A guide for canola and camelina research in California

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Introduction

Canola (*Brassica napus*) and camelina (*Camelina sativa*) could be used to diversify winter crop rotations in California. Canola is a well-established crop in Canada, Europe and Australia (FAOSTAT, 2014). The United States is a relatively small canola producer, with some production in North Dakota, Oklahoma, Montana, Idaho and Minnesota (USDA NASS, 2014) and effectively no commercial production in California at the present time.

Relative to other oilseeds, canola has received the greatest research and development effort, and has the greatest yield potential under good growing conditions. However, it can become unreliable in low rainfall conditions (Farré, Robertson, et al., 2007) and there are also other agro-ecological circumstances where it may not be compatible with existing rotations. Camelina, which is more cold tolerant and matures faster than canola (Allen, Vigil, et al., 2014, Jiang, 2013, Putnam, Budin, et al., 1993), could therefore be a good alternative for growers.

Our research group at the University of California, Davis, has been investigating canola and camelina since 2006. This work has included extensive variety trials and agronomic research at locations throughout California. In this report, we document our experiences from this work to provide California-specific information to complement existing production guides and help inform future research and developed efforts.

Suggested information sources

For information relating to canola production in North America, please refer to grower manuals provided by the Canola Council of Canada, the United States Canola Association, and also the Great Plains Canola Production Handbook (Boyles, Bushong, et al., 2012, CCC, 2015, USCA, 2015). In some instances, the information in these guides is not applicable to Californian conditions so we also refer people to canola production information for southern Australia (Duff, Sermon, et al., 2006, McCaffery, Potter, et al., 2009). This region is climatically comparable to much of California.

Given its status as a minor crop, information regarding camelina production is more limited than for canola, although a number of short production guides are available (Enjalbert and Johnson, 2011, Hulbert, Guy, et al., 2012, Lafferty, Rife, et al., 2009, McVay and Lamb, 2008).

When conducting variety assessments on canola and camelina, we suggest workers adhere to established protocols for oilseeds. Good sources of information include the Australian Grains Research & Development and the Kansas State University National Winter Canola Variety Trials (GRDC NVT, 2015, KSU, 2015).

Successful introduction and adoption of new crops requires rigorous, high quality and efficient research and development. We strongly suggest that those wishing to undertake field research relating to canola or camelina in California therefore consult production guides and published research relating to both species.

Variety selection

Our work suggests canola has good yield potential in California. The best-adapted varieties tend to be short-season spring-types developed in Australia. Across sites and years the best varieties have achieved approximately 3000 to 3500 kg/ha. Winter-adapted varieties have failed to produce seed in California, even in the inter-mountain region.

Camelina yields in our trials are comparable to what has been achieved elsewhere in North America (Putnam, Budin, et al., 1993), with the best varieties reliably producing 1000 to 1200 kg/ha of seed. In contrast to canola, camelina yields are more uniform across varieties; however the best performing varieties in our trials tend to be commercial lines.

Preliminary analysis of our field data suggests there is only minimal genotype by environment interaction occurring in either canola or camelina across California. In other words, variety rankings seem to be consistent across sites and years.

Site selection

Soil type

Canola yields best when grown on deep, well-drained, silt loam soils that do not crust; however, it can be grown successfully on a wide range of soil types (CCC, 2015, Duff, Sermon, et al., 2006) and should be suited to the loam soils commonly found throughout the Central Valley, Central Coast and Imperial Valley of California. There is less information regarding the soil types suitable for camelina, but it is a relatively adaptable species (Campbell, Rossi, et al., 2013, Putnam, Budin, et al., 1993) and in California we have observed camelina to perform well in similar soils to canola.

Rotations

Canola is most commonly grown following cereals or pastures. However, California agro-ecosystems are more diverse than many other regions, so canola and camelina could follow multiple different crops.

To reduce the risk of problems from soil-borne diseases, the field should not have had a brassica crop in the past four years. It should also be one year since dicotyledonous crops like legumes or sunflowers have been grown because these can also harbor disease that can affect canola. Camelina is potentially more disease resistant than canola (Putnam, Budin, et al., 1993), but similar rotational practices should still be observed.

Water-logging

Canola and camelina are both less tolerant of waterlogging than cereals and our observations suggest camelina is more sensitive to waterlogging than canola. Short periods of inundation or saturated soil can cause crop injury, particularly when plants are small. Short durations of waterlogging can also reduce the yield potential of canola, and presumably also camelina, even without obvious crop injury (Duff, Sermon, et al., 2006, McCaffery, Potter, et al., 2009). Fields with poorly drained soils or a history of flooding should therefore be avoided. If waterlogging is unavoidable then bedding is recommended (McCaffery, Potter, et al., 2009). We have found bedding can reduce waterlogging damage relative to flat-planting under Californian conditions.

Herbicide carryover

Brassicas can be very sensitive to herbicide carry-over (notably from sulfonylureas) so the herbicide history of the field must be known. Refer to the Canola Council of Canada for information regarding plant-back restrictions for canola. Similar restrictions are also thought to apply for camelina (Enjalbert and Johnson, 2011).

Wildlife damage

In Canada, Australia and the northern and eastern United States, vertebrates are generally not reported to cause significant damage to large-scale plantings of canola or camelina. Farmers and other researchers conducting large-scale trials of canola and camelina in California also do not report vertebrate damage. For this reason, we do not anticipate vertebrate pests will cause serious yield losses to large-scale commercial plantings of canola or camelina in California. Nevertheless, vertebrates can cause serious damage to research-scale plots.

In California 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 maturing 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. Damage from vertebrates should therefore be expected in small-plot experiments and steps taken to mitigate it.

If deer damage is likely, an electric fence can be erected (Figure 1). We have found that these fences are a simple and cost effective way to exclude deer from sites. If rabbits are likely to be problematic, plastic mesh fencing can be attached to the fence.

Figure 1: Dual electric fence to exclude deer.

Bird damage to canola and camelina plots has been common and widespread across California. Birds will damage seedlings, green pods and mature seed (Figure 2, Figure 3, Figure 4, Figure 5). We have completely lost experiments to bird damage.

Preventing bird damage is challenging, and although there are many bird control methods available on the market, there are very few that are truly effective, especially in the long-term (Bishop, McKay, et al., 2003, Salmon, Whisson, et al., 2006). The only effective means to exclude birds is through netting; however, fully netting research sites is practically challenging and prohibitively expensive under most circumstances, and therefore not usually a viable option.

Bird deterrent chemicals are available. These include methyl anthranilate (Bird Shield/Avian Control) and anthraquinone (Avipel). Methyl anthranilate is a pre-ingestive trigeminal irritant and anthraquinone is a post-ingestive cathartic emodin purgative (Werner and Provenza, 2011). Whilst not completely effective, research shows these chemicals can be useful tools for repelling birds (Avery, 2003, Avery and Mason, 1997, Avery and Cummings, 2003, Bishop, McKay, et al., 2003, Linz, Homan, et al., 2006, Linz, Homan, et al., 2011, Mason and Clark, 1997, Moran, 2001, Salmon, Whisson, et al., 2006, Schafer, 1991, Shefte, Bruggers, et al., 1982, Werner and Provenza, 2011). APHIS suggests that decoy crops, and seed provided for birds to feed on can also be effective for reducing damage to research plots. We have used bird repellents in conjunction with decoy seed and believe it substantially reduced bird activity in research plots.

Figure 2: This image shows where birds have damaged the majority of the pods from maturing canola grown at Davis, CA.

Figure 3: Detail of bird damaged.

Figure 4: An individual pod showing damage from birds.

Figure 5: Image showing quail damage to canola seedlings.

Field Preparation

Seed bed

Both canola and camelina seed are relatively small and therefore the field must be cultivated to incorporate residue material from previous crops and to break up soil clods. Both species are susceptible to soil crusting, so conduct just enough tillage to achieve a reasonably level, uniform, well packed, surface structure with a mix of granules in the 1 to 5 mm size range (CCC, 2015). We typically disk and then harrow fields.

Fertilization

Fertilization amounts should be based on reliable soil analyses and field history. The nutrient needs of canola are approximately P 20 kg/ha, K 200 kg/ha and S 30 kg/ha (CCC, 2015). We have found that soils at our Californian research sites tend to have sufficient P, K and S for canola, although not in all cases. If P, K or S fertilization is needed, it should be incorporated into the soil prior to planting.

Nitrogen requirements for irrigated canola in Australia, which we believe should be similar for California, are 40 to 60 kg/ha to produce a 1000 kg/ha of grain (Pritchard, Marcoft, et al., 2010). Total nitrogen requirements for canola in California could therefore be over 200 kg/ha.

Total nitrogen is considered more important than the timing or type (McCaffery, Potter, et al., 2009), but split nitrogen applications are recommended by a number of sources. Split applications spread risk and avoid excessive losses to leaching or nitrification. Under this system, fertilizer is incorporated before sowing and then when plants begin to show increased growth in spring, but before they start to bolt. Fall-planted canola in California has been observed to bolt as early as mid-January, so the top-dress application could be needed as early as this.

Camelina is often considered to have low nutrient requirements, although evidence suggests its nutrient requirements are not dissimilar to other brassicas, including canola, especially on a per yield basis (Hulbert, Guy, et al., 2012, Putnam, Budin, et al., 1993, Solis, Vidal, et al., 2013, Wysocki, Chastain, et al., 2013). To achieve the highest yield potential, camelina should be fertilized at a similar level to that required by canola on an expected yield basis.

Pre-plant weed control

Canola, and to a lesser extent camelina, is very competitive against weeds once established, however good weed control is critical during establishment. If establishment is slow or patchy, weeds can become established and can then be difficult to control.

Chemical weed control options for both species are relatively limited. Fields with high weed pressure should therefore be avoided. Treflan (trifluralin) is currently labeled as a pre-emergent herbicide for canola (it is not labeled for use with camelina) and we use it successfully in our trials. Cultivation and Roundup (glyphosate) can also be used for pre-plant weed control.

Soil sampling & weather data

To facilitate both field preparation and interpretation of experimental data, it is essential that the physical and chemical properties of all research sites be well recorded. Canola and camelina can root to depths of 2 m so we recommend soil samples be taken from throughout the profile to this depth, or until restrictive soil layers are reached. Soil samples should be analyzed for nutrient content, texture, field capacity and wilting point. It can also valuable to know the starting soil water content.

Basic weather data is essential to the interpretation experiments, so research sites must be in the proximity of a reliable weather station. We use the weather stations of the California Irrigation Management Information System (CIMIS) and have deployed our own temporary weather station when CIMIS stations are not available.

Site establishment

Planting date

Planting date strongly influences the seed yield and oil content of canola and camelina - both decline linearly with later autumn sowing (Allen, Vigil, et al., 2014, Edwards and Hertel, 2011, Farré, Robertson, et al., 2007, Farré, Robertson, et al., 2002, Hocking and Stapper, 2001, Richards and Thurling, 1978, Robertson, Holland, et al., 1999, Si and Walton, 2004). In southern Australia, canola is usually sown as soon as sufficient autumn rain has fallen (Duff, Sermon, et al., 2006, Eksteen, 2000, Sharma, Riethmuller, et al., 2012). Our work suggests this strategy is not appropriate in California because sufficiently early fall rain is unreliable.

Under field conditions, the germination and establishment of canola seed can be suboptimal below approximately 10°C (CCC, 2015, Chen, Jackosn, et al., 2005, Edwards and Hertel, 2011, Nykiforuk and Johnson-Flanagan, 1994, Nykiforuk and Johnson-Flanagan, 1999, Vigil, Anderson, et al., 1997), and approximately 80 growing degree days with a base temperature of 0.9°C are required for 50% germination (Chen, Jackosn, et al., 2005, Vigil, Anderson, et al., 1997). Our research has found that throughout most of California, seedbed temperatures will usually reach the 10°C threshold by the end of November. This suggests that canola should therefore be sown no later than mid-November.

Camelina is more tolerant of cold than canola. It can germinate at close to freezing, and requires only 50 growing degree days with a base temperature of -0.7°C for 50% germination (Allen, Vigil, et al., 2014). The average seed bed-temperature across the growing regions generally does not drop below 7°C, suggesting there is no temperature-based cutoff date for sowing camelina in much of California.

Our experiments with winter canola lines show they tend not to flower when planted in the central valley (Figure 6). Winter-adapted varieties may, however, be adapted to winter production in the intermountain region of California.

Winter-type canola is generally planted six weeks before the average killing frost date (-4°C). Both earlier and later plantings can result in reduced yields. Long-term climate data from the Tulelake area suggests the killing freeze date for the intermountain region will generally occur around the middle of November, although it can be as early as the middle of October. This suggests the ideal planting date for the intermountain region is around the end of September.

Figure 6: A comparison between winter and spring canola lines growing in the San Joaquin valley. Winter lines have not begun flowering due to insufficient chilling hours.

Sowing

Uniform, vigorous, crop establishment is critical for successful canola production and most likely for camelina as well. Changing sowing practices to achieve good establishment, which has relatively little impact on production costs, can have a large impact on final yield (Duff, Sermon, et al., 2006).

Canola and camelina can be planted using a range of methods. Direct drilling canola at seeding rates of 4-6 kg/ha with 15 cm row spacing and at less than 2.5 cm planting depth generally results in the highest yields for canola (CCC, 2015). Slightly lower seeding rates and shallower planting depth are suggested for camelina (Lafferty, Rife, et al., 2009, McVay and Lamb, 2008). We follow these recommendations in our trial work in California with good success.

Plot size and layout

Plot size and layout is an important consideration for experimental field trials for both canola and camelina. Harvested plots need to be of a sufficient size to ensure that yield data is reliable. The minimum plot size accepted by the Australia Crop Accreditation System for oilseed trials is 5 m^2 and should have other plots grown along their axes.

Post planting management

Irrigation

In other regions, canola and camelina are usually grown using only rainfall or stored soil moisture. The total water-use of both species under high yield potential is reported to be 350 to 400 mm (Lafferty, Rife, et al., 2009, McCaffery, 2006) and work by our group in California using soil moisture sensors supports this.

The growing season for canola and camelina in California will be roughly between October and June. The average rainfall in the Sacramento Valley during this period is over 400 mm, which should be sufficient to support high yield potential of both canola and camelina with little irrigation. However, we believe supplemental irrigation may be needed in early fall to allow for the earliest possible planting and to avoid establishment issues from cold soil. Workers in Australia have also found this to be the case (McCaffery, 2004, McCaffery, 2006).

Canola is not considered reliable with less than 250 mm (8 inches) of plant available water. Average winter rainfall in the San Joaquin and Imperial Valleys is usually less than 250 mm, which is too low to support canola without supplemental irrigation.

The minimum water requirement for camelina is less clear but we have obtained crops from only 190 mm (7.5 inches) of rainfall, so it may be possible to grow camelina in the San Joaquin Valley without irrigation.

To achieve high yields in both species, some supplemental irrigation may be required in dry years or prolonged dry spells. Supplemental irrigation can also provide more flexibility in the timing of spring fertilizer applications.

Canola and camelina are sensitive to waterlogging and excess soil moisture can also cause crop lodging (Hang, Collins, et al., 2009, McCaffery, 2006, McCaffery, Potter, et al., 2009). We have encountered both of these problems in California. The timing and amount of irrigation applied will therefore need to be managed to avoid these problems.

In Australia, the best canola crops are irrigated to facilitate establishment and then receive between two and four spring irrigations (McCaffery, 2004, McCaffery, 2006, McCaffery, Potter, et al., 2009). In Australia peak water use in canola is from stem elongation until the end of pod filling (about 25 days after the end of flowering) when any stress will result in yield loss (McCaffery, Potter, et al., 2009). This is in agreement with our work in California. We have found that both canola and camelina have low water demand during the first 90 days after sowing, and water use then increases between 90 and 160 days after planting. This suggests that in California irrigation should commence around 90 days after sowing.

Canola is considered moderately tolerant to salinity, showing no yield reductions up to levels of 5 to 6 dS/m (CCC, 2015). Camelina is also reported to be moderately salt tolerant. We have not encountered obvious salinity problems in California

Post-planting weed control

Post-emergent weed control options in canola and camelina are limited. If grassy weeds become problematic, then Poast (sethoxydon), which is labeled for both canola and camelina, can be applied.

Crop monitoring & data collection

It is important to monitor field trial sites on a regular basis and to collect data to facilitate the interpretation of trial results. If irrigation is applied, the timing and quantity of the application should also be recorded. For variety trials, some groups will assess crop vigor. The Australian National Variety Trials assess vigor based on at least five experimental sites over two or more years using a visual rating on a scale of 1 to 9 (1 being poor and 9 being high). The date when approximately 50% of the plants in the field have one or more flowers is also useful.

Harvesting

Determining harvest date

In California, canola and camelina will usually be ready for harvest between early May and early June. Camelina is usually mature about two weeks prior to canola. We have found that, depending on weather conditions, the harvest window for both crops in California is usually around one week, although in some cases we have observed mature crops persisting for up to a month without problematic shattering.

Since both species mature during the onset of dry summer weather they tend to dry-down quickly and evenly.

Both species can be considered mature when the pods are dry and rattle when shaken. In California, the stems of both canola and camelina may still be partly green at this stage. Pods should shatter easily when beaten/crushed - *if seed cannot be threshed freely by hand then crop is not ready to harvest*. Once the plants thresh freely the site must be harvested immediately.

Harvesting small-scale research plots

Hand harvesting of research plots may be necessary due to a lack of suitable small plot equipment. For data accuracy, minimum plot sizes of no smaller than 5 m^2 must still be observed. Hand harvesting can therefore be time-consuming so efficiency is important. We cut plants with a brush cutter or tractor mounted sickle mower. Cutting with pruners or hand shears is far too slow for large trials. Machetes, walk-behind sickle mowers or hedge trimmers are rapid but tend to shake the crop and lead to excessively shattering.

When hand harvesting, the seed must be manually threshed and then separated from chafe. In-field threshing and seed cleaning is considerably more practical and efficient than bagging plots and threshing later. Thresh plants onto tarps by stamping/walking on them. To crudely separate seed from chafe in the field we use wooden boxes fitted with 3 mm perforated metal screens as sieves.

In California, canola and camelina mature at a time of increasing temperatures and decreasing rainfall and humidity. This promotes rapid and even stand drying and means crops can generally be directly combined without the need for swathing or desiccants. Some degree of pod shatter is always present and essentially unavoidable.

Modern combines generally have specified settings for canola, and other small-seeded crop species, so consult these for the combine model being used. Both canola and camelina will partially thresh at the reel, so if small plots are being harvested combines will need to have belt-conveyors in the throat to move seed into the body of the combine. Small differences in combine setup and operation can greatly affect the outcome of combining operations in canola and camelina. One of the most important factors is speed. Problems from jamming can be alleviated by reducing ground, reel and cylinder speeds. The crop should also be cut as high as possible, just below the seed canopy, to minimize the amount of material moving through the combine. Since both canola and camelina are easily threshed, the cylinder/rotor speed can be lower than that used for cereals. This will reduce damage to seeds. The concave should be wide open but not fully so that if plugging occurs there is still an opportunity to clear jams. Both canola and camelina have small seeds, so set fan speeds low and then raise them slowly to ensure seed is not being blown out the back of the combine.

Data collection at harvest

The following data is useful for the interpretation of oilseed experiments and therefore should be collected at harvest:

1) Crop height, maturity, lodging and shattering (maturity, lodging and shattering are recorded qualitatively).
2) End of season soil moisture content throughout the soil profile.
3) Plot dimensions for yield estimates.
4) Stand counts.
5) Total seed yield.
6) The oil and moisture content of the seed.

Volunteers & weed risk

Controlling volunteers

Concerns have been raised regarding the weed risk posed by canola in California, especially from herbicide tolerant lines (Munier, Brittan, et al., 2012). Those undertaking research on canola in California need to be sensitive to this.

Even with ideal timing and methodology, seed losses during the harvesting of canola are unavoidable. It is normal to have seed losses of 20 to 30 kg/ha, which is around five times the recommended seeding rate (Gulden, Thomas, et al., 2004). We have found seed losses from camelina to be similar. Both species are therefore prone to volunteering.

Canola has been grown for many decades in places such as Canada, Europe and Australia and has not become a problematic agricultural weed in these regions. Southern Australia is climatically comparable to California, therefore the experiences there are likely to be transferable to California. So given suitable management canola and camelina are unlikely to become problematic agricultural weeds in California.

As with all crops, proper management is necessary to ensure control of volunteers. The Canola Council of Canada and the Western Australian Agricultural Department provide best practices for the management of volunteer canola (CCC, 2015, Duff, Sermon, et al., 2006). These practices should also apply to camelina.

To minimize seed loss, harvest at the correct time using the correct combine set up. Following harvest, avoid burying seeds by not cultivating the field. Burial of canola seed, particularly under cold, wet conditions, can lead to secondary dormancy and the formation of a soil seed bank (Gulden, Thomas, et al., 2004). Seed on the soil surface will have high chance of predation and seedling death. If irrigation is possible, fields can be irrigated shortly after harvest to encourage lost seed to germinate. Actively control any remaining volunteers prior to seed set. Australian research has found that soil seed banks of canola rapidly decline if proper management methods are followed (Baker and Preston, 2008).

Broader weed risk

The species *B. napus* and *C. sativa* and their wild relatives are already naturalized in North America and feral canola is reported from most regions where the crop is commonly grown, including Europe, Canada, the United States and Australia (Crawley and Brown, 1995). Canola is already growth for seed increases in California.

Canola and camelina are not reported to be problematic weeds of non-agricultural land anywhere in the world. Canola is an early successional species, and is not a competitive weed in established vegetation (Crawley and Brown, 1995). Camelina is a smaller plant than canola and we observe it to be even less competitive against weeds. It is therefore unlikely that either species will become an important weed outside of cultivated land in California.

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, Smyth, et al., 2011). With the exception of situations where management methods are more limited, we expect the situation in California will be similar (Munier, Brittan, et al., 2012).

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

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