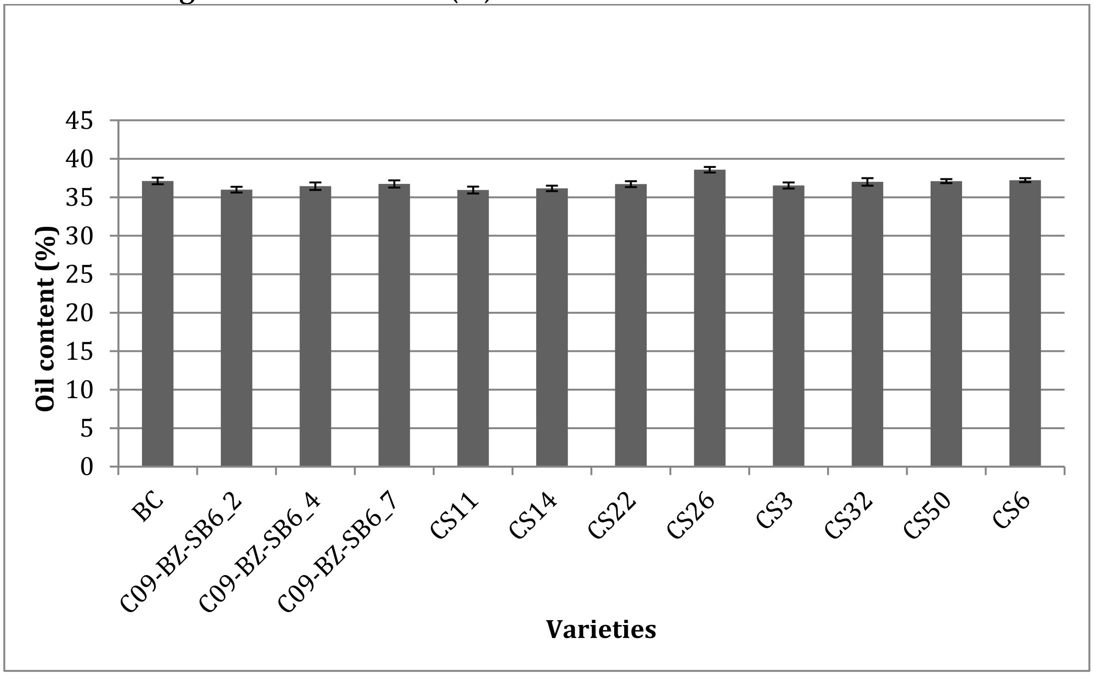


Figure 30. Oil yield (% oil x seed yield) at WSREC in 2009-10.

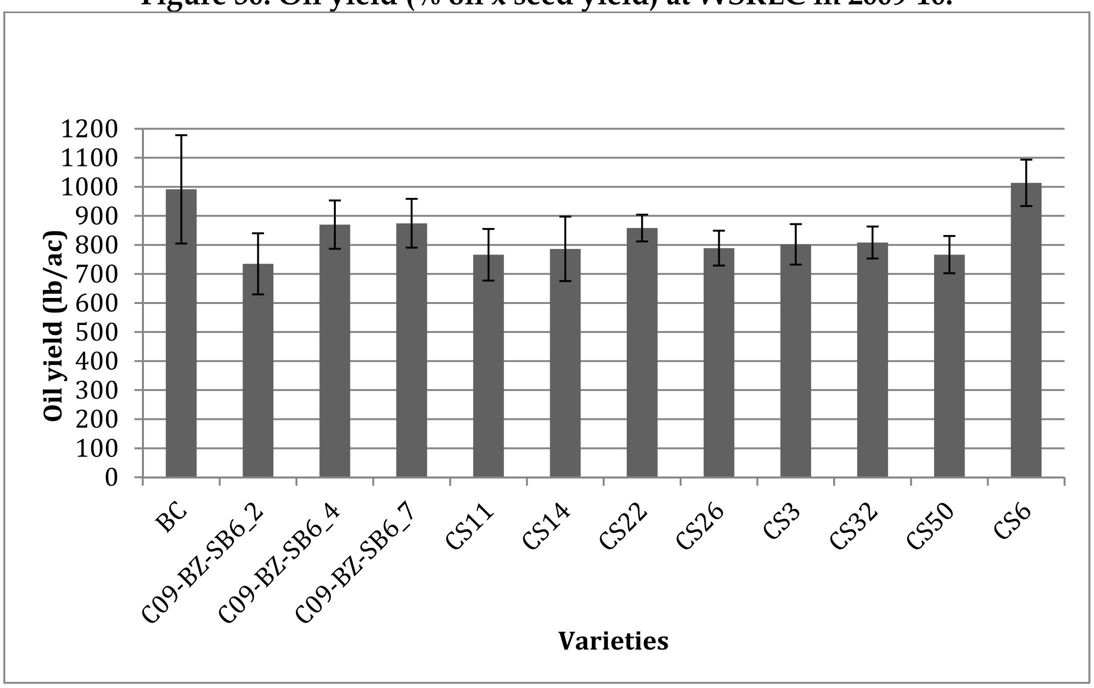


Figure 31. Oil content (%) in response to N fertilizer at WSREC in 2009-10. There was no response to increasing rates of N.

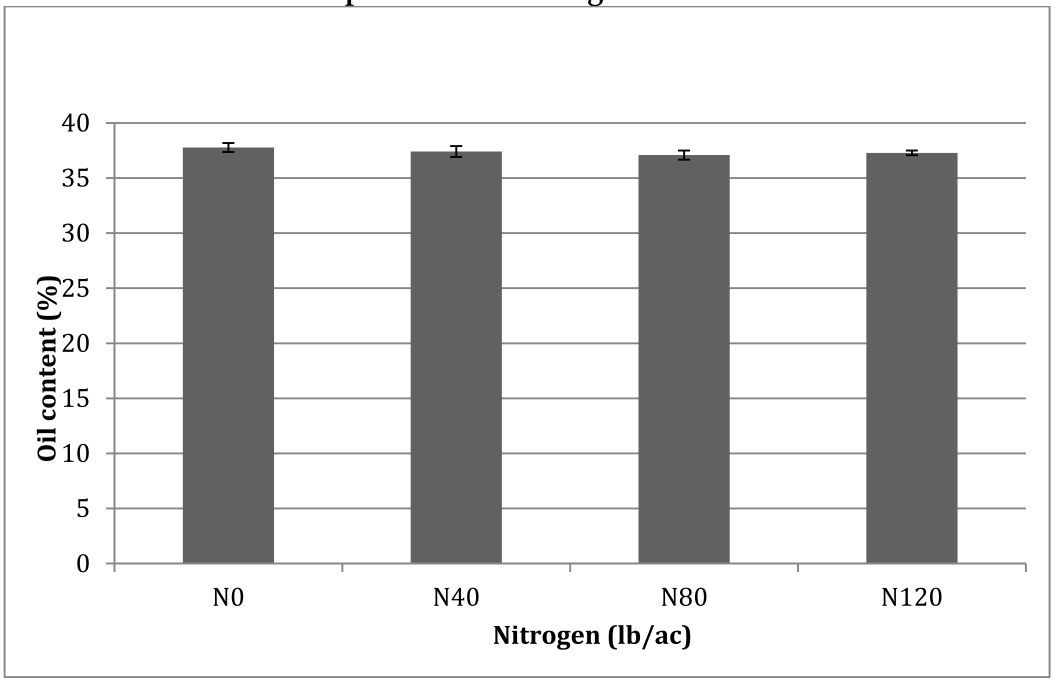


Figure 32. Oil yield in response to N fertilizer at WSREC in 2009-10.

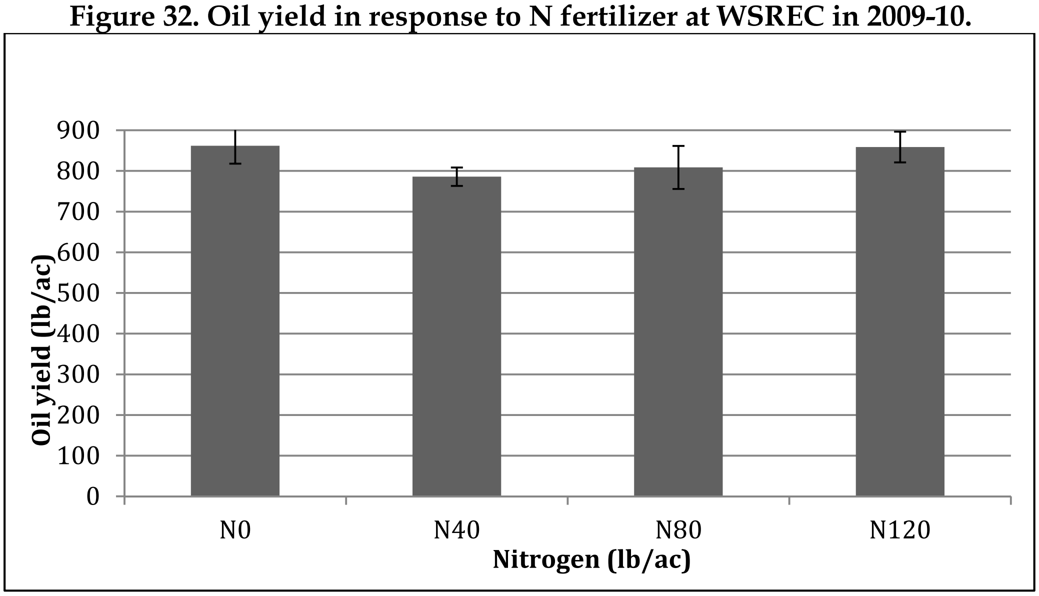


Figure 33. Oil % in response to supplemental spring irrigation at WSREC. There was no significant difference between the treatments.

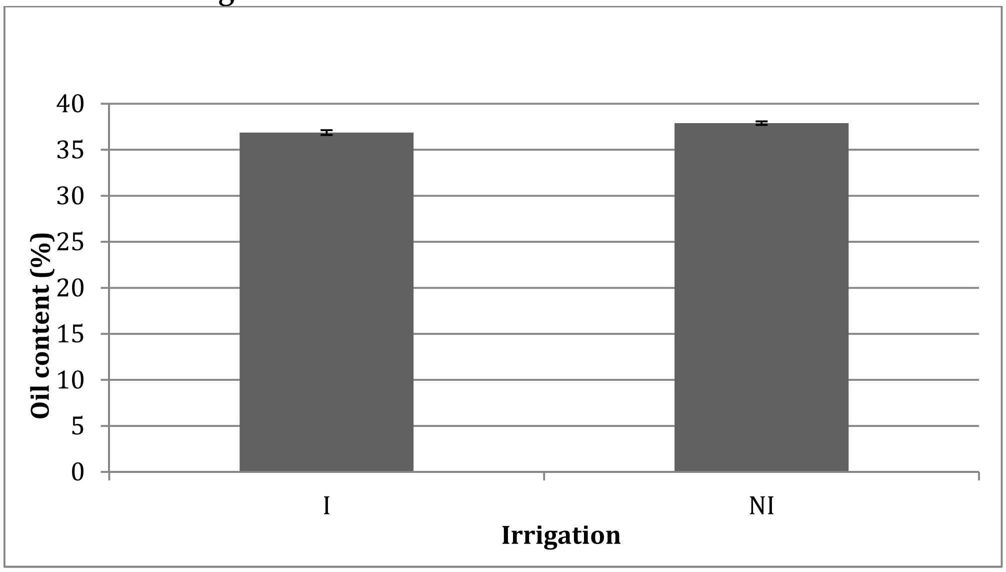
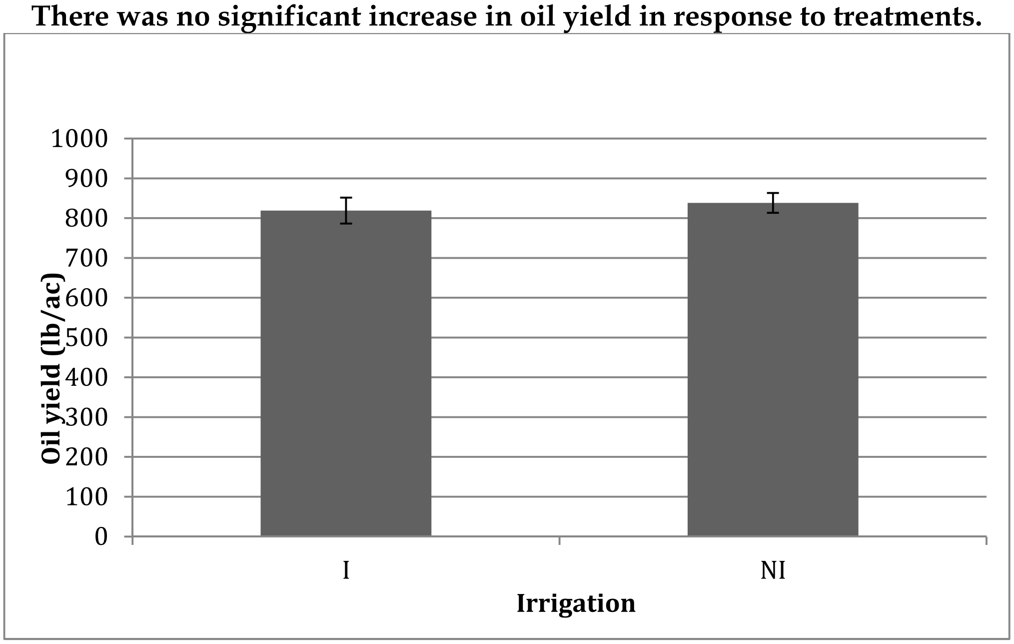


Figure 34. Oil yield in response to supplemental spring irrigation at WSREC in 2009-10. There was no significant increase in oil yield in response to treatments.



2010-11 Trials

Camelina was grown at both Davis and the WSREC in 2010-11. Yields were less than half those observed at the WSREC during 2009-10. Variety yields at WSREC were higher on average at than at Davis (Figure 35). Unlike 2009-10, there was a response to N fertilizer, with maximum yields observed at 80 lb N/ac at both locations. Maximum yields in the N trial were larger than in the variety trial by 600 lb/ac at WSREC and approximately 200 lb/ac at Davis (Figure 36).

Supplemental irrigation had not effect on yield at either location (Figure 37). Seed oil content was higher in 2010-11 than in 2009-10 at both locations, but there were no significant differences among varieties (Figure 38). Oil content was higher on average at Davis than at WSREC. Oil yield did vary among varieties, largely as a function of differing seed yields (Figure 39). Similar to 2009-10, there was no significant difference in oil yield in response to fertilizer N at WSREC, but N applied at both 40 and 80 lbs N/ac increased seed oil yield at Davis (Figure 40).

Figure 35. Variety trial seed yields at Davis and WSREC and 2010-11.

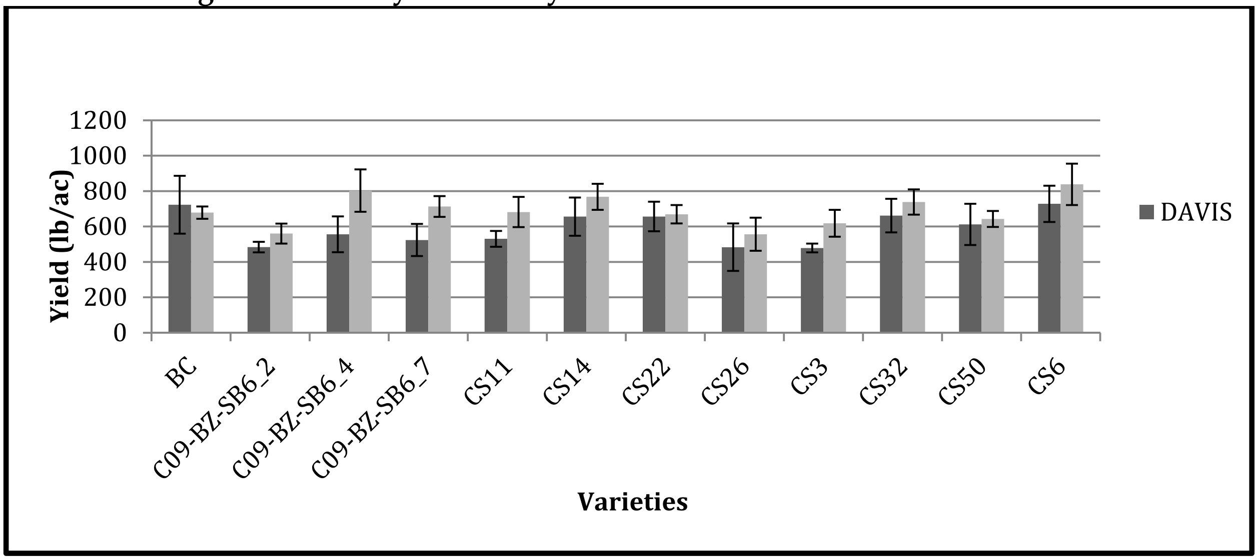


Figure 36. Camelina seed yield response to fertilizer N in 2010-11. In both trials, the highest yields were achieved at 80 lb N/ac.

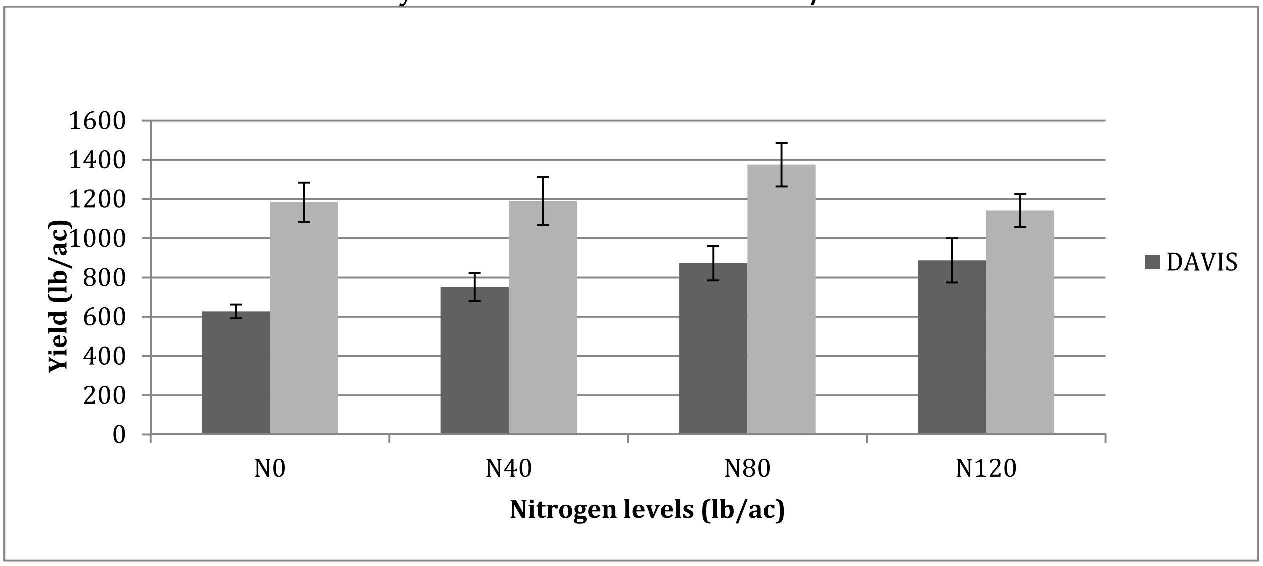


Figure 37. Seed yield response to supplemental spring irrigation at Davis and WSREC. Differences were not significant.

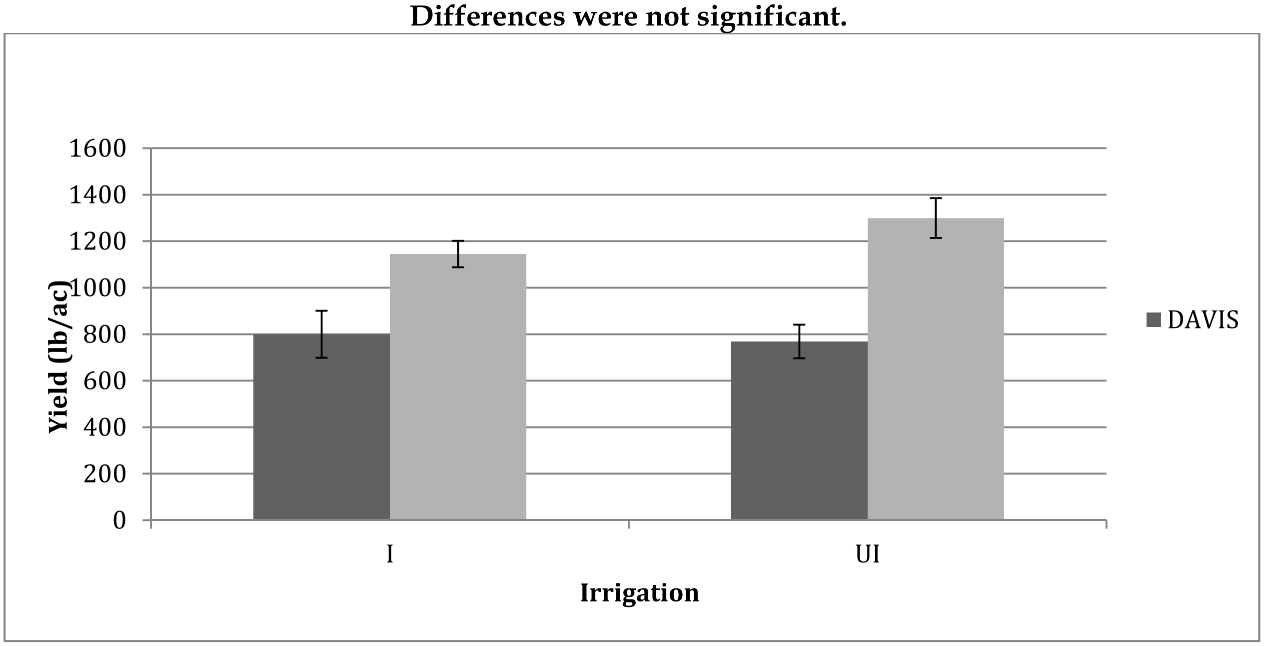


Figure 38. Oil content in variety trials at Davis and WSREC in 2010-11. There were no significant differences among the varieties, but average oil contents were greater in Davis than at WSREC.

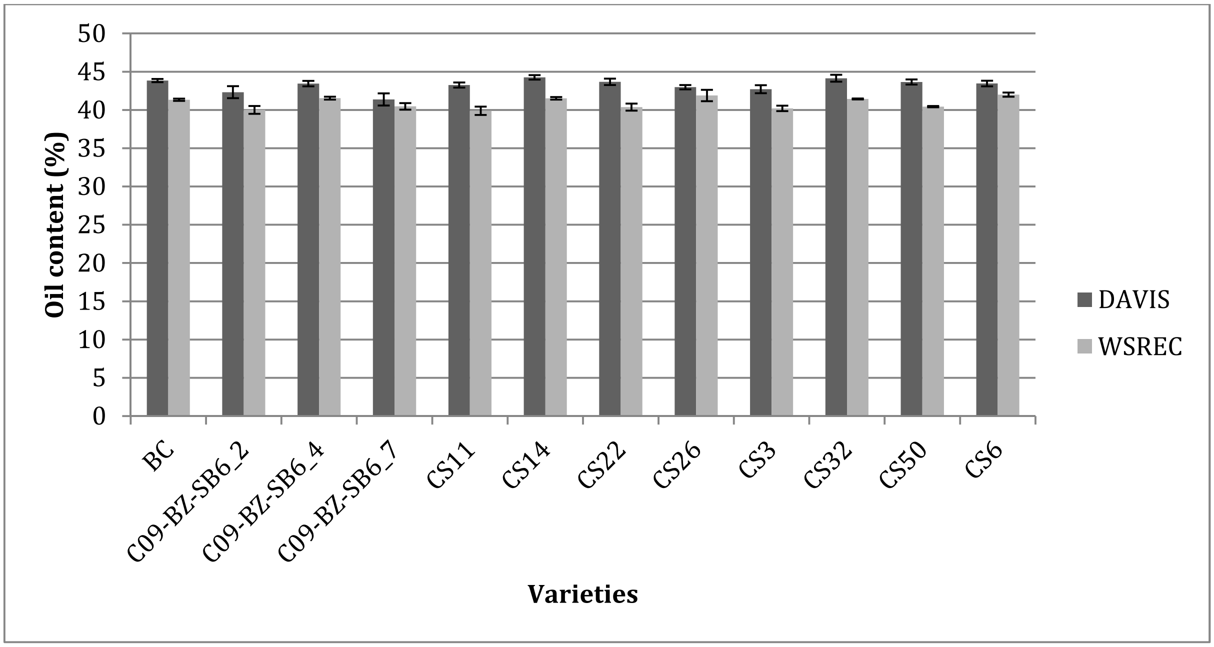


Figure 39. Oil yields at Davis and WSREC in 2010-11.

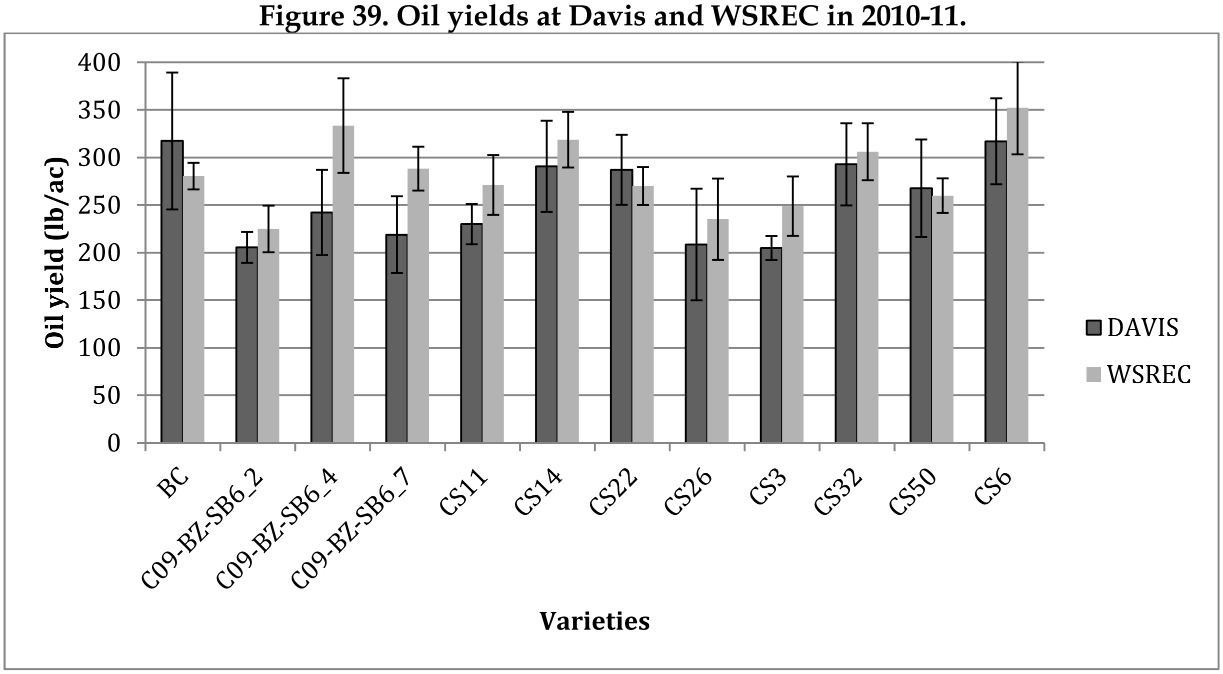
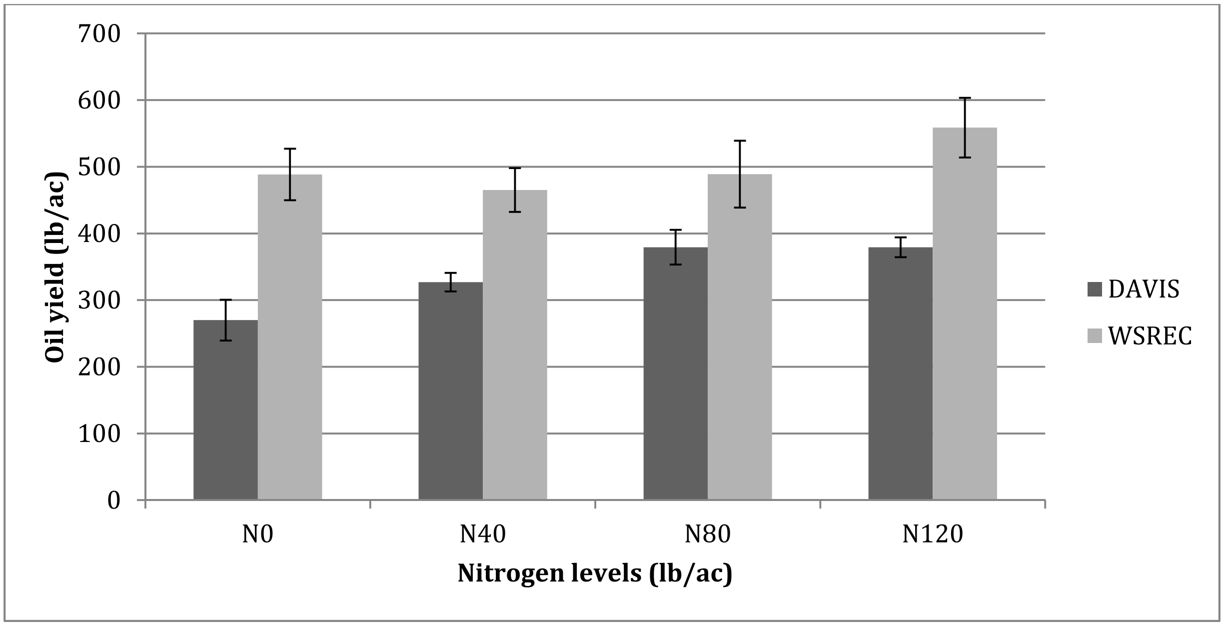


Figure 40. Oil yield (lb / ac) in response to fertilizer N. Maximum yields at Davis were observed at the 80 lb / ac rate. There was no significant response to N at WSREC, similar to 2009-10.



2011-12 trials

Four planting dates were evaluated at Davis and WSREC for camelina in 2011-12 (October, November, December (WSREC only) and January). In addition, at the second planting date, a third site was added, the NRCS Western Plant Materials Center (PMC). The PMC is immediately adjacent to the Consumnes River, on alluvial, coarse-textured soils. Yields for individual planting dates are summarized in Figures 41 to 43. A comparison of variety means across all four planting dates is provided in Figure 44. The highest individual variety yields were achieved at Davis in November compared to other dates. In 2011-12, there was no advantage for earlier or later planting. Yields were uniformly low for all planting dates at WSREC where severe damage from residual herbicides was suspected. Despite low yields, seed oil content was not apparently affected at WSREC. Seed oil contents for all three locations are compared in Figure 45. Seed oil yields for Davis and the PMC are compared inFigure 46. In general oil percent was lowest at the PMC compared to the other locations, and oil yields were lower than at Davis. N response was similarly suppressed at WSREC in 2011-12, while at Davis, maximum yields were observed at 80 kg N/ac (Figure 47). In a separate trial evaluating herbicides, but located at a different location at the field station, highest yields from untreated or grass-herbicide treated plots were closer to 1000 lb/ac, approximately similar to those observed at Davis (Figure 48).

Figure 41. Variety trial seed yields at WSREC and Davis in 2011-12 for an October planting date.

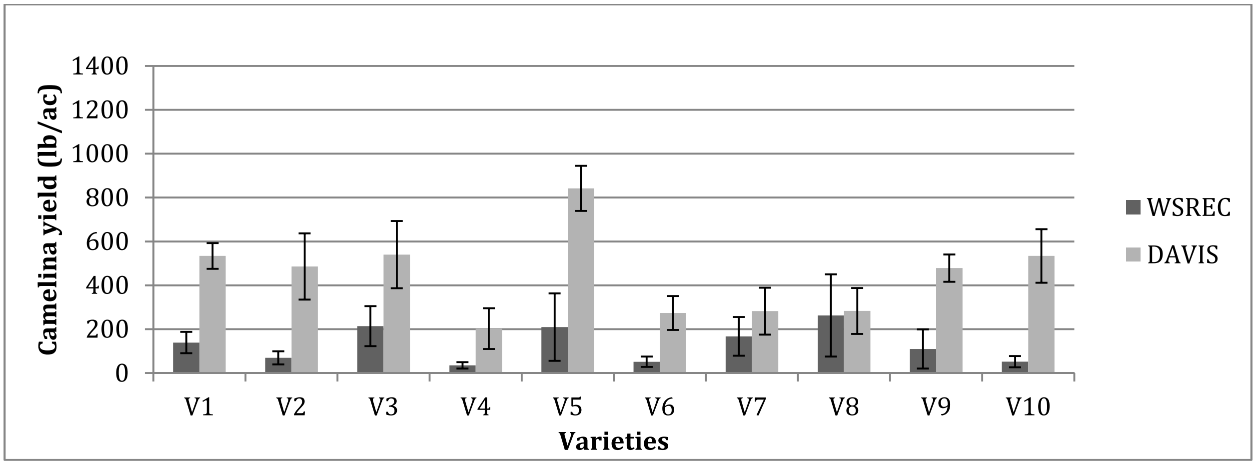


Figure 42. Variety trial seed yields at WSREC, Davis, and the Plant Materials Center near Lockeford. Yields were highest at Davis. Plots at WSREC were adversely affected by residual herbicides.

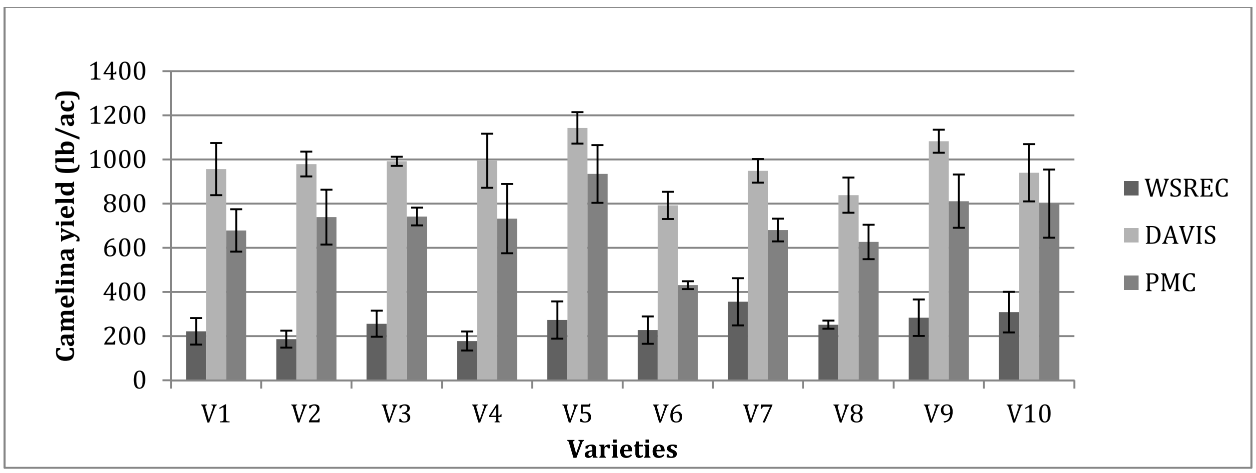


Figure 43. Variety yields at WSREC and Davis for a January planting date at WSREC and Davis in 2011-12.

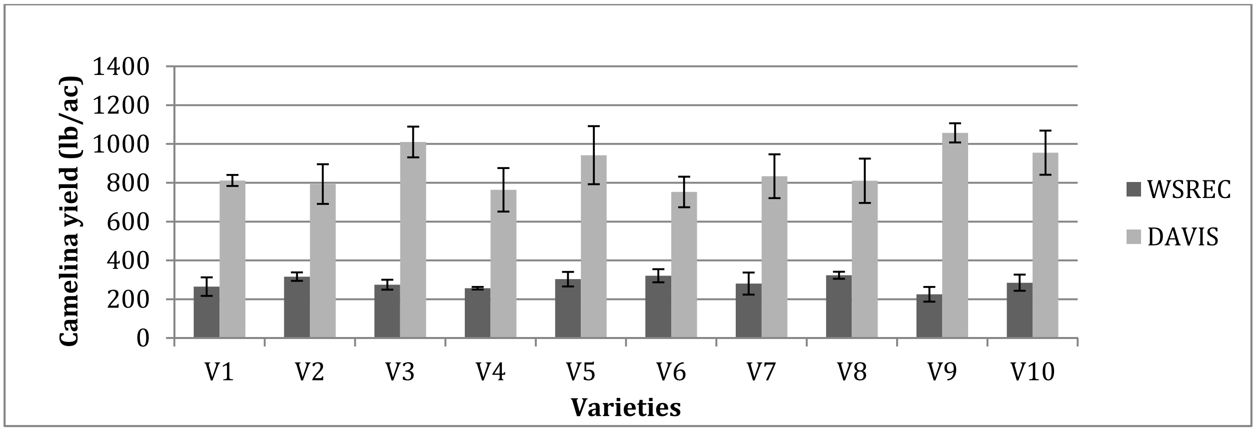


Figure 44. Comparison of seed yields at differing planting dates in 2011-12 at WSREC and Davis. The best planting date was in November.

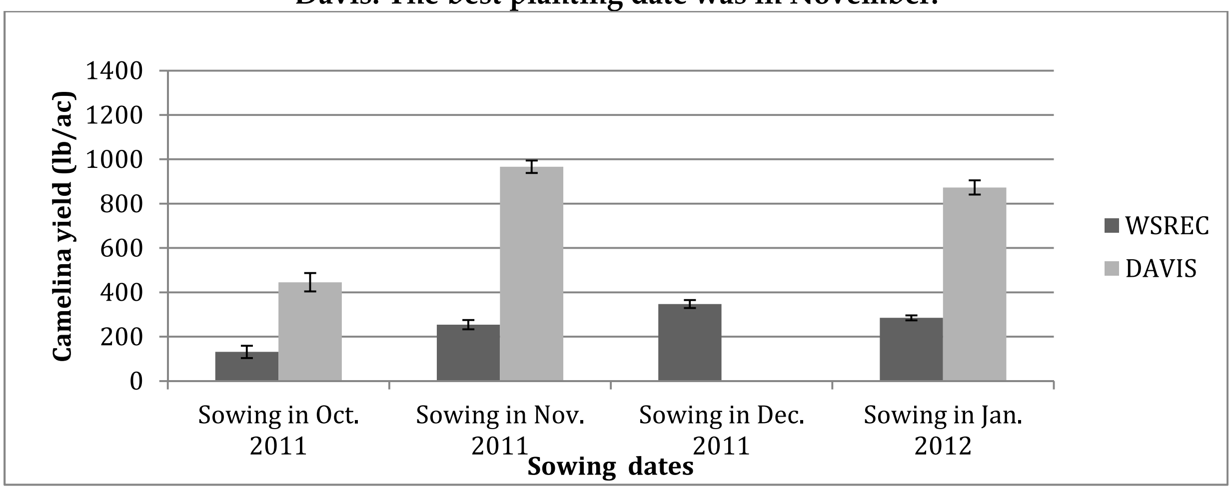


Figure 45. Oil content by variety, November planting date (2011-12).

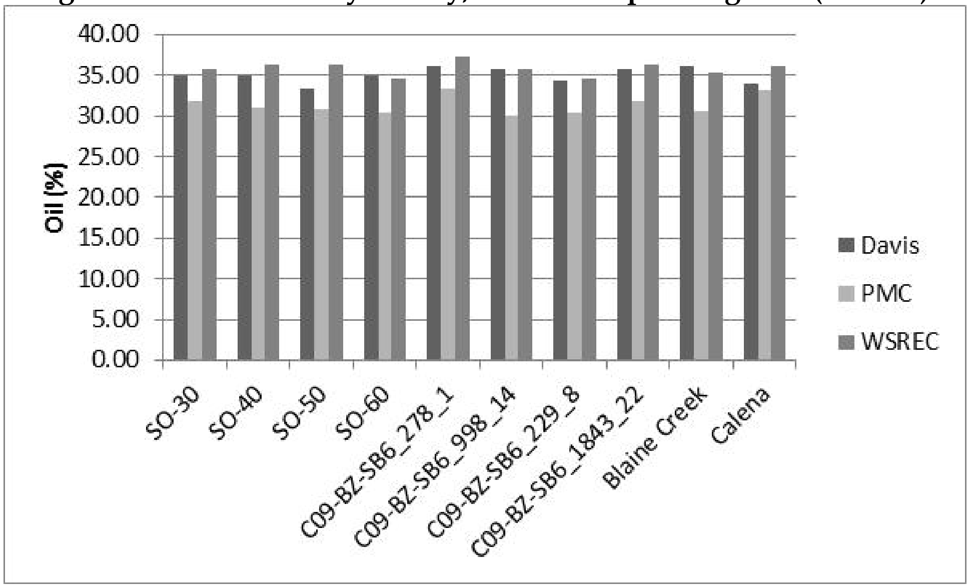


Figure 46. Oil yield by variety (2011-12).

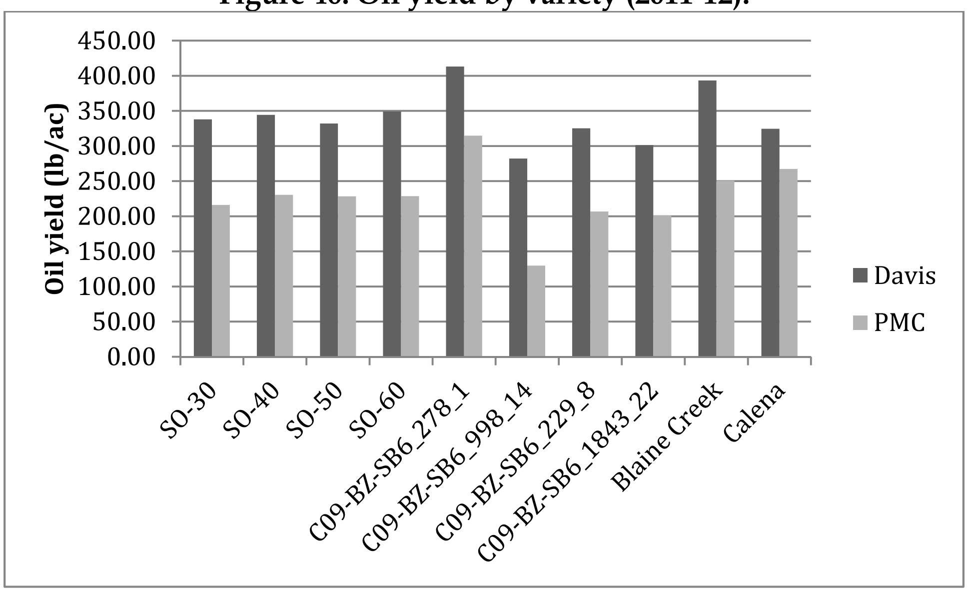
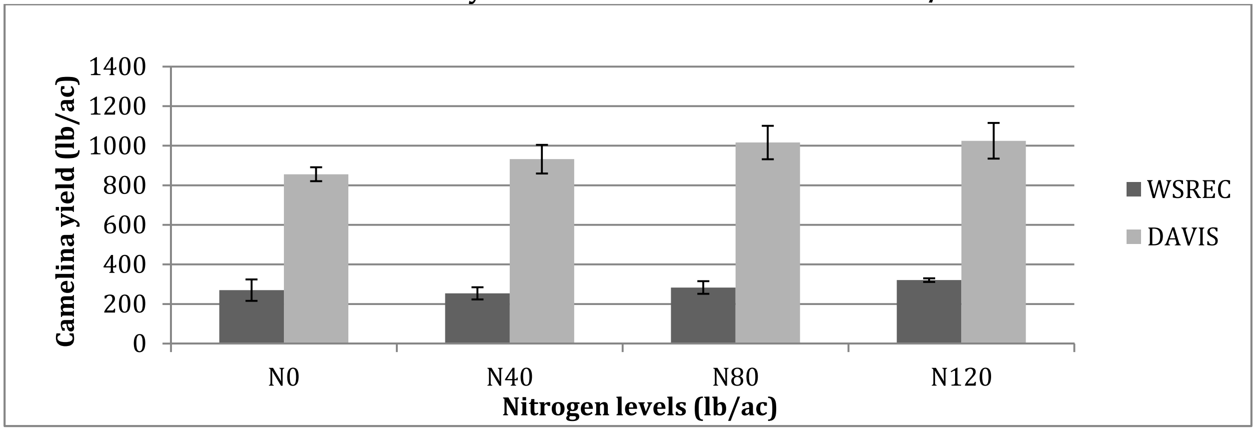


Figure 47. Response to N at WSREC and Davis in 2011-12. There was no response at WSREC, but maximum yields occurred at Davis at 80 lb N / ac.



Herbicide evaluation (2011-12) (Steve Wright, UCCE-Tulare County).

Camelina herbicide trial at WSREC in 2011-12.

There are no broad-spectrum registered herbicides available for use with camelina. Two grass-control herbicides are available. Weed control can be challenging because a number of adapted winter annual weeds emerge in the late autumn with onset of the rains that are used to establish camelina as well. Unlike canola, there are no herbicide tolerant varieties, so tillage methods and crop rotation are the only means to control weeds currently available. Steve Wright (UCCE Tulare County) supervised an herbicide evaluation trial at WSREC in 2011-12. This trial was carried out separately from the others reported here at that location. A combination of different herbicide materials was compared for their effect on camelina seed yield, including those that control only grass weeds, and others that control broad-leaved weeds similar to canola (Table 3).

Results are presented inFigure 48. . The post-emergent grass control herbicides Puma, Axial, Poast, and Select Max resulted in almost no crop injury. Simplicity and Fusilade did cause significant injury. The pre-emergent herbicide Prowl did not cause crop injury. All broadleaf herbicides including Buctril, Express, MCPA, 2,4-D, Shark, and Transline gave significant crop injury. There were no grasses present in the study, although considerable information is available in other studies on the efficacy of these herbicides. Express gave the highest level of control of all broadleaves and especially difficult to control burning nettle, groundsel, chickweed and fiddleneck. Transline gave the poorest control of most weeds. MCPA amine, a commonly used herbicide in wheat, injured the primary camelina variety plots at WSREC in 2012. These plots were planted following many years of wheat and MCPA application, so residual herbicide accumulation was likely the cause of injury. There was significant variance within treatments in this trial. Weed management where winter annual weeds are abundant remains problematic for camelina.

Figure 48. Camelina seed yields after pre-plant or post-emergence herbicide treatments. The herbicides evaluated are identified in Table 3.

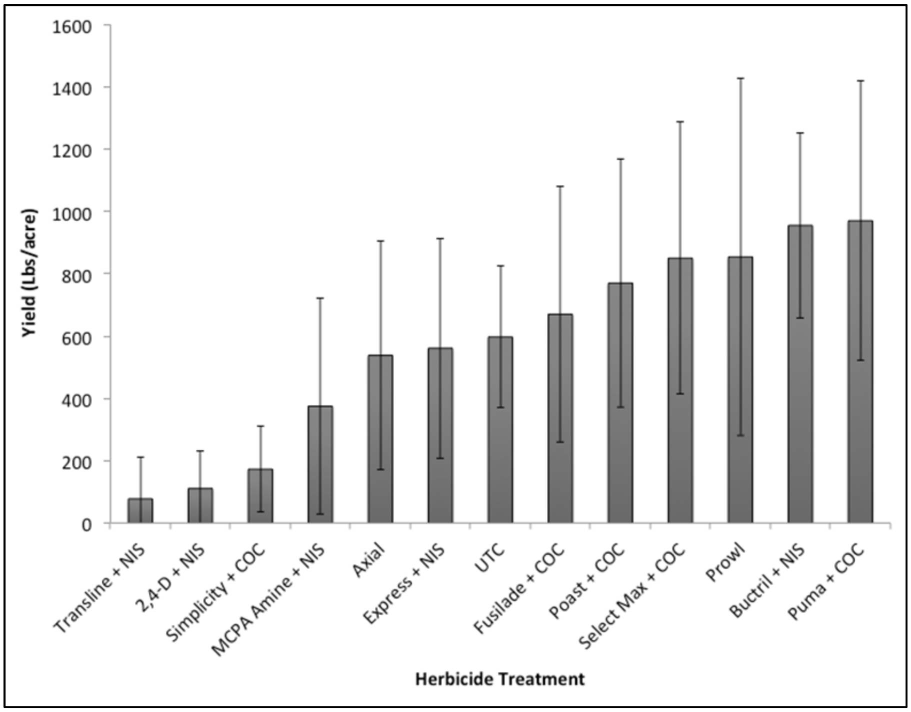


Table 3. List of herbicide treatments, their common names, and the rate applied.

Treatments	Common Name	Rate / A
1. Prowl H2O	Pendimethalin	3 pts
2. Axial	Pinoxaden	16.4 fl oz
3. Puma + COC	Fenoxapop-P-ethyl	10.6 fl oz + 1 pt
4. Simplicity + COC	Pyroxsulam	6.75 oz + 1 pt
5. Bucatril + NIS	Bromoxynil	1.5 pt + pt
6. Transline + NIS	Clopyralid	1 pt + 1 pt
7. MCPA Amine + NIS	MCPA	1 pt + 1 pt
8. 2,4-D + NIS	2,4-D	1 pt + 1 pt
9. Select Max + COC	Clethodim	18 fl oz + 1 pt
10. Poast + COC	Sethoxydim	2.5 pt + 1 pt
11. Fusilade + COC	Fluazifop-butyl	17 fl oz + 1 pt
12. Express + NIS	Tribenuron-methyl	0.5 oz + 1 pt
13. UTC		

Discussion: Multi-year comparisons and general conclusions.

Camelina yields varied considerably among the four years of the trials at WSREC and Davis. The effect of different years was highly significant (Table 4, 5). Even excluding suspect results from 2011-12, year-to-year differences remained significant. Some of the reasons have already been discussed, particularly herbicide damage in 2011-12. When a new site at the WSREC was used in 2012-13 where MCPA had not been applied, seed yields during a mild winter were the largest observed during the four years of the trials conducted, and most similar to high levels previously observed in 2009-10 at WSREC (Table 5), and were also larger than in previous years at Davis (Table 4). One apparent source of variation among years was exceptionally cold weather experienced in the 2010-11 growing season. In particular, a large number of days with temperatures at or below freezing were experienced in late winter, especially February, in 2011 compared to other years (Table 6). January through March was unusually cold in Davis as well. Freezing or near freezing temperatures experienced while flower buds were forming or when early bloom was occurring reduced camelina yield compared with other years with more normal temperature patterns (Appendix A). This is in contrast to freezing temperatures earlier in the crop's development, experienced in December 2009 when high yields were observed..

In contrast to differences among years, camelina variety differences were small non-significant (Table 7). Excluding 2011-12 and herbicide damaged plots, one variety (CS6) was best performing at both WSREC and Davis, while two varieties were poor performing across sites and years (CS26 and C09-BZ-SB6_02).

In general, seed yields were larger in the San Joaquin Valley at the WSREC than in the southern Sacramento Valley at Davis. Seed oil content (%) was higher in most years at Davis (39.9%), however, than at WSREC (37.7%). Both values are towards the higher range of values reported in the literature from other locations where camelina is grown. This reduces differences in oil yield between the two locations. Both locations have high quality agricultural soils and had similar plot management so differences appear to be due primarily to climate.

Typically temperatures are warmer in western Fresno County and the frost-free growing season is longer than at Davis. In the series of trials reported here, the best planting period is mid to late November, effectively at the expected start of the winter rainy season in California's central valley. Harvest occurred one to three weeks earlier in the San Joaquin Valley than at Davis in the Sacramento Valley. This is due to warmer early spring temperatures on average at that site. The earlier occurrence of high temperatures signals winter annual crops, such as cereals and oilseeds, to cease growing. This is hypothesized to be the reason oil content is lower on average at WSREC than at Davis, since plants stop adding seed energy storage in the form of oil sooner. Warm, dry temperatures in early spring also cause camelina to be more prone to seed shatter than at Davis, where shattering was not observed.

Table 4. Camelina variety trial yields (lb / ac) in Davis.

Year	Number	Mean	Std. Dev.	Std. Err. Mean	Loser 5%	Upper 5%	
2010-11	48	590	200	28	530	650	
2011-12	40	970	180	28	910	1020	
2012-13	40	1680	570	124	350	2950	
Quantiles							
Level	Minimum	10%	25%	Median	75%	90%	Maximum
2010-11	170	360	440	590	750	840	1060
2011-12	620	710	860	950	1110	1230	1310
2012-13	970	440	630	1630	1130	1640	3120

Table 5. Camelina variety trial yields (lb / ac) at WSREC.

Year	Number	Mean	Std. Dev.	Std. Err. Mean	Lower 5%	Upper 5%	
2009-10	48	2010	430	62	1890	2140	
2010-11	48	690	160	23	640	740	
2011-12	40	250	130	21	210	300	
2012-13	40	2310	360	82	150	2670	
Quantities							
	Minimum	10%	25%	Median	75%	90%	Maximum
2009-10	860	1460	1770	1970	2260	2550	3210
2010-11	310	460	560	690	770	930	990
2011-12	40	70	160	230	370	460	520
2012-13	1700	220	460	2260	2010	2360	3100

Table 6. Number of days with freezing or below freezing temperatures by month.

	WSREC		Davis	
	2009-10	2010-11	2009-10	2010-11
Oct.				
Nov.	10	**7**	4	**5**
Dec.	12	**4**	14	**4**
Jan.	1	**2**		**7**
Feb.		**11**		**11**
Mar.				**1**
Apr.	2		2	**1**
May.				
Jun.				
Jul.				

Table 7. Variety differences and probability level for significant differences among varieties (2009-2011 only).

Variety	WSREC				Davis	
	2009-10	Order	2010-11	Order	2010-11	Order
BC	2218	2	678	7	723	2
C09-BZ-SB6_2	1818	11	560	11	484	10
C09-BZ-SB6_4	2113	4	803	2	556	7
C09-BZ-SB6_7	2140	3	713	5	524	9
CS11	1997	6	682	6	530	8
CS14	1821	10	768	3	656	5
CS22	2093	5	669	8	657	4
CS26	1707	12	556	12	483	11
CS3	1965	7	618	10	479	12
CS32	1958	8	738	4	662	3
CS50	1866	9	643	9	612	6
CS6	2335	1	838	1	728	1
p	0.789		0.2648		0.568	

Meadowfoam

Meadowfoam is an annual, native California plant that emerges in the fall and flowers and dies in the spring. It is adapted to moister environments. In recent years, meadowfoam has been the subject of agronomic improvement, first starting at UC Davis, and then at Oregon State University. More recently, the University of Georgia has initiated a research and breeding program. Cultivars used in these trials were derived from that source. There is a small commercial industry in Oregon where seed yields exceed 1,000 lb/ac.

Trials: Methods and results

Two sets of trials evaluating meadowfoam performance were conducted on the UC Davis campus and at the UC Westside Research and Extension Center near Five Points in western Fresno County during 2009-2011. Three varieties from the University of Georgia, Athens' Center for Applied Genetic Technologies[7] (CAGT) were compared in both years (GA-1, GA-2 and Ross). A second set of trials evaluated the response of meadowfoam to nitrogen fertilizer, with or without supplemental irrigation in spring.

Materials and Methods

Meadowfoam cultivars (variety trial) were grown at each location in a randomized complete block design with four replications, and three replications for each N x irrigation treatment. Plots were 30 feet in length and 4 feet in width. The variety trial was fertilized with 40 pounds per acre N, applied in two applications, half at planting and half prior to flowering. The irrigation x nitrogen trial was fertilized at four levels (0, 20, 40, and 80 pounds of N per acre), applied in two applications. These values were derived from previous reports about meadowfoam management and were chosen to include the largest N rate thought to be reasonable. Plantings took place in both years in late November or early December at a time when winter rains can be expected to provide moisture for germination and crop growth. Supplemental irrigation was applied only at WSREC in February and March. Rainfall at WSREC is much less on average than at Davis. Both locations experienced higher annual precipitation than average during the 2009-2010 and 2010-11 growing seasons, and a prolonged rainy season

[7] http://www.caes.uga.edu/applications/personnel/deptunit.cfm?caesdept=Center%20for%20Applied%20Genetic%20Technologies%20

at the Davis location in spring 2010 (Appendix A). Rainfall amounts and distribution precluded supplemental spring irrigation at the Davis site. Harvest occurred in early June at Davis and late May in Five Points. The center 50 square feet of each plot was harvested by hand. Seeds were threshed mechanically. Oil content was analyzed at the University of Georgia.

Results

In both years, all cultivars matured earlier at WSREC near Five Points than at Davis. Figures 49 and 50 summarize average yield at each location. Meadowfoam yield at Davis is larger than in Five Points either variety trail or Irrigation x Nitrogen trial. Yield of three cultivars of Ross, GA-2 and GA-1 ranges from 554 to 685 pound per acre in Five Points and from 846 to 1020 pound per acre, respectively (Figure 49). Meadowfoam yield increased with nitrogen level at Davis with a longer and lower temperature growing season, but there was no response under more moisture and temperature-limited conditions at WSREC, despite supplemental irrigation (Figure 51). Yield increased with supplemental irrigation at WSREC, but irrigation treatment differences at Davis were not significant (Figure 51). Oil content did not vary with location (Figure 52).

Figure 49. Meadowfoam yield by variety, 2009-10.

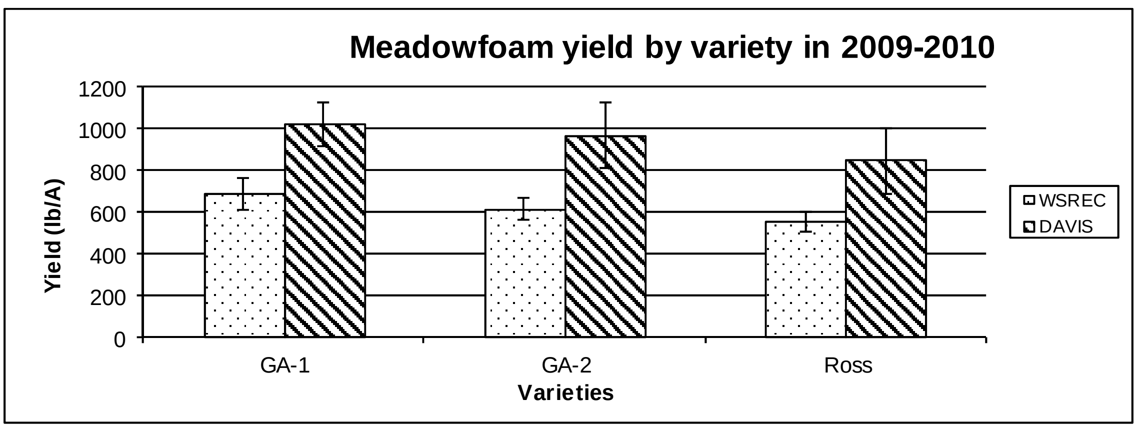


Figure 50. Meadowfoam yield by nitrogen level (2009-10).

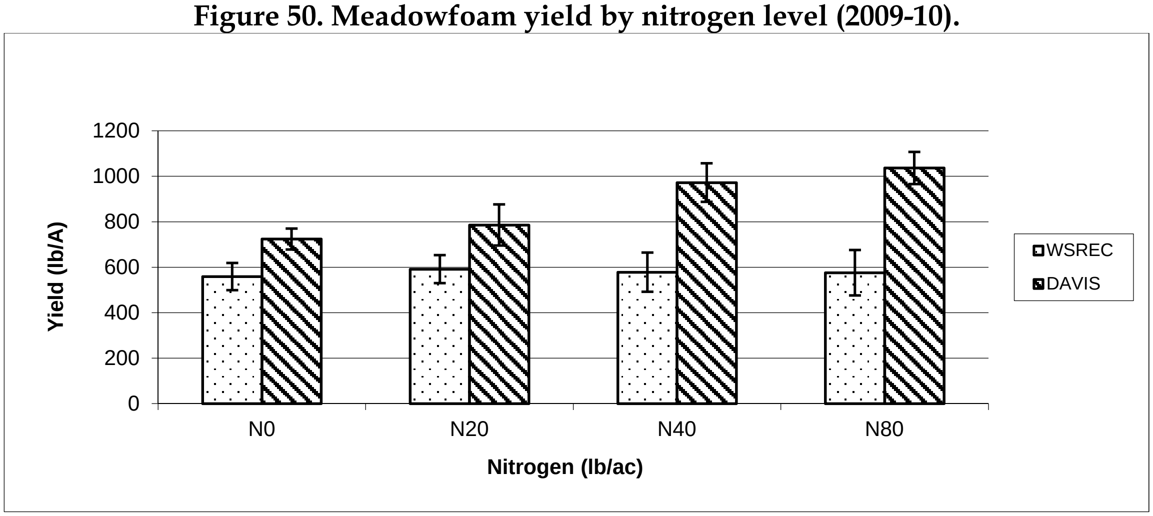


Figure 51. Meadowfoam yield by irrigation treatment (2009-10). At the lower rainfall site (WSREC) in a normal rainfall year, meadowfoam benefited from supplemental irrigation in spring.

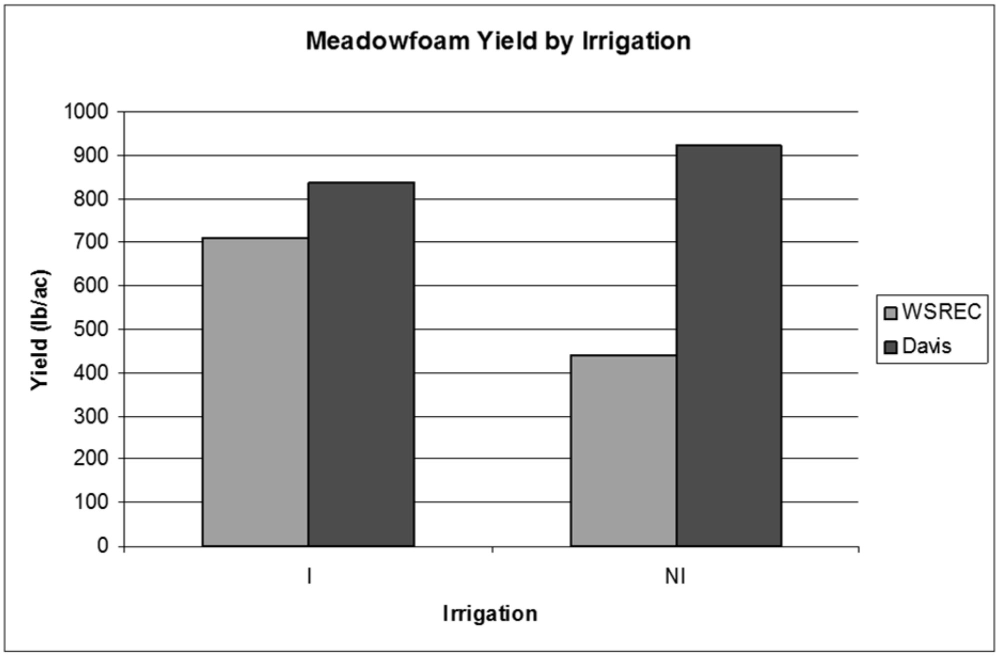
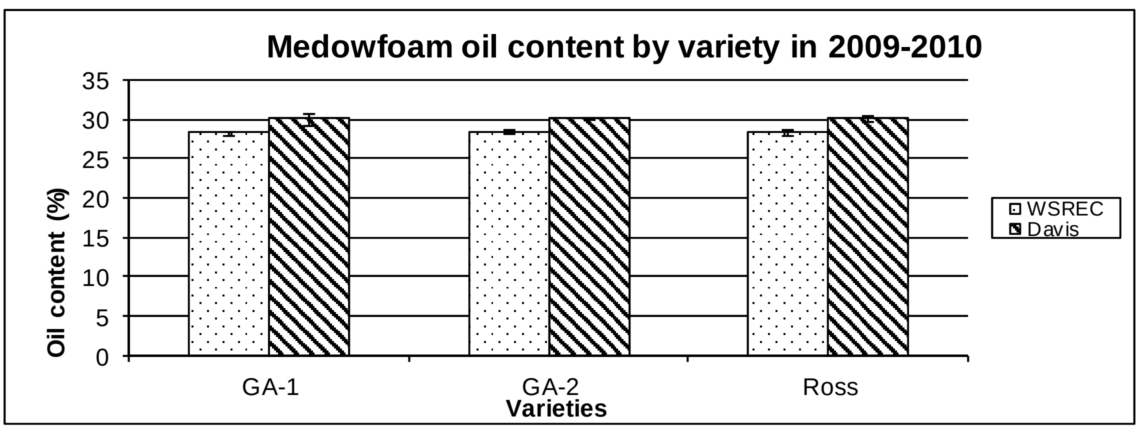


Figure 52. Oil content by variety. N fertilization did not influence oil content in any of the trials (data not shown).



2010-11 Results

As in 2009-10, all cultivars matured earlier at WSREC than at Davis in 2010-11. Figures 53 and 54 summarize average yield at each location and response to fertilizer N. Meadowfoam yield at Davis was greater than at WSREC in both the variety and cultivar trials. Yield of the three varieties Ross, GA-2 and GA-1 varied from 64 to 166 pound per acre at WSREC, and from 292 to 343 pound per acre at Davis, respectively (Figure 53). Under the unusually cold conditions experienced during the winter of 2010-11, Meadowfoam yield did not respond to fertilizer N at either location (Figure 54). Yield increased with supplemental irrigation at both locations (Figure 55). Oil content did not respond to fertilizer N (Figure 55).

Figure 53. Meadowfoam yield by variety. (Error bars are standard errors.)

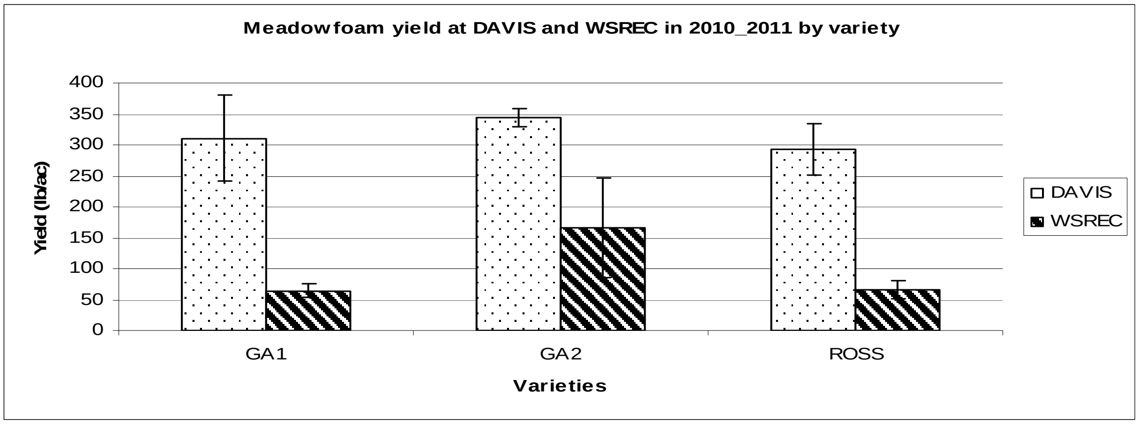


Figure 54. Meadowfoam yield by nitrogen level. (Error bars are standard errors.)

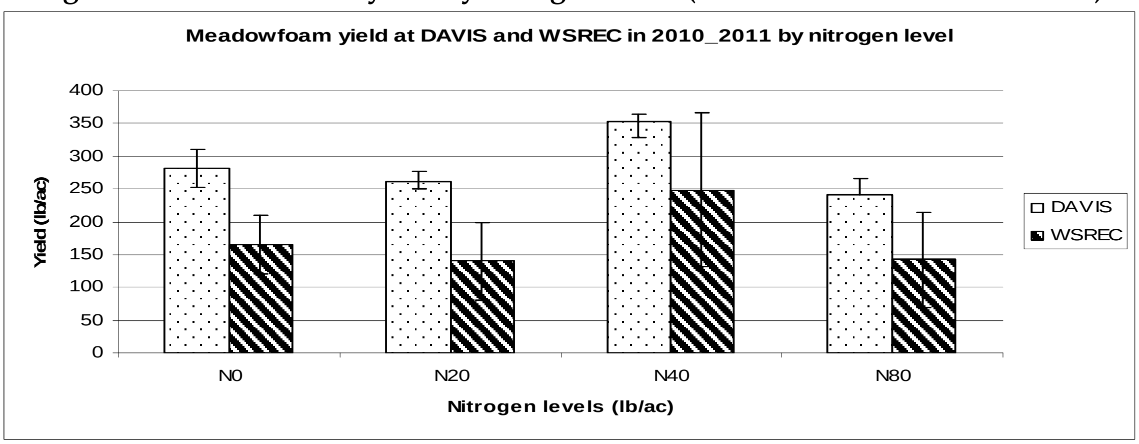


Figure 55. Meadowfoam yield by irrigation treatment. (Error bars are standard errors.)

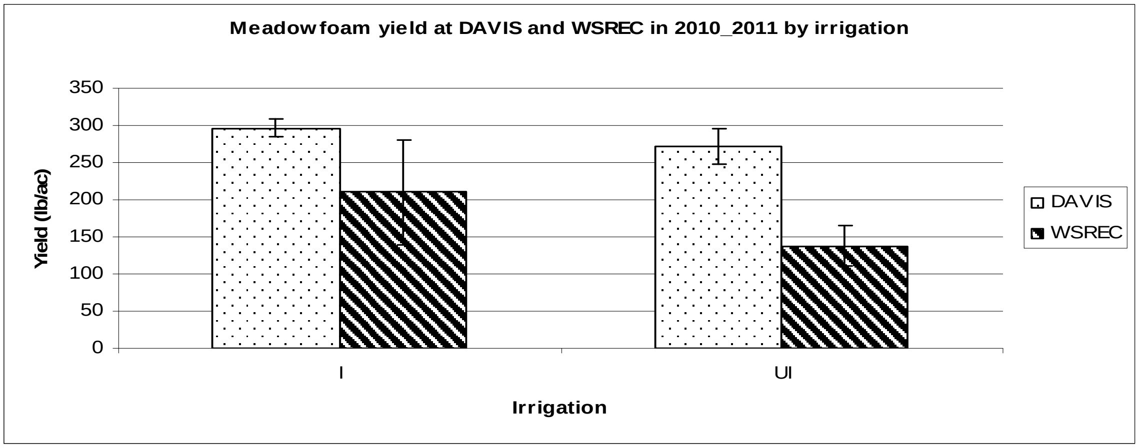
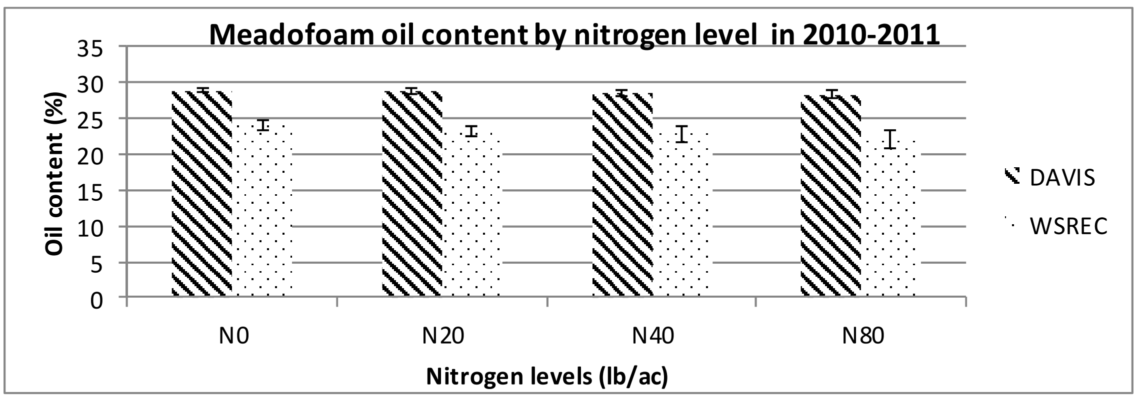


Figure 56. Meadowfoam oil percent by N level. There were no significant differences in oil content among varieties at either site (data not shown).



Discussion: multispecies comparisons

Canola was always the highest yielding species among the winter annual oilseeds tested across all sites and years (Figure 57, 58). Oil content was on average 10% greater in in canola than in camelina and 20% greater than in meadowfoam. Because of its longer growing season and larger overall DM accumulation, canola uses more water, responds to larger amounts of N fertilizer, and has different effects on cropping systems in which it is included (Section 1). But for farming situations where moisture is limiting or where earlier harvest and removal is desired for double cropping purposes, Camelina may be chosen. Meadowfoam is very low yielding. Its oil has advantageous properties for biodiesel production (Section 3) but it is unlikely to be of use in the cropping systems in California due to its very low and variable yields.

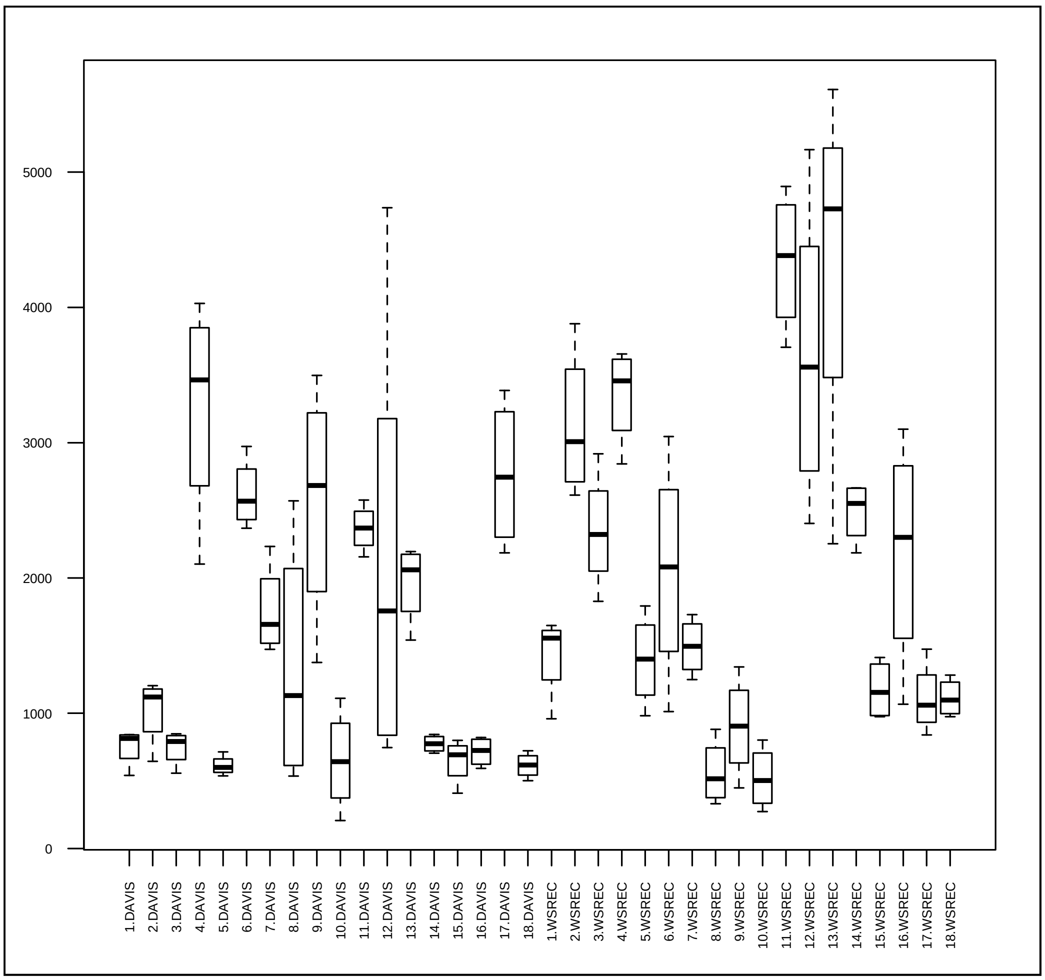


Fig. 57. Box plots of canola yields by site and year. Varieties varied from year to year and are averaged. Variances were non-heterogeous. Kruskall-Wallace rank-sumtests of significance indicate that variety, year and location effects were all sigifnicant.

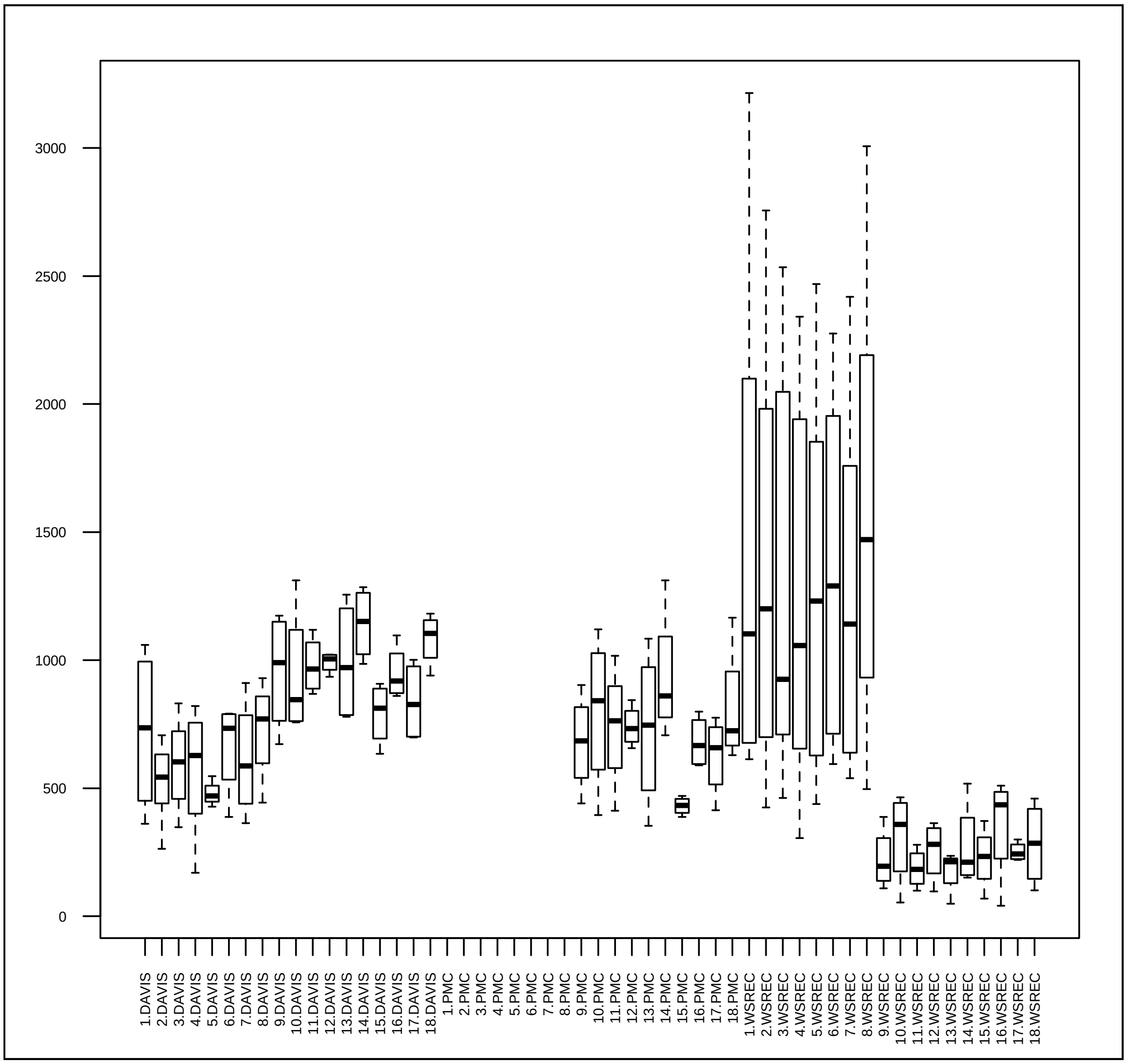


Fig. 58. Box plots of camelina yields. Varieties vried from year to year and are averaged. Kruskall-Wallace rank-sum tests of significance indicate that variety andyearr differences were significant, but location differences were not

Conversion Systems (Technology) - biochemical pathways for converting vegetable oils to biodiesel

Virgin Oils to Biodiesel

The characteristics of biodiesel fuels derived from vegetable oils or fats and greases depend on the fatty acid composition of the feedstock source (Knothe, 2005). In general, the shorter the fatty acid chain length, the more readily the resulting biodiesel fuels will tend to solidify in cold weather (a temperature called the cloud point), and also exhibit oxidative instability leading to water formation and other undesirable changes with storage. Fats, oils, and greases (FOG) have a majority of shorter chain fatty acids and free fatty acid contaminants and are more difficult to convert into high quality biodiesel than vegetable oils using the most common process, called FAME (discussed below). Alternatively, they are subject to hydrocracking in which they are converted to esters with the addition of hydrogen and are made into greed diesel or renewable diesel. These fuels are largely indistinguishable from conventional petroleum diesel. In a similar manner, they can serve as a source for biojet fuel (discussed below). Vegetable oils with a large amount of oleic fatty acids (18:1) generally can be converted into well-performing biodiesel and are desirable feedstock sources. They still have some difficulties with cloud point in cold climates (fuels thicken) and can degrade over time due to oxidative instability.

Meadowfoam is unique due to its high oxidative stability. This property results from a large amount of C20 and greater fatty acids (>98%), compared to other oilseeds. It also has very low amounts of short carbon chain fatty acids such as palmitic, stearic, oleic, linoleic, and linolenic, which result in poor cold flow properties in biodiesel and low oxidative stability (Moser et al., 2010). This suggests that blending with meadowfoam oil would improve biodiesel fuels made from other types of oils and fats. When used for biodiesel manufacture, it results in a fuel with the highest cetane number of any common vegetable oil. Cetane number is a measure of the combustion quality of diesel fuel during compression ignition. Typical oilseed composition of the oils investigated here and comparisons with safflower (commonly produced in California) and other Brassica species are presented inTable 8.

Table 8. Typical fatty acid composition of vegetable oils, with data from diverse sources.

	Principal Fatty Acids								
Species	16:0 Palmitic	18.0 Stearic	18:1 Oleic	18:2 Linoleic	18:3 Linolenic	20:0	20:1*	22:0; 22:1	22.2**+> 22:2
Canola (Br. Napus)	6.20	0	61.30	21.60	6.60				
Rape seed	3.50	1.40	60.00	20.50	10.00		0.90	0.20	
Indian mustard (B. carinata)	7.80	3.00	16.80	23.00	31.20				
Camelina	20.70	6.10	53.50	9.80			12.00	2.80	
Meadowfoam	0.60	0.20	1.00	0.90		0.80	64.20	10.40	19.50
Safflower	5.00	<1.00	77.00	15.00					

The protein-rich meals remaining after oil extraction from canola and camelina are valuable livestock feeds and can be further converted into other products, including, in some cases, biopesticides (rape seed, Indian mustard).

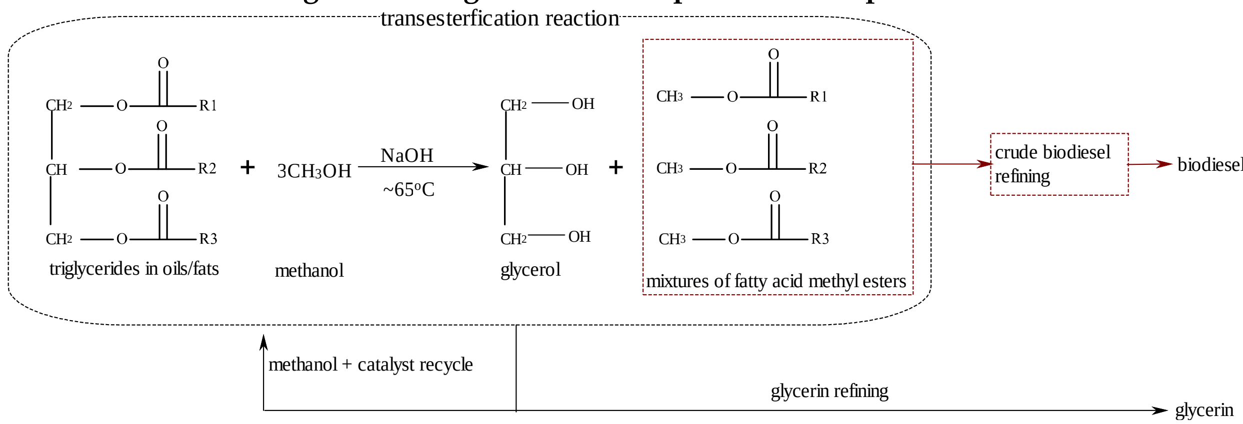
Fatty Acid Methyl Ester (FAME) Process

Fatty acid methyl esters (FAME) are long-chain mono alkyl esters converted from oils or fats, also called biodiesel. As shown in Figure 57, the core technique of the FAME process is a transesterfication reaction between methanol and triglycerides, which contain three fatty acids, in vegetable oils, animal fats, or recycled cooking oil. The transesterfication reaction is reversible and carried out with either strong base or acid catalysts at modest (low temperature and pressure) conditions. At an industrial scale, sodium hydroxide or potassium hydroxide is the catalyst most used because of low cost. Methanol is mostly used for the transesterfication process due to advantages of low cost and easy separation from glycerol residues compared to other alcohols. If anhydrous ethanol were available at low cost, it could be used as well. To achieve nearly complete conversion of triglycerides, excessive methanol (4.5 to 6 molar ratios to triglycerides) must be employed in the transsterfication reaction, but which results in high yields (~95% of fatty acid methyl esters). However, excessive methanol also affects subsequent separation of methanol from glycerol (Figure 57).

Overall, the FAME process is a relatively simple technique and has modest capital costs, which allows for small production units to be built without excessive extra costs. Smaller units can be located nearer to sources, with potential savings from reduced feedstock transportation and other related logistical costs. This basic process for biodiesel production has been successfully employed for many different vegetable oils, fats, and other feedstocks. However, the FAME process has a very limited scope for modifying FAME biodiesel properties since the structures of fatty acids, including unsaturated carbon-carbon bonds and oxygen content, remain unchanged. Therefore, the properties of biodiesel fuels produced via the FAME process are highly dependent on the composition of the feedstocks. In this case, the distribution of fatty acids in the vegetable oils or fat quality determines the properties of its biodiesel. For example, the cetane number increases with longer C chain fatty acids, and with more saturated C bonds (Gerpen, 1996).

Canola oil, camelina oil, and meadowfoam are useful feedstocks for biodiesel production via FAME processes. As a commercially available source, canola oil has 92.6% unsaturated C18 fatty acids (63.9% C18:1, 19.0% C18.2, and 9.7% C18.3) and less than 2% erucic acid (Sanford, 2009). Compared to canola oil, camelina oil has more carbon-carbon double bonds, since the largest portion of unsaturated C18 fatty acids is C18:3 (37.9%) and 73.6% unsaturated C18 fatty acids (17.7% C18.1, 18.0% C18.2, and 37.9% C18.3), as well as 11.4% unsaturated C20 fatty acids (9.8% C20:1 and 1.6% C20:2) and 4.5% unsaturated C22.1 fatty acids, which resulted in lower oxidative stability and higher cold soak filtration (223 s) versus 113 s of canola bidiesel (Sanford, 2009). Overall, camelina bidiesel is comparable to canola oil for average oil quality values, but less is known about variation in oil quality by variety and location. Since meadowfoam oil has more stable fatty acids (64.2% C20:1(5(Z)-eicosenoic acid) and more fatty acids withcarbon chain equal to or longer than 20), meadowfoam biodiesel has much higher oxidative stability and higher energy content. It could be blended with soybean biodiesel or other vegetable oil-derived biodiesels to improve the oxidative stability and energy content of the fuels, as well as reducing the higher kinematic viscosity of meadowfoam biodiesel to meet the requirement of ASTM D6751[8] and EN 14214[9] (Moser et al., 2010). Therefore, meadowfoam biodiesel might be more valuable to be blending into soybean biodiesel via FAME.

Figure 57. Diagram of the simplified FAME process.



There are thirteen companies producing biodiesel in California in 2013. Most use residual FOG materials, but some also use vegetable oils derived from diverse sources. Total in-state capacity varies between 40 and 60 mgy. Additional oilseed feedstocks would support an increase of in-state biodiesel production beyong the limited supply of available waste fats. Oils and greases.

[8] D6751-12 Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels. http://enterprise.astm.org/filtrexx40.cgi?+REDLINE_PAGES/D6751.htm

[9] EUROPEAN STANDARD EN 14214 Automotive fuels- Fatty acid methyl esters (FAME) for diesel engines- Requirements and test methods. http://www.novaol.it/novaol/export/sites/default/allegati/EN14214.pdf.

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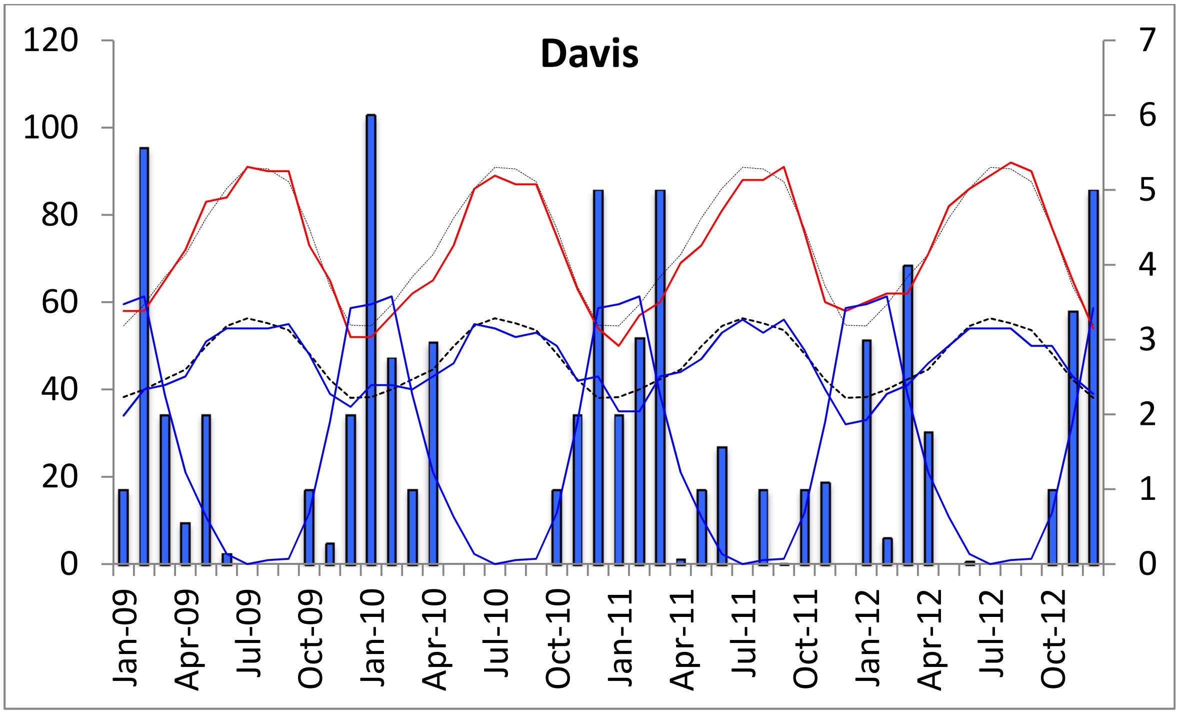
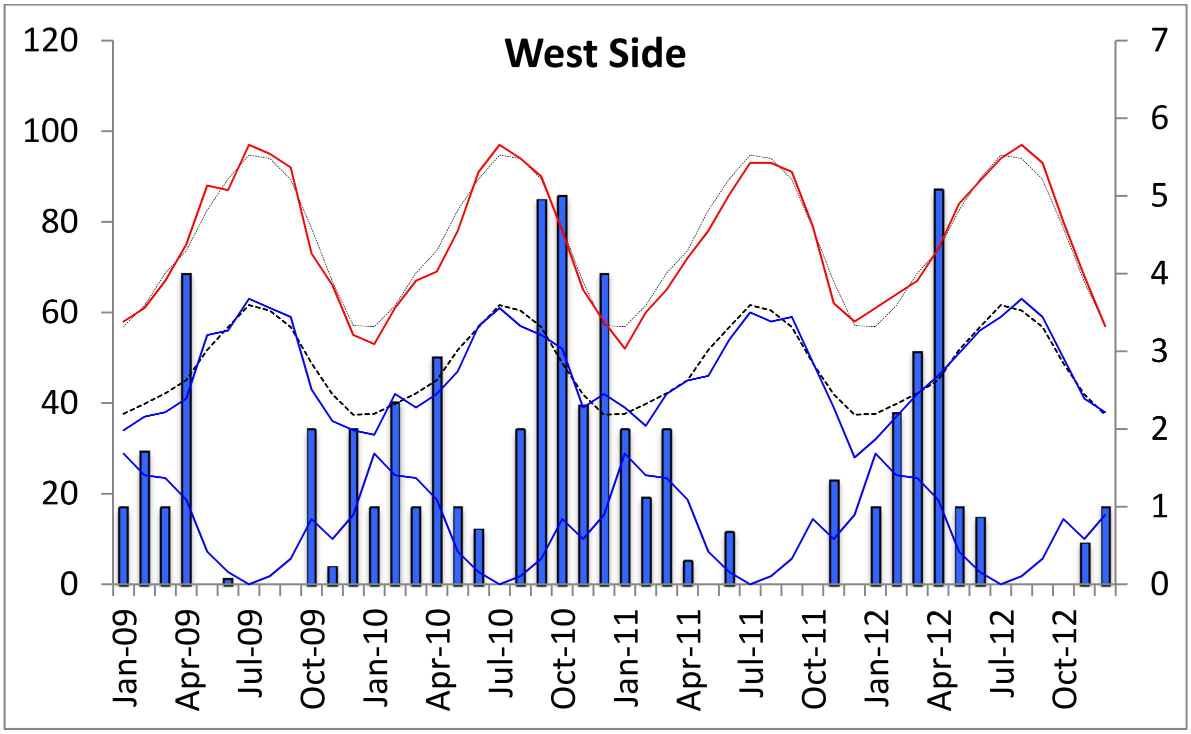
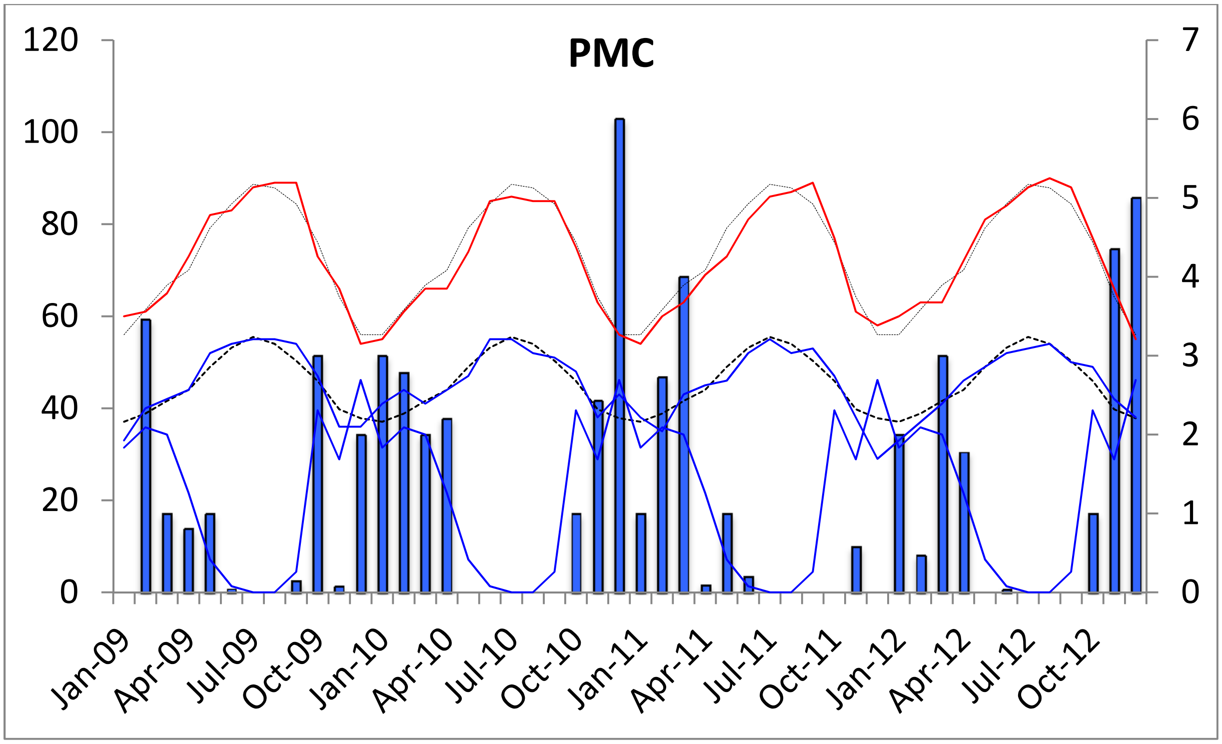
APPENDIX A

Weather data at the primary research sites (Davis, Five Points, Lockeford (PMC) <u>and Macarthur during the trial years. (Add the IV).</u>






PMC
120
100
80
60
40
20
0
7
6
5
4
3
2
1
0
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
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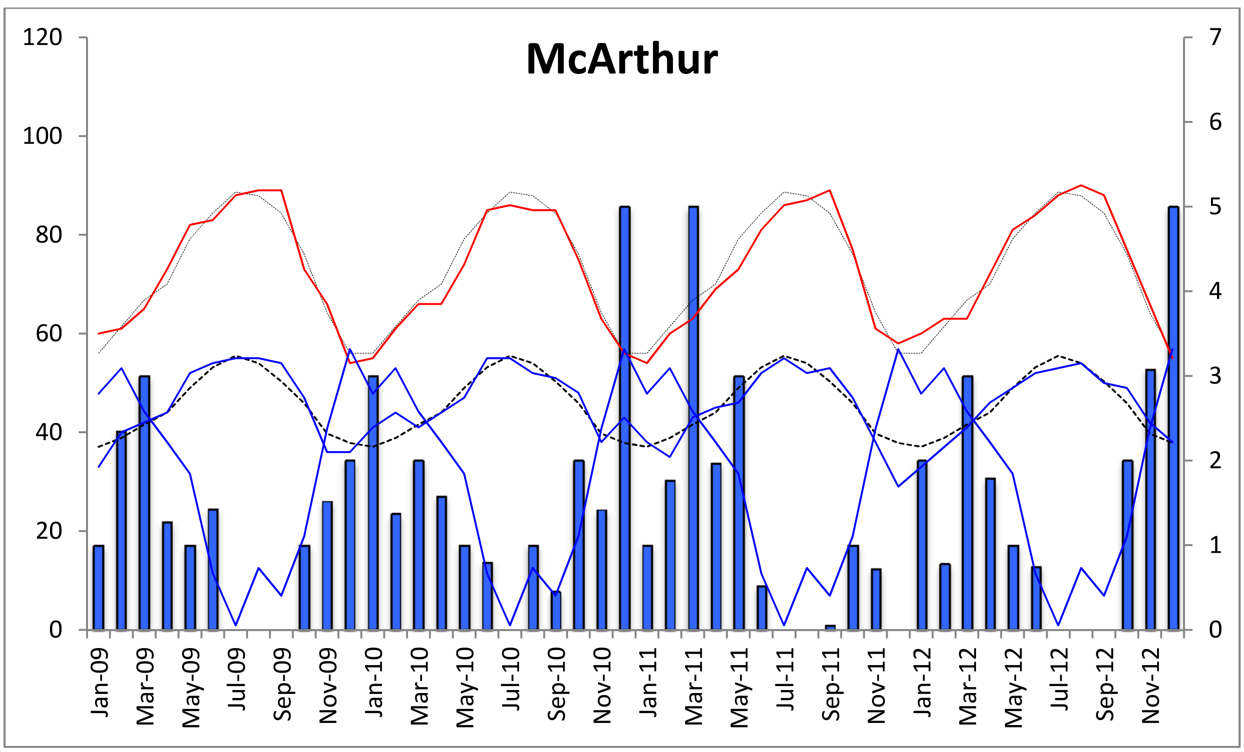
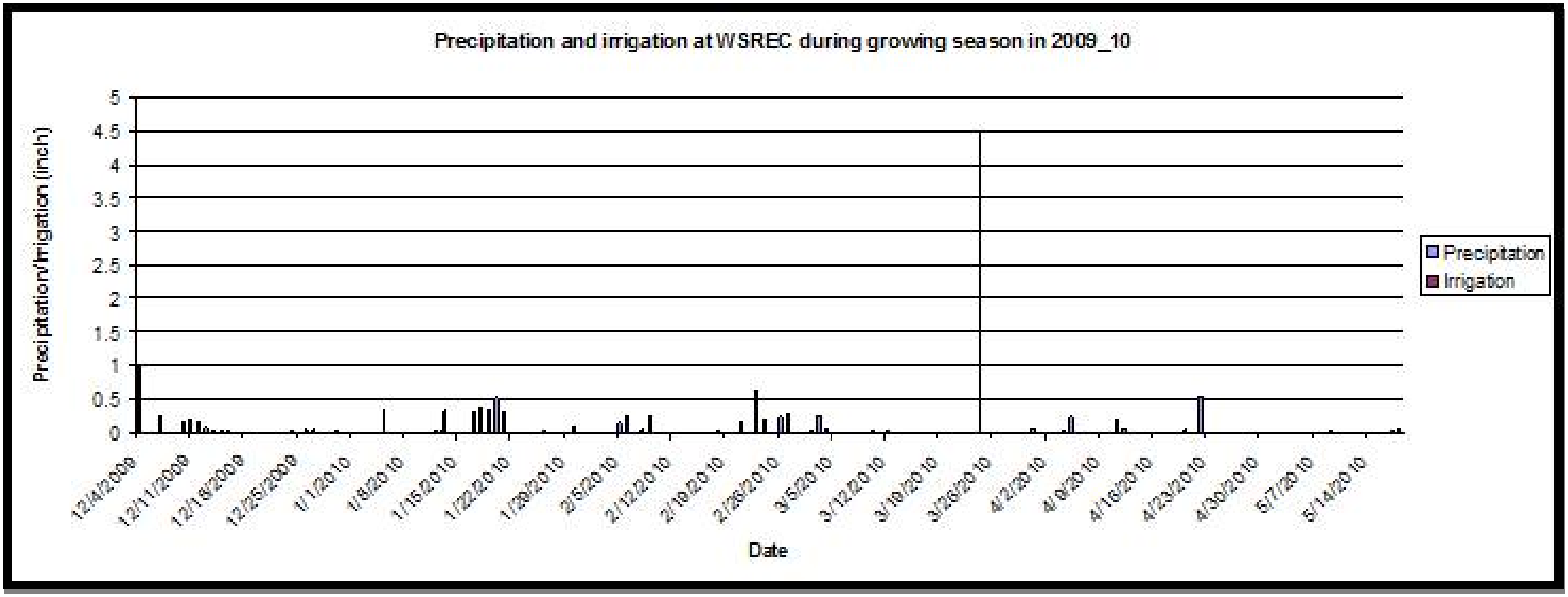
Apr-12
Jul-12
Oct-12


McArthur
120
100
80
60
40
20
0
7
6
5
4
3
2
1
0
Jan-09
Mar-09
May-09
Jul-09
Sep-09
Nov-09
Jan-10
Mar-10
May-10
Jul-10
Sep-10
Nov-10
Jan-11
Mar-11
May-11
Jul-11
Sep-11
Nov-11
Jan-12
Mar-12
May-12
Jul-12
Sep-12
Nov-12

APPENDIX B:



Precipitation and irrigation at WSREC during growing season in 2009_10
Precipitation/Irrigation (inch)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12/4/2009
12/11/2009
12/18/2009
12/25/2009
1/1/2010
1/8/2010
1/15/2010
1/22/2010
1/29/2010
2/5/2010
2/12/2010
2/19/2010
2/26/2010
3/5/2010
3/12/2010
3/19/2010
3/26/2010
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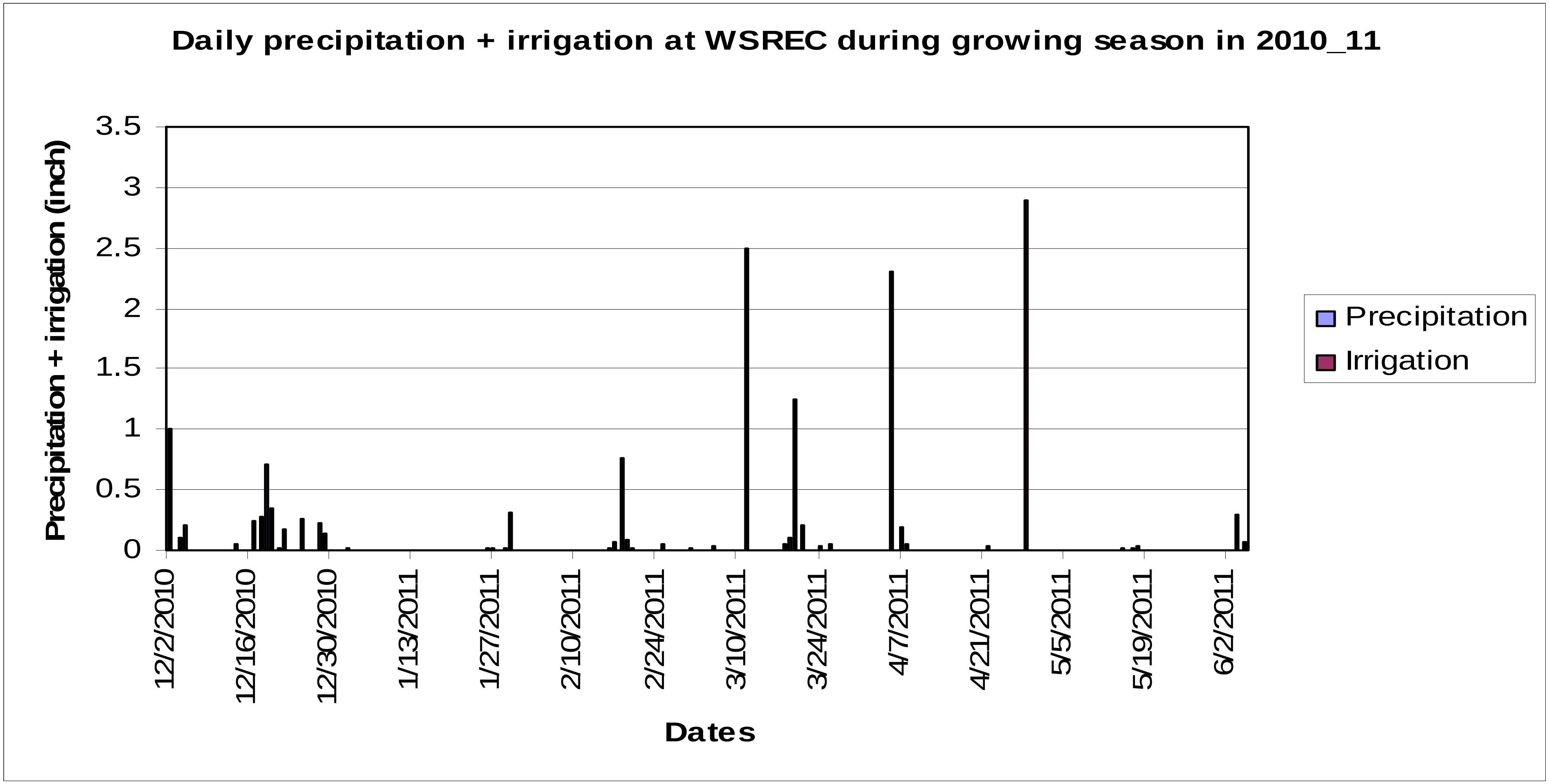
5/7/2010
5/14/2010
Date
Precipitation
Irrigation


Daily precipitation + irrigation at WSREC during growing season in 2010_11
Precipitation + irrigation (inch)
3.5
3
2.5
2
1.5
1
0.5
0
12/2/2010
12/16/2010
12/30/2010
1/13/2011
1/27/2011
2/10/2011
2/24/2011
3/10/2011
3/24/2011
4/7/2011
4/21/2011
5/5/2011
5/19/2011
6/2/2011
Dates
Precipitation
Irrigation

APPENDIX C: Potential canola pests and diseases in California[10]

Flea beetles and cabbage worms. Flea beetles can be damaging at establishment and cabbage worms can affect the crop at any time. Observed at non-damaging levels in some of the trials reported

Green peach aphids and cabbage aphids, commonly found on brassica sp. crops in spring. Observed at non-damaging levels in some of the trials reported.

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[10] http://www.ipm.ucdavis.edu/PMG/C108/m108yiformsphotos.html

Schlerotinia. Not observed in these trials.

Alternaria. Not observed in these trials.

Phoma (blackleg). Common in canola producing regions, but not obsaerved in these trials or reported in California.

Root knot (Meloidogyne sp.) and Cyst nematodes (Heterodera sp.). Occur in individual fields.

Appendix D. Oilseed trial sites and images

Meadowfoam in March WSREC.

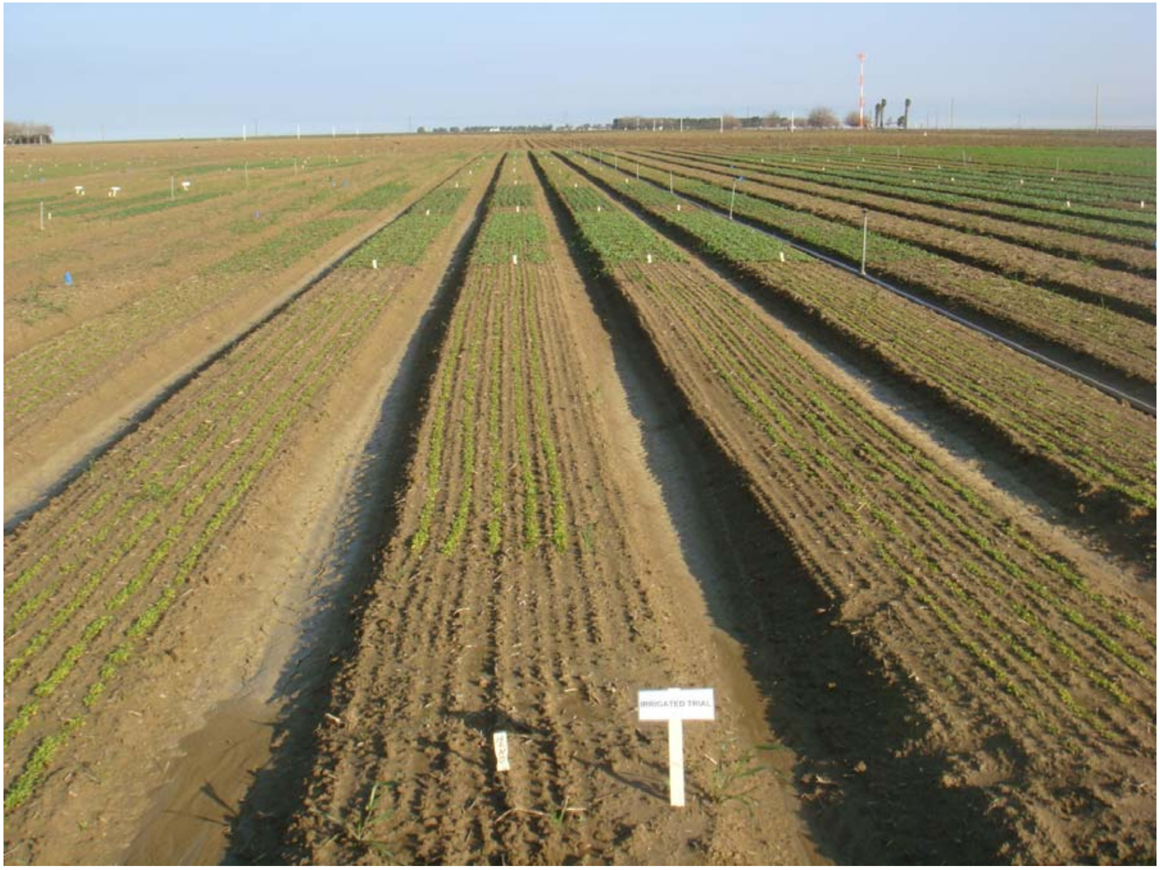
Camelina plots in March at WSREC.

Canola variety trials in early January and late April, 2012 .

Canola variety trial at WSREC, January 2011.

***Brassica juncea* (light green, left) and *Brassica napus* (dark green, right) at WSREC in 2010.**

Meadowfoam (foreground) and Camelina (background at WSREC in 2011. Meadowfoam performed poorly in the San Joaquin Valley.



Camelina (foreground) and canola trials (background) in early January 2011 at WSREC.

Meadowfoam (foreground), Camelina (background left) and Canloa (background right) prior to harvest at Davis in 2011. Meadowfoam always matured earliest, followed by camelina and then canola.

Camelina prior to harvest at Davis in May 2011.

Canola plots ready for harvest at Macarthur (late summer 2011).