Canola and camelina: winter annual oilseeds as alternative crops for California

Two year progress report for the ANR competitive grants program oilseed project

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1. Takeaway

Key takeaway messages from this report:

- A greater diversity of economically viable winter annual crops are needed in California.
- Canola (*Brassica napus*) is one of the most important oilseed crops globally. It has a large domestic market in the United States, which exceeds local production. Canola is widely and profitably grown as a winter crop in southern Australia, which is climatically comparable to California. It is likely that varieties developed for that region will be adapted to California.
- The oilseed species camelina (*Camelina sativa*) is lower yielding than canola, but more compatible with shorter rotational windows and later planting.
- We established a project to evaluate the suitability of canola and camelina as winter oilseed crops for California with funding from the University of California Division of Agricultural and Natural Resources.
- A diverse range of commercial and experimental varieties of both canola and camelina have been evaluated at multiple sites in California.
- As hypothesized, the best-adapted canola varieties in our work are short-season spring-types developed in Australia. These yield over 3000 kg/ha. The best camelina varieties tend to be commercial lines and yield over 1000 kg/ha. These yields should be economically viable.
- In California, canola must be planted before soil temperatures drop below 10°C to avoid establishment issues. Typically, this will be around the end of November. Early season irrigation may be needed to ensure even germination and establishment. Camelina has more flexibility in planting dates in California because of its greater tolerance to low soil temperatures. It can be planted at any time in the winter.
- Both canola and camelina use at most 380 mm (15 inches) of water from all sources. This water use is relatively low compared to summer rotations and comparable to, if not lower than, alternative winter rotations.
- Both canola and camelina can be cut for biomass early in the growing season with no significant impact on seed yields. Biomass is suitable for hay and silage production.
- There is tentative agreement between the APSIM crop model and our field trial data for canola, suggesting the APSIM model can be used as a research and management tool for canola in California.
- Initial project results are promising. Future work is needed to refine our knowledge regarding variety performance and crop agronomy of canola and camelina in California.

2. Introduction

2.1. Oilseeds for the diversification winter rotations

There is a need for economically viable winter crop options to diversify annual cropping systems in California. California has one of the most valuable agricultural industries in the world (FAOSTAT, 2014; TOLOMEO et al., 2012), but in terms of economic value and crop diversity it is dominated by warm-season species that are reliant on irrigation (TOLOMEO et al., 2012; USDA NASS, 2015). A multi-year drought has drastically reduced irrigation water supplies in the state, and climate change may lead to additional water supply constraints in the future, with potentially adverse consequences for summer cropping systems (CAYAN et al., 2008; COOK et al., 2015; JACKSON et al., 2012; LEE AND SIX, 2010; PARRY et al., 2007). To maintain the long-term productivity and sustainability of farming in California under a more water-limited future, it will be important to have a larger number of economically viable annual crops that can be grown during winter. Given that winter crops are grown when evapo-transpirational requirements are reduced, it results in significantly less irrigation water demands relative to summer crops. Depending on the growing region in California, winter crops could also be produced on rainfall and stored-soil moisture alone.

In terms of harvested area, the winter rotations of California are dominated by cereals (TOLOMEO et al., 2012; USDA NASS, 2015). Winter crop alternatives should therefore aim to compliment or integrate with cereal cropping systems. In other regions of the world, canola is often used to diversify cereal-based agricultural systems (BOOTH AND GUNSTONE, 2004; DUFF et al., 2006; POUZET, 1994). Consequently, there is interest amongst agricultural researchers and growers in the potential of canola as a crop for California. There is essentially no commercial canola production in California at the present time, apart from seed increases in the Imperial Valley.

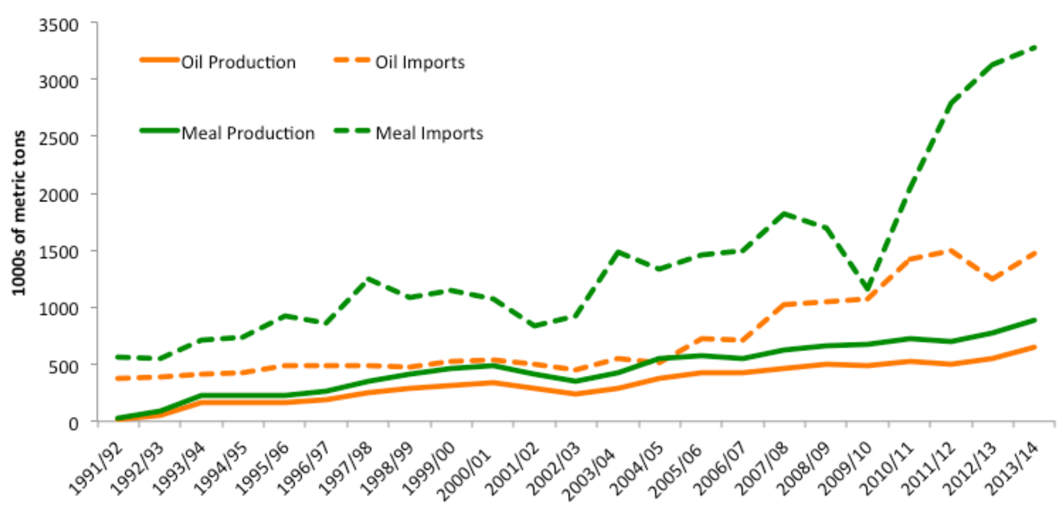

Figure 1: US canola oil and meal production versus imports (USDA NASS, 2015).

2.2. Australian canola varieties for California

In North America, variety development for canola has primarily focused on Canada, the Pacific Northwest, Midwest and Atlantic regions. Varieties developed for these regions are unlikely to be well adapted to the Mediterranean climate of California. In contrast, over the past thirty years, a sustained research effort supporting canola production in the Mediterranean agricultural zones of Australia has been carried out. Australia is now the fourth largest canola producer globally (FAOSTAT, 2014). This region is broadly similar to California in terms of latitude, temperature range, rainfall and rainfall distribution, so Australian varieties could form the basis of an expanded oilseed industry in California and expand the US canola industry.

2.3. Alternative oilseed options for California

Relative to other brassica oilseeds, canola is generally the highest yielding and has received the greatest research and development effort; however, canola can become unreliable in medium to low rainfall conditions (FARRÉ et al., 2007).There are also other agro-ecological circumstances in the state where canola may not be compatible with existing rotations. Other oilseed species may offer a wider range of adaptations and yield more reliably under low input farming conditions, including limited rainfall (FRANCIS AND CAMPBELL, 2003; GUNASEKERA et al., 2009; HUNT AND NORTON, 2011). The oilseed species camelina (*Camelina sativa*) is more cold tolerant and matures earlier than canola (ALLEN et al., 2014; JIANG, 2013; PUTNAM et al., 1993), and could therefore be more compatible with shorter rotational windows or later planting.

2.4. Markets for oilseeds

Canola oil is widely used for human consumption (DUFF et al., 2006; JOHNSON AND FRITSCHE, 2012) and this market is expected to grow in the future, especially given research findings about its health benefits[1] (FRANCIS AND CAMPBELL, 2003; LIN et al., 2013; MCDONALD, 2004). Camelina oil is not currently considered edible, but there is research directed towards this end use (BELANCOR et al., 2015; CAMPBELL et al., 2013; VOLLMAN et al., 2007).

Seed oil from most brassica species makes good-quality biodiesel, and several species, including canola and camelina, are already used commercially for this purpose (KÖRBITZ, 1995). Biofuels are needed in California to meet the state's requirements for low carbon fuels under the Low Carbon Fuel Standard. California currently has several companies producing biodiesel[1], which would benefit from additional supplies of locally-produced vegetable oils.

Californian livestock industries are an important component of the state's agricultural sector, with a value of over $12 billion in 2012 (TOLOMEO et al., 2012). Canola produces high-quality seed meal that is nutritionally complimentary to soybean meal, and is already used commercially to feed poultry, pigs, dairy and beef cattle (DUFF et al., 2006; NEWKIRK, 2009). Similar to the case for canola oil, local demand for canola meal is

[1] http://californiabiodieselalliance.org/page1/page1.html

greater than domestic production (ERS, 2014; USDA NASS, 2015) (Figure 1). In 2009 the U.S. Food and Drug Administration's Division of Animal Feeds also approved camelina meal for use in the livestock industry. Any food-grade oil and biodiesel industries based on canola or camelina that develop in the state will have markets for the meal by-product that remains after oil extraction.

Canola makes good-quality hay and silage (MCCORMICK, 2007), and recent research suggests both winter and spring canola could be used for forage as well as for seed production (KIRKEGAARD et al., 2008; KIRKEGAARD et al., 2012a; KIRKEGAARD et al., 2012b; MCCORMICK et al., 2012; SPRAGUE et al., 2014). Canola will therefore complement existing California livestock enterprises. There is no published information regarding the feed quality of camelina, although anecdotally people report that it is suitable for this end use.

2.5. Previous oilseed research in California

Plant breeding and variety evaluation of brassica oilseeds in California was begun by Paul Knowles in the 1970s-and 1980s. Canola variety trials were also conducted intermittently by Tom Kearney (UCCE, Yolo County) until his retirement. Stapelton and Banuelos (2009) evaluated canola in the San Joaquin Valley, and reported that canola crops can tolerate irrigation with moderately saline water and accumulate selenium. Trials conducted by our research group of differing oilseed species, in several locations, have identified canola as the highest yielding winter annual oilseed alternative[2].

Despite this long history of research and development aimed at canola in California, an industry has never become established. In part, it is because oilseed crushing capacity in the state has been limited, but we believe it is primarily because of poor variety options and abundant irrigation water supplies that have allowed farmers to emphasize summer annual horticultural crops. More recently, increased plantings of woody perennials, especially almonds and grapes, has resulted in significantly curtailed water supplies for annual crops. As explained above, there is now renewed demand for winter crops that could be met by canola. The state's growing biodiesel industry, developed in response to the state's aggressive greenhouse gas regulations, creates additional new demand for canola, while the state's large dairy industry provides profitable outlets for canola meal. In combination, all these factors provide an opportunity to establish canola as a viable option for farmers across the state. Both high-yielding, well-adapted varieties and clear production guidelines are needed.

2.6. Project goals and objectives

With funding from the University of California Division of Agricultural and Natural Resources, we established a project to evaluate the suitability of canola and camelina as winter oilseed crops for California and, depending on project findings, facilitate their adoption by the Californian agricultural sector. The work is ongoing, but the aim of this

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[2] http://agric.ucdavis.edu/Oil_Seeds/

report is to provide a preliminary summary of research findings, and results from the winter growing seasons in 2012-13 and 2013-14.

3. Project progress report (2012-2014)

A diverse range of canola and camelina varieties have been assessed at sites located across the state, providing valuable information regarding their performance under California's agro-ecological conditions.[3] In this section we provide a summary of the outcomes of the work so far.

3.1. *Project challenges*

Weather-related issues

Weather varies from year to year normally, but in both 2012-13 and 2013-14 seasons, exceptionally dry winter weather resulted in a loss of several un-irrigated sites (Figure 2a) and two locations where oilseeds were planted as cover crops in orchards and vineyards. Unusually cold weather following sowing damaged other sites, notably, a late fall freeze (the so-called "polar vortex") killed all plants at a site in northern California (UC IREC Modoc County) in 2013-14. The loss of research sites or commercial crops to weather is not a failure *per se* because farmers could experience similar weather events, although it does lead to a loss of project data.

Vertebrate pests

Oilseeds are an excellent energy and protein source, and can be attractive to many wild species of birds and mammals. Anticipating and managing for such damage will be an important feature of wider adoption of winter oilseeds. The types of damage experienced with small plots can be expected to occur in fields as well, especially along field margins. Heavy damage of research plots by vertebrate pests was a serious problem at many research sites (Figure 2b-d). We have observed extensive damage to plants from Columbian black-tailed deer (*Odocoileus hemionus columbianus*), black-tailed jackrabbit (*Lepus californicus*) and California quail (*Callipepla californica*), as well as moderate to heavy damage to seedpods by birds. The most problematic species appear to be purple finches (*Carpodacus purpureus*) and/or house finches (*C. mexicanus*). Our colleagues conducting small-plot oilseed research elsewhere in California have also encountered similar problems. We do not expect this problem to dramatically impact yields in large-scale commercial plantings of either canola or camelina, but it is problematic for small-plot research.

At a plot-scale, installation of electric fences has alleviated problems from grazing mammals (Figure 2e). Birds have been a more difficult problem to manage (Figure 2b,c,d,f). Bird damage to research plots has been severe, both at establishment and prior to harvest. Notably, in the 2013-14, house finches destroyed a canola variety trial planted near Lockeford, CA. Canola appears to be more prone to seed predation by birds than

[3] Results from two field seasons, 2012-13 and 2013-14, are included here. Trials continue in 2014-15 and will be reported subsequently.

camelina. The only effective means to exclude birds is netting[4], but fully and thoroughly netting research sites is practically challenging and prohibitively expensive. All available evidence shows that less costly methods such as noisemakers (i.e. electronics, gas canons and pyrotechnics), visual repellent (i.e. streamers and balloons) and predator models (i.e. fake owls and hawk kites) are of limited value or have short-term effectiveness (BISHOP et al., 2003; SALMON et al., 2006). Bird deterrent chemicals are available (SCHAFER, 1991), and while not completely effective, research shows that they can be useful tools for repelling birds if used correctly (AVERY AND MASON, 1997; AVERY AND CUMMINGS, 2003; BISHOP et al., 2003; SALMON et al., 2006; SHEFTE et al., 1982; WERNER AND PROVENZA, 2011). We have found that planting unprotected decoy crops and providing seed for birds to eat can also be effective in deterring damaged to research plots.

[4] George Linz from the United States Department of Agriculture Animal and Plant Health Inspection Service., personal communication.

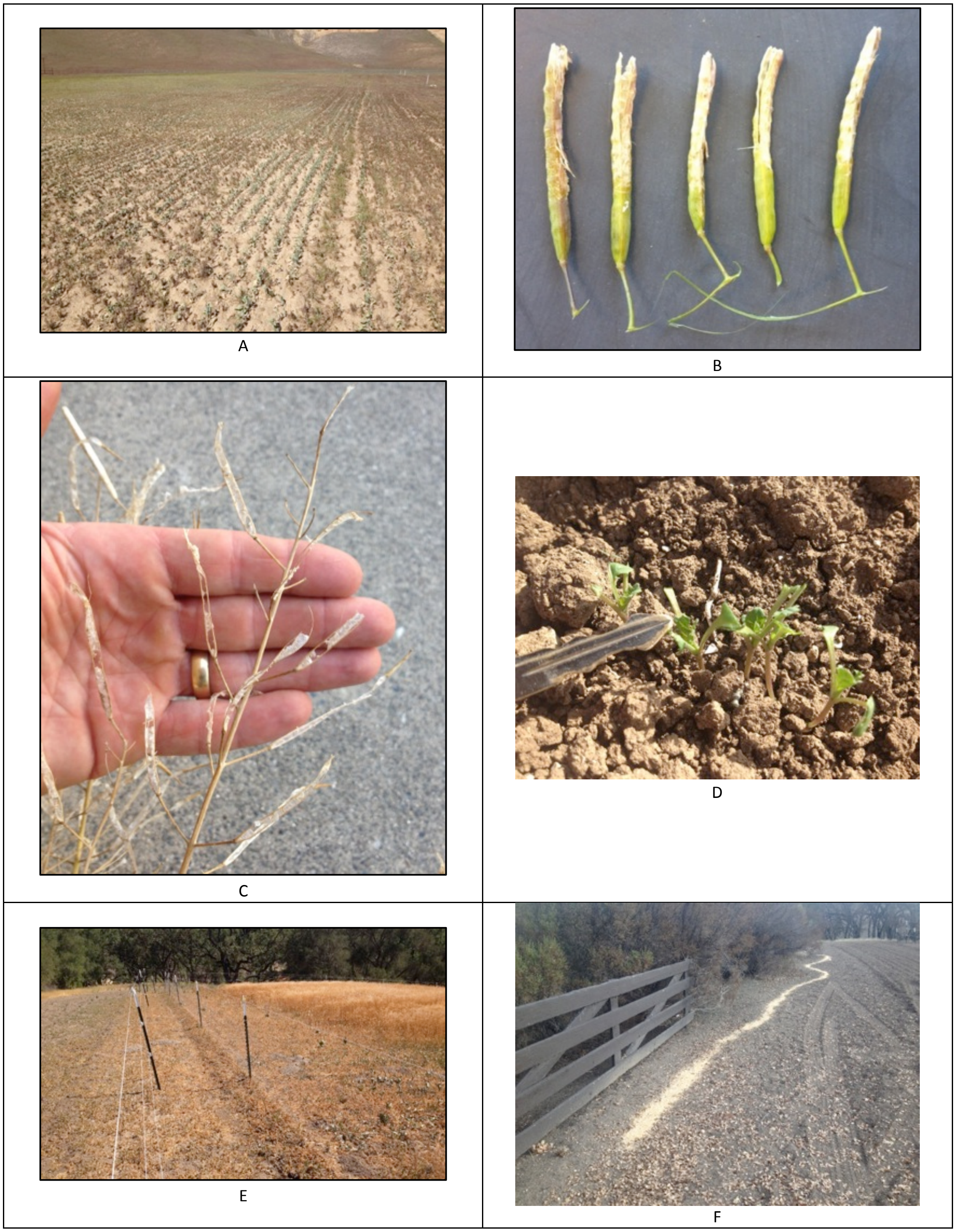


Figure 2: A) A dryland canola site killed by drought, Shandon. B) Canola pods showing damage from bird feeding. C) Mature canola plant showing the complete destruction of all pods from bird feeding, Lockeford. D) Canola seedling eaten by quail. E) Double row fence for excluding deer and rabbits. F) Bird seed, used to deter quail from plots.

3.2. Species and variety selection

To date, one hundred and twenty commercial and experimental varieties of canola, supplied by six private companies[5] and Kansas State University, and one hundred and five varieties of camelina from the company Sustainable Oils and the USDA Germplasm Resources Information Network, have been grown in a multi-environment trial at locations across California, including University of California and USDA research stations as well as private farms (Figure 3 & Figure 4). The objective of the work is to obtain accurate and reliable predictions regarding the yield potential of these canola varieties in California.

Multi-environment trials of this type tend to produce unbalanced/incomplete data sets due to issues such as the addition and/or removal of varieties over the course of the work, limited seed supplies, and the loss of plots due to uncontrollable environmental factors such as drought. The wide geographic spacing of sites in multi-environment trials also stretches personal, time and financial resources of small research groups. Anticipating these challenges, we elected to use a partially replicated trial design and to analyze data using a mixed model approach so as to maximize the efficiency of our work.

Fully replicated designs are expensive, and unnecessary from a statistical perspective. Instead, it is more cost effective if a percentage of test lines are replicated and fewer replicates, or even single plots, of the remaining varieties are used (CULLIS et al., 2006; SMITH et al., 2006). This reduces the size of individual trials sites and thereby saves resources at the trial level. More widely used analytical methods, such as ANOVA, cannot be readily used for this type of experimental design. Mixed models can accommodate incomplete data sets of this sort, and they can also accommodate variance heterogeneity between sites, which is another common problem in multi-environment trials (SMITH et al., 2001a; VAN EEWIJK et al., 2001). By considering variety effects as random, and by including other terms in the model for environmental effects, mixed models also produce more reliable estimates of genotype performance, and genotype by environment interaction across different environments, than more conventional analytical methods (BEECK et al., 2010; SMITH et al., 2001a; SMITH et al., 2001b).

To maximize the value of crop yield data gathered by our project, detailed soil and climatic data has been taken at all study sites. Information regarding the chemical and physical properties of soil has been taken from throughout the soil profile at all study sites, to a depth of 150 cm. This includes starting and ending volumetric soil water content, soil bulk density, wilting point, field capacity, organic matter percentage, nitrogen, phosphorous, potassium and micronutrient content, pH, cation exchange capacity, and soil particle size fractions. Weather data between planting and harvest,

[5] Pacific Seeds – Australia, NPZ– Australia, Winfield Solutions – USA, Cibus – USA (California), DL Seeds – Canada, Kaiima – Israel.

including temperature, rainfall, humidity, and solar radiation has been recorded using both the CIMIS station network[6] and our own weather stations.

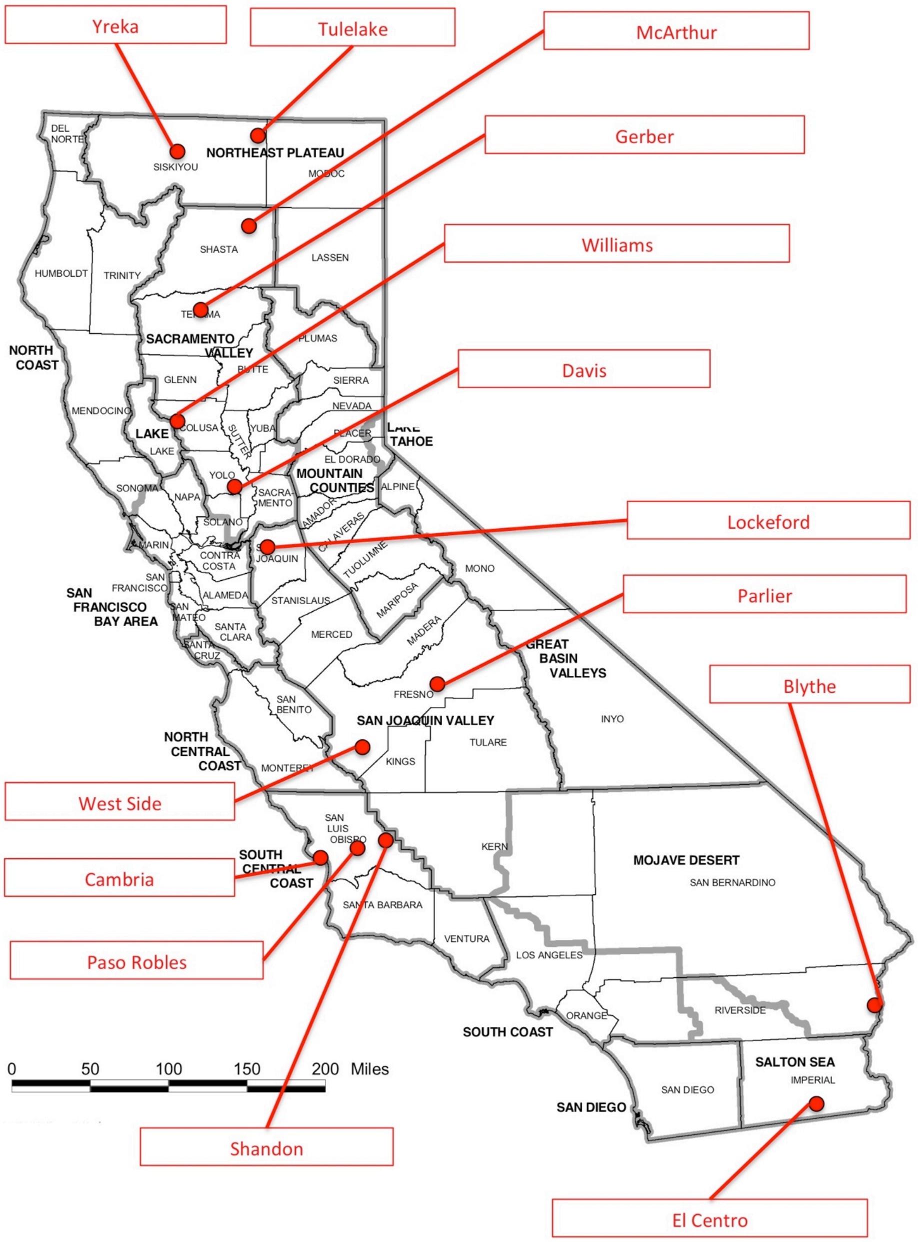


Figure 3: The locations used for canola and camelina variety evaluations.

[6] http://www.cimis.water.ca.gov/

A

B

C

D

E

F

Figure 4: A) Collection of soil samples, Davis. B) Early season camelina variety trial, Parlier. C) Adjacent canola and camelina variety trials, Paso Robles. D) Canola variety trial, showing difference in flowering times, Davis. E) Later season camelina variety trial, West Side. F) Harvesting camelina variety plots, West Side.

Variety trial work is ongoing and therefore the most reliable estimates of variety performance will not be available until after the third field season of the current project is completed; however, preliminary performance estimates are given here. Sites that were lost to drought or animal damage are not included in the yield estimates. A greater number of trial sites are available for camelina than canola, reflecting the fact that camelina has been more tolerant of drought and bird damage.

Canola has good yield potential in California compared to other canola-growing regions such as Canada and Australia. There are significant differences between varieties, with the best performing varieties tending to be short-season spring-types developed in Australia. Small plot yields of close to 5000 kg/ha have been observed in some locations (Davis and the Imperial Valley), although across all sites and years the top ten percent of lines have achieved approximately 3000 kg/ha to 3500 kg/ha. This is higher than the average yield for canola in North America, which is around 1800 kg/ha (USDA NASS, 2015). Winter-adapted varieties from temperate regions have failed to produce seed in California, even in the inter-mountain region (Modoc County) where similar temperatures occur. In the central valley, coastal and desert regions, it did not get cold enough to meet the chilling requirement necessary for flowering of the varieties.

Camelina yields are comparable to what have been achieved elsewhere in North America (PUTNAM et al., 1993). Camelina yields have been more uniform across varieties than canola, with the top ten percent reliably yielding 1000 kg/ha.

Preliminary analysis suggests there is only minimal genotype by environment interaction occurring in either the canola or the camelina. In other words, variety rankings seem to be consistent across sites and years. This is interesting given the climatic and soil differences between sites and suggests fewer research sites could be used in the future.

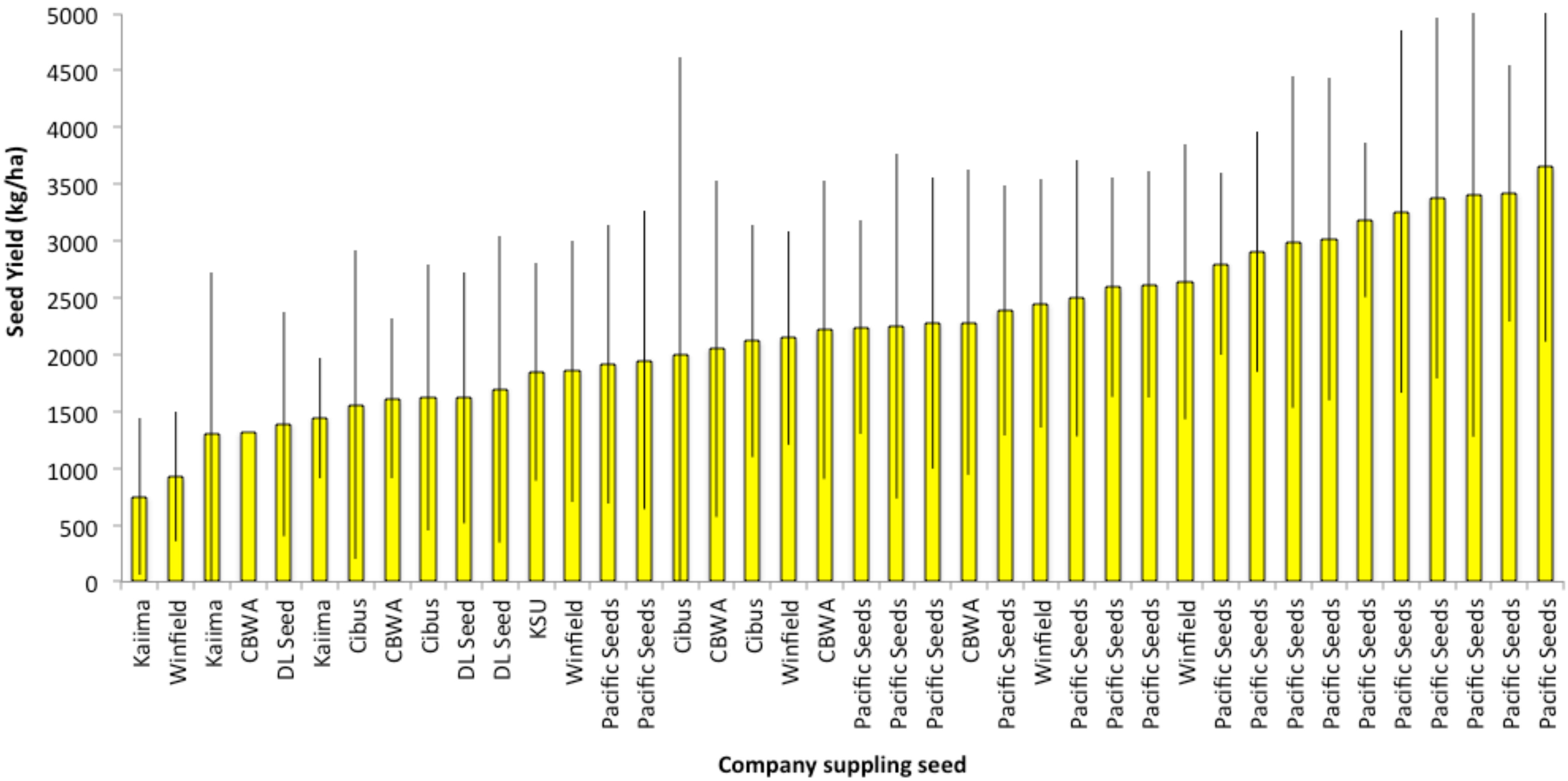


Figure 5: Yield performance of canola varieties in California. Values are best linear unbiased predictions with standard errors. Variety names are not presented for legal reasons.

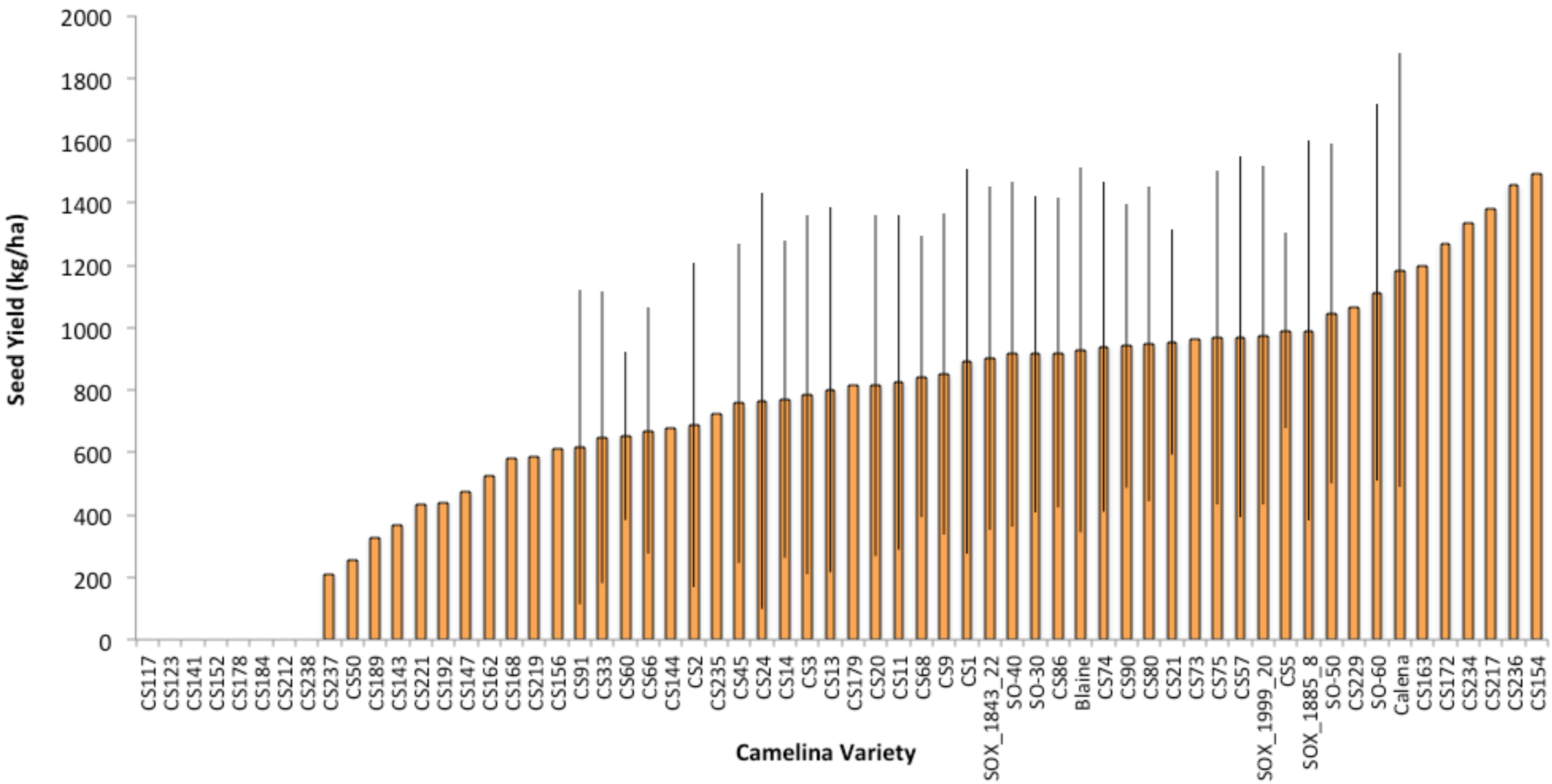


Figure 6: Yield performance of camelina varieties in California. Note: some varieties have only been included in a single site so variance estimates are not yet available. Values are best linear unbiased predictions with standard errors.

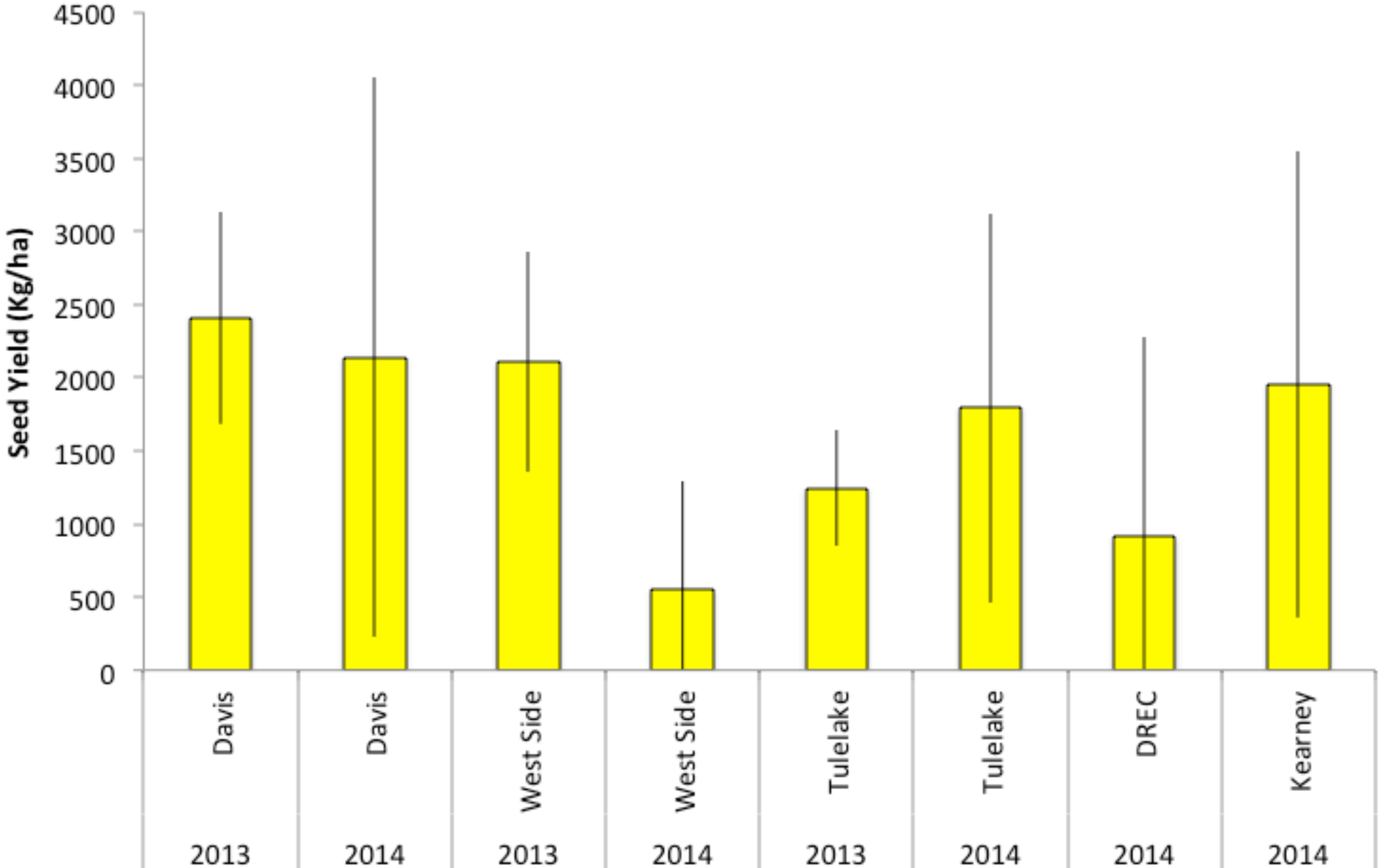


Figure 7: Yield performance of canola varieties by site and year. Data are summarized raw data. Standard deviation is given.

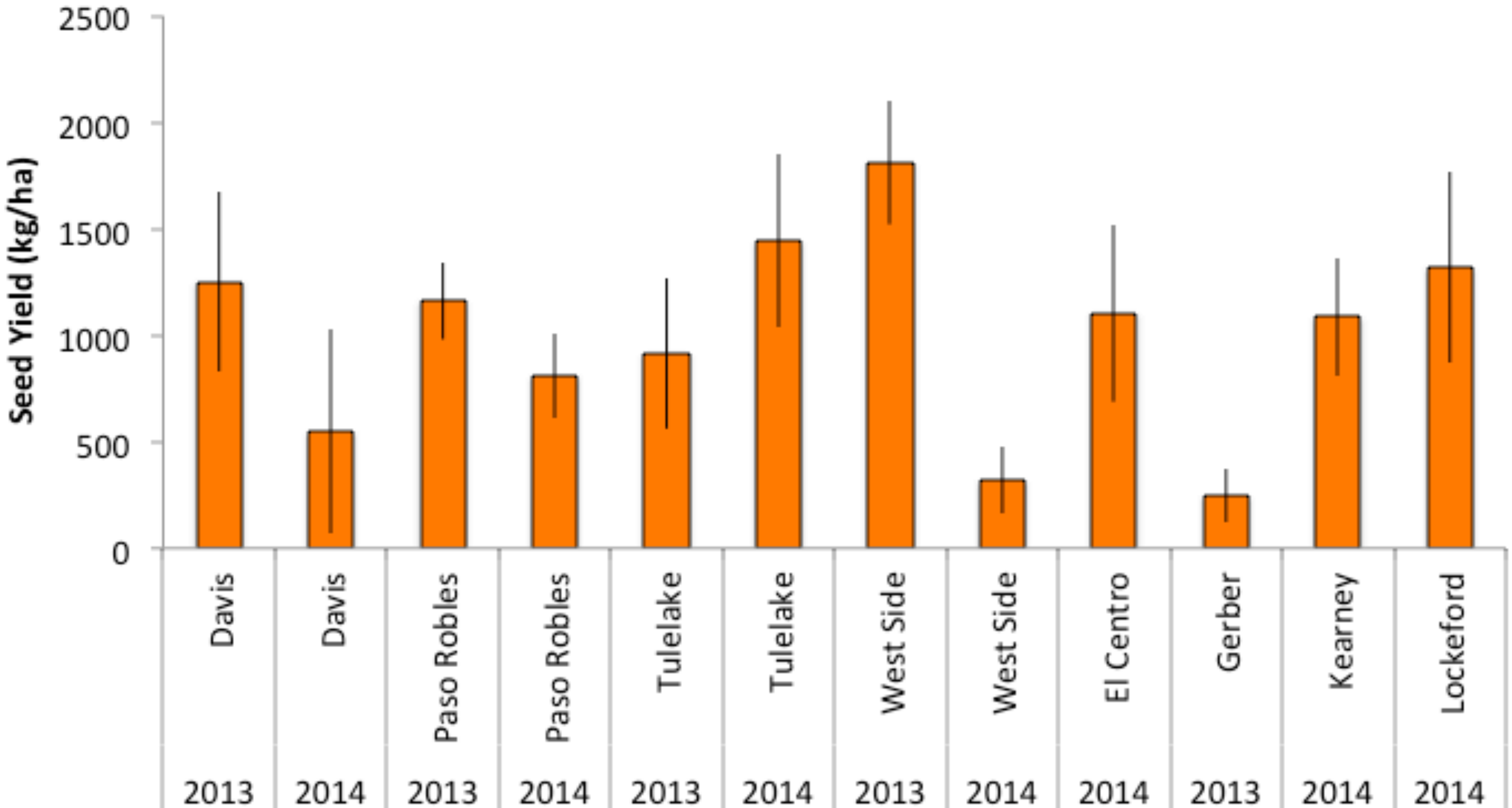


Figure 8: Yield performance of camelina varieties by site and year. Data are summarized raw data. Standard deviation is given.

3.3. *Agronomic requirements*

Besides varietal selection, the most critical agronomic issue for canola in California appears to be identifying an optimal planting time. Correct planting date is an important factor dictating the yield potential of canola and camelina (ALLEN et al., 2014; EDWARDS AND HERTEL, 2011; FARRÉ et al., 2007; FARRÉ et al., 2002; HOCKING AND STAPPER, 2001; RICHARDS AND THURLING, 1978; ROBERTSON et al., 1999; SI AND WALTON, 2004). Unlike the areas of southern Australia where top-performing varieties from our trials were developed, we have observed that soil seedbed temperatures in California routinely become too cold to support uniform and reliable crop establishment before adequate rain has fallen. We therefore chose to investigate this issue using a modeling approach.

Under field conditions, the germination and establishment of canola is sub-optimal below 10°C (BLACKSHAW, 1991; CCC, 2015; NYKIFORUK AND JOHNSON-FLANAGAN, 1994; NYKIFORUK AND JOHNSON-FLANAGAN, 1999; RUSSON et al., 2010; VIGIL et al., 1997) and germination is reduced when soil matric potential is below -0.4 Mpa (BLACKSHAW, 1991; WILLIAMS AND SHAYKEWICH, 1971)). The temperature and moisture thresholds for the germination and establishment of camelina under field conditions are not well documented, however the species is known to be more cold tolerant than canola. In laboratory tests, 100 % germination occurs at temperatures as low as 0°C (ALLEN et al., 2014) and germination can occur at very low soil water potentials (< -3.0 MPa) (JIANG, 2013). We have observed reasonable germination and establishment of camelina crops in the field with soil temperatures of around 5°C.

Seedbed temperatures were estimated for a dry loam soil at 2.5 cm with no soil cover based on average air temperatures (KÄTTERER AND ANDRÖN, 2008; THOMPSON et al., 2014). The soil temperature model was validated by comparing soil temperature estimates with soil temperatures at a depth of 15 cm recorded by the California Irrigation Management Information System weather station (CIMIS, 2015).

Soil water potential and soil moisture content were estimated for 31 years (1983 through 2013) at eleven California Irrigation Management Information System weather station (CIMIS, 2015) sites throughout the Sacramento Valley, San Joaquin Valley, and Central Coast of California using Hydrus 1D (SIMUNEK et al., 2014). Each combination of year, soil type, and site requires Hydrus to be run once. This is very time consuming so we developed a program in Matlab to automate the process. CIMIS solar radiation, temperature, humidity, and wind speed data from each of the sites for all years available from 1983 through 2013 were utilized. Soil moisture and matric potential are functions of soil type. Therefore soil types from regions around each CIMIS station were obtained from the United States Department of Agricultural Natural Resources Conservation Service (NRCS, 2015). As most loam soil types were represented in these regions, we estimated values for all loam varieties.

This modeling work found that soil temperatures in the agricultural regions of California will typically decline below 10°C at the end of November but in only a third of years will soils be sufficiently moist for reliable germination under rain-fed conditions by this time. This demonstrates a constraint on the success of canola production in California. To ensure stand establishment in canola in California, early planting will be needed in conjunction with supplemental irrigation in a portion of years. The need for irrigation will depend on soil type and be less dependent on specific location.

In production situations with water supply constraints or no ability to irrigate, canola will need to be planted opportunistically under conditions of early rainfall or sufficient warm seedbed conditions. Canola varieties that germinate more reliably under colder soil conditions, and which can therefore be planted later in the season, might also be worth investigating.

Camelina, being more tolerant of cold and dry soils than canola, does not have the planting constraint of canola in California. Our analyses suggest the species can be sown in California at any time during winter as soon as seedbed moisture is sufficient.

As variety trialing in California progresses, information regarding soil moisture and temperature effects on germination of best-adapted varieties would be useful in making more accurate predictions regarding planting dates.

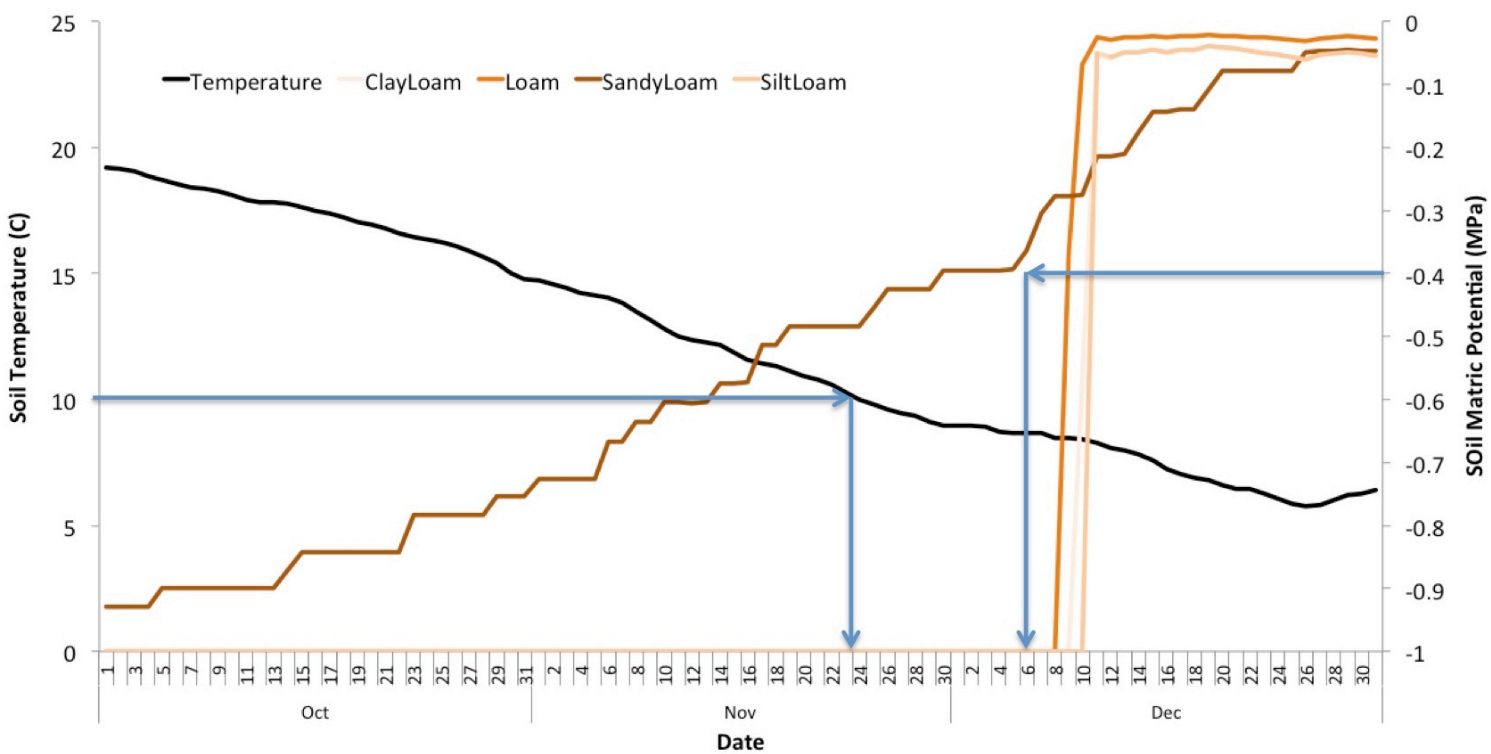


Figure 9: Estimated soil temperature and matric potential for the Davis region. The minimal soil temperature for canola germination is 10°C, the minimum soil matric potential for germination is -0.4 MPa.

3.4. Water use

Current drought conditions in California have limited surface water deliveries, increased the use of possibly unsustainable groundwater supplies, and resulted in agricultural land being fallowed. Future climatic changes could further increase the demand for irrigation while reducing irrigation water availability (CAYAN et al., 2008; COOK et al., 2015; JACKSON et al., 2012; LEE AND SIX, 2010; PARRY et al., 2007). It is therefore important to understand the water requirements of canola and camelina in California before they are actively promoted as crops. If new species can be shown to use less water than other annual crop alternatives, while providing adequate economic returns, then it makes a strong argument that these species should be investigated further.

At selected research sites, we are measuring soil moisture content using volumetric water content sensors[7]. Using data from these sensors we have made an initial estimate of daily evapotranspiration (ET) in canola and camelina, and its relationship with yield (Figure 10 & Figure 11). This suggests that maximum water use for canola during our study has been around 380 mm. The water use of camelina is less clear, but may be as little as 250 mm to achieve full yield potential. This is similar to, or possibly lower than, winter wheat in California, which can be as high as 560 mm for wheat grown for grain (JACKSON et al., 2006), and substantially lower than summer crop rotations.

We have compared modeled daily evaporation and CIMIS reference evaporation to make a preliminary estimate of crop coefficients (Kc). In the literature the maximum Kc values for canola and camelina are approximately equal to pan evaporation or 1.0 (FAO, 1998; HUNSAKER et al., 2013). Our initial results are consistent with this, maximum values are generally not larger than 1.0, although average daily Kc values during active growth periods are usually around 0.5 for both species. Additional data and analyses are required to strengthen these results, but they can be used to inform the agronomic management of these crops in California. Water use is quite low compared to many other crops in California, especially those grown in warmer times of the year.

[7] http://www.decagon.com

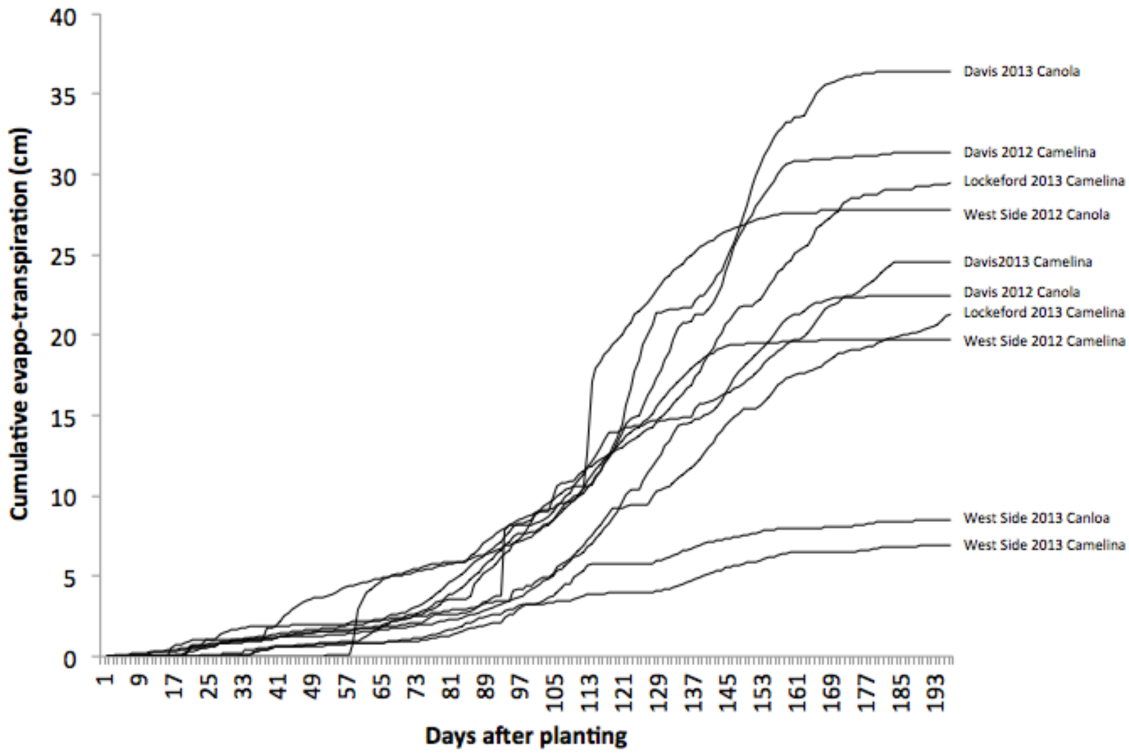


Figure 10: The estimated cumulative evapotranspiration from canola and camelina crops at multiple locations in California estimated using volumetric soil water content data.

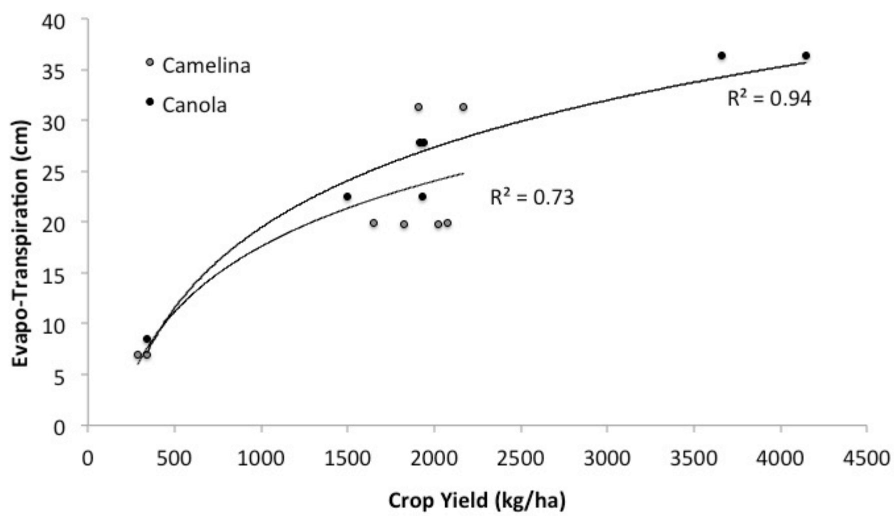


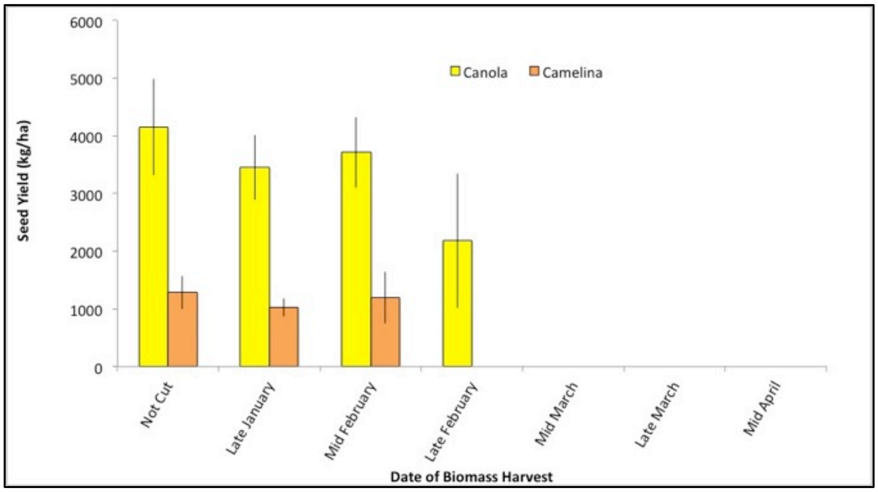
Figure 11: The relationship between yields and total water use for both canola and camelina at multiple sites in California.

3.5. Grazing (dual-purpose) canola

The use of canola for both oil and seed meal is well established (CCC, 2015), but it is also suitable as a source of forage (MCCORMICK, 2007). Canola could therefore be a useful source of feed for the Californian livestock industry. Work from Australia has shown that under diverse climatic conditions, including conditions similar to some California locations and years, commercial quantities of forage biomass can be removed from canola without incurring a reduction in seed yield (KIRKEGAARD et al., 2008; KIRKEGAARD et al., 2012a; KIRKEGAARD et al., 2012b; MCCORMICK et al., 2012). Dual-purpose grain cropping – when a crop is first grazed and then permitted to re-grow for grain production – is a well-established practice in cereals (HARRISON et al., 2011). A dual-purpose broadleaf crop, with a high value grain, would be valuable for mixed crop and livestock farming operations in California that are common along the central coast. The published work regarding the use of camelina for hay or silage suggests it provides a forage with a good nutritive value when harvested at a stage before the flowering period (PERIETTI AND MEINERI, 2007). There is no published information regarding whether it is suitable for dual-purpose systems.

We investigated the effect of different cutting-times on the biomass yield, biomass quality and seed yield of both canola and camelina (Figure 12). Cutting was used to simulate grazing. There was no significant reduction in seed yield of either canola or camelina if biomass was removed before the end of February (Figure 13). Yields of dry biomass for the mid-February cutting date were approximately 700 kg/ha and 900 kg/ha for camelina and canola, respectively and the biomass was of a good quality for use as forage (Table 1). This work suggests both species could be used in dual-purpose systems in California. Further investigation is justified.

Figure 12: A) The dual purpose study, showing plots of canola and camelina, some of which have been cut. B) A plot of canola being harvested for biomass. C) Canola plants that have been cut. D) Canola plants resprouting after being cut. E) Two plots of camelina, the plot on the left is uncut, the plot on the right has been cut and is regrowing.



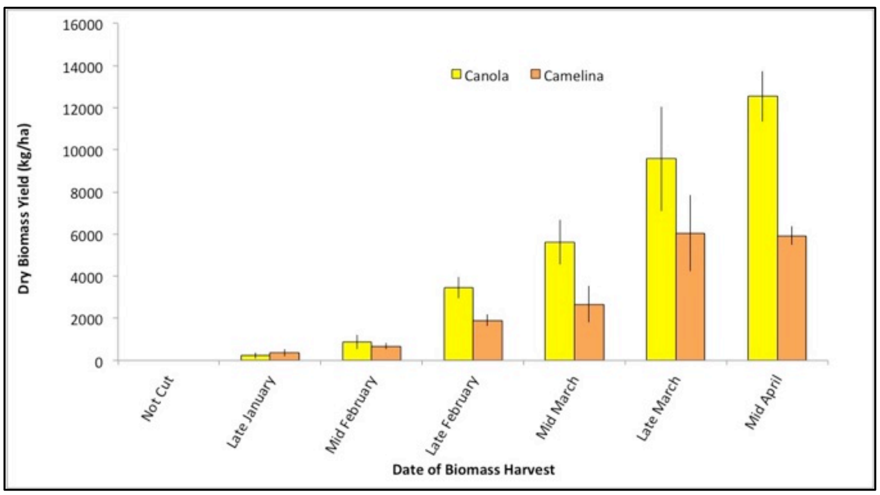


Figure 13: The seed and biomass yield from canola and camelina cut at different times throughout the growing season.

Table 1: Feed quality analysis of biomass from both canola and camelina at different times during the growing season.

	Camelina			Canola	
Cutting Date	**Protein %**	**ADF %**		**Protein %**	**ADF %**
Late Jan	35	34		40	17
Mid Feb	36	24		40	15
Late Feb	32	28		32	32
Mid March	25	32		22	43
Late March	17	38		16	36
Mid April	17	36		14	38

3.6. *The Agricultural Production Systems Simulator (APSIM)*

Crop modeling is becoming increasingly important as a tool for agricultural research (HOLZWORTH et al., 2014). Well-calibrated crop production models are therefore valuable tools for extending the results of trials at limited locations, assessing the potential of a new crop in a new location or across a wider range of years, identifying additional research questions, and better targeting further field research.

The Agricultural Production Systems Simulator (APSIM) is an open-source modular modeling framework, developed by the Agricultural Production Systems Research Unit (in the Australian government scientific body CSIRO), that combines biophysical and management modules to simulate cropping systems (HOLZWORTH et al., 2014; KEATING et al., 2003). APSIM was designed as a farming systems simulator that could combine accurate yield estimation in response to management with prediction of the long-term consequences of farming practices on the soil (Keating et al., 2003). The program contains modules for simulating crop growth, development and yield, as well as soil water, nitrogen and carbon dynamics (Keating et al., 2003). Independent research has found good agreement between APSIM predictions and field observations, demonstrating the model's validity and robustness for simulating yield estimates, whole farm modeling, effects of agriculture on water quality, climate change effects and adaptation (HOLZWORTH et al., 2014; KEATING et al., 2003).

APSIM has modules for simulating canola production, although at this stage no module is avilable for camelina. We used APSIM to investigate the yield potential of canola in multiple locations in California (GEORGE et al., 2012). The model suggests that, under rainfed conditions in the Sacramento Valley, the long-term average yield for canola could be approximatley 3000 to 3500 kg/ha, similar to observations from our field trials to date. With supplemental irrigation, yields in the San Joaquin Valley should be similar. Our current project aims to make an initial validation of APSIM for canola production in California using our in field trial data relating to crop yield, soil and weather conditions.

3.7. *Weed management & volunteer risk*

There is concern among growers and individuals in the public regarding the risk of canola becoming agricultural and/or environmental weeds in California (for example (MUNIER et al., 2012)). Even with ideal practices, the size and physical characteristics of the seed of canola will inevitably lead to seed loss during harvest and transportation, and the establishment of feral populations (GULDEN et al., 2004). We have observed seed losses from camelina to be similar to that of canola.

Agricultural weed risk

Canola has been grown for many decades in places such as Canada, Europe and Australia and is not reported to be a problematic agricultural weed in these regions. Southern Australia is climatically comparable to California; therefore the experiences there are likely to be similar. Improper volunteer management of canola can cause yield loss in subsequent crops (SEEREY AND SHIRTLIFFE, 2010). As with all crops, proper management is therefore necessary to ensure control of volunteers. Soil seed banks of canola decline quickly with corrected management (BAKER AND PRESTON, 2008). The Canola Council of Canada and the Western Australian Agricultural Department provide best practices for the management of volunteer canola (CCC, 2015; DUFF et al., 2006). So given suitable management we contend that canola is unlikely to become a problematic agricultural weeds in California. Information regarding the agricultural weed risk of camelina is not as available as for canola. Camelina can be a weed of cereals (FRANCIS AND WARWICK, 2009). Volunteer management guidelines are likely to be similar as those for canola.

Environmental weed risk

Feral canola is reported from most places where the crop is commonly grown, including Europe, Canada, the United States and Australia (CRAWLEY AND BROWN, 1995; CRAWLEY AND BROWN, 2004; FLORABASE, 2013; MUNIER et al., 2012; SCHAFER et al., 2011; SQUIRE et al., 2011). Both canola and camelina, and their relatives, are already present throughout North America, although camelina is not common in California, and neither species is listed as an invasive or noxious weed (USDA NRCS, 2015). The production of both crops in California will therefore not result in the introduction a new species into North America.

Neither canola nor camelina is reported to be a problematic weed of non-agricultural land (USDA NRCS, 2015). Canola is an early successional species, and is not competitive in established vegetation (CRAWLEY AND BROWN, 1995), and we believe the biology of camelina is most probably similar. We believe it is unlikely that canola or camelina will become important weeds outside of cultivation in California in the future.

Weed risk from herbicide tolerant canola

Varieties of canola resistant to Glufosinate, Triazine, Glyphosate and Imidazolinone are commercially available. These varieties have been adopted by growers in the United States, Canada and Australia. From a weed-management standpoint, the use of herbicide tolerant lines will reduce the number of herbicides that can be used to effectively control both volunteer and feral canola. With alternative herbicides, and standard non-herbicide management methods, it is straightforward to deal with herbicide tolerant canola that volunteers (BAKER AND PRESTON, 2008). In areas of Canada where herbicide tolerant canola has been grown for a number of decades surveys of growers find the majority do not have trouble managing volunteers in subsequent crops (GUSTA et al., 2011). With the exception of situations where management methods are more limited, we expect the situation in California will be similar (MUNIER et al., 2012).

Herbicide tolerant canola has become established outside of agricultural environments in Canada and the United States (KNISPEL et al., 2008), and has already escaped cultivation in California (MUNIER et al., 2012). Outcrossing amongst feral canola populations has also led to the stacking of herbicide tolerance traits (KNISPEL et al., 2008). It is therefore likely that if herbicide tolerant canola varieties are grown in

California, feral populations will become established, but canola is not a competitive weed in established vegetation and herbicide tolerance traits will generally not provide a selective advantage. Herbicide tolerant feral canola is therefore no more likely to become a problematic weed than non-herbicide tolerant canola. The exception to this will be in areas such as road verges where chemical weed control is frequently utilized.

Canola will hybridize with its wild relatives (WARWICK et al., 2003) and whilst hybridization rates are low, it is possible that herbicide tolerance could transfer to other Brassica species, although it is worth noting that herbicide tolerance has been evolving in other Brassica weeds in the absence of herbicide tolerant canola (HEAP, 2013). Under cultivation alternative weed control methods can be used to control these types of weeds, similar to the control of volunteer canola. Similarly, herbicide tolerance will not offer a competitive advantage to these weeds under feral conditions unless herbicides are used in those environments. Under situations where there is a reliance on a small number of herbicide for weed control, such as orchards and road verges, herbicide tolerant Brassica weeds could become more difficult to control.

4. Conclusions

This report provides a summary of the findings from our work relating to canola and camelina in California. Key findings are:

- Canola and camelina varieties with the high yield potential in California are being identified.
- Yields of canola in California have been greater than average yields in other canola growing regions and camelina yields are comparable to yields achieved elsewhere.
- Camelina yields are lower than canola, although similar to yields obtained elsewhere in North American. This suggests camelina will need to occupy a different agro-ecological niche to be economically competitive.
- Yields from both canola and camelina should be economically viable.
- Agronomic challenges specific to canola in California have been identified, notably temperature and water constraints to germination and planting.
- Water use is relatively low compared to summer rotations and comparable to alternative winter rotations.
- Preliminary assessment suggests the APSIM crop model may be useful as tool for R&D relating to canola in California.

5. Future R&D needs

5.1. Phenology and environmental responsiveness of canola and camelina

There is a lack of specific information regarding the developmental phenology and environmental responsiveness of canola and camelina varieties under Californian conditions. Environmental response, such as temperature and moisture thresholds for germination and growing degree-days required for different growth stages, are variety specific. This information is needed to inform the agronomic management of canola and camelina in California and to calibrate crop models that can then be used as strategic and tactical planning tools.

5.2. Crop water use

We have developed the first estimates of evapotranspiration for canola and camelina in California and can now make recommendations regarding water use and irrigation management. To develop detailed water use models for new oilseeds, and to estimate the water-use implications for using oilseeds instead of wheat, it will be necessary to directly compare canola, camelina and wheat via more intensive instrumentation.

5.3. Ongoing field evaluation

To facilitate the adoption of oilseeds as crops in California we think it is necessary to continue to build grower and industry confidence in canola and camelina. This can be achieved via demonstration crops and ongoing variety evaluation.

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