Energy Research and Development Division
DRAFT FINAL PROJECT REPORT

CALIFORNIA TRANSPORTATION FUELS CROPS DEVELOPMENT AND DEMONSTRATION PROJECT

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Prepared by: California Biomass Collaborative, University of California, Davis and California Department of Food and Agriculture

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PREFACE

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ABSTRACT

This research investigated crop feedstocks, including three winter annual oilseed crops, to determine potential success for bioenergy businesses in California and potential environmental effects. The feedstocks that were evaluated in research and demonstration trials over a four year period at several sites throughout California included: canola (*Brassica napus*; *B. juncea*), camelina (*Camelina sativa*), and meadowfoam (*Limnanthes alba*). Sweet Sorghum (*Sorghum bicolor*) evaluation focused primarily on the San Joaquin Valley, where climate and soil conditions are most favorable for its production. Similarly, evaluation of sugarcane (*Saccharum oficianarum*) and energy cane (*S. oficianarum x spontaneum*) focused on the Imperial Valley, which has a year-round climate with sufficiently warm winter temperatures to sustain production of these tropical perennial grasses.

In all cases, crop yields are high enough and costs of production are competitive enough to suggest that farmers would produce these crops if new bioenergy businesses create sufficient in-state demand. The exception is meadowfoam, which produces high quality oils, but is too low-yielding and variable to be of interest to growers. The adoption of these crops would not require new land and water resources, but instead cause farmers to adjust their complex cropping systems to accommodate new crop enterprises. The effects of new crop adoption vary by crop and region. Environmental effects from crop shifting associated with new crop adoption are expected to be minimal if not marginally positive. The technology needed to use these crops for energy purposes is well-known and already established and could be established here based on models for successful systems.

Formal life cycle analysis was not conducted as part of this analysis, but based on current reported standards, it appears likely that alternative fuels produced from the feedstock crops analyzed here would meet the standards required by the State's Low Carbon Fuel Standard and the Federal Renewable Fuel Standard. The stability of both policies in their present form is essential to secure confidence that investments in expanding existing facilities, and especially in new types of biorefinieries, are prudent. California's well-known high costs for regulatory compliance, and financial conditions affecting the cost and availability of capital remain obstacles to the successful development of new bioenergy enterprises in the state.

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EXECUTIVE SUMMARY

The State's Low Carbon Fuel Standard and the Federal Renewable Fuel Standard create demand for compliant alternative fuels for light duty and heavy duty vehicles in California that will increase with time. Currently, the majority of alternative fuels used in California are imported from other US or international locations. To evaluate prospects for increased in-state production of alternative fuels in California from purpose-grown agricultural feedstocks, the California Energy Commission and the California Department of Food and Agriculture (CDFA) jointly supported a multi-year year evaluation of promising feedstock crops. These crops were identified through the efforts of a technical advisory committee assembled for the project composed of farmers, participants from current or potential biofuel businesses, agency staff, university scientists, and non-profit staff.

Three winter annual oilseed crops: canola (*Brassica napus*; *B. juncea*), camelina (*Camelina sativa*), and meadowfoam (*Limnanthes alba*) were evaluated in research and demonstration trials over a four-year period at several sites throughout California. Sweet sorghum (*Sorghum bicolor*) evaluation focused primarily on the San Joaquin Valley, where climate and soil conditions are most favorable for its production. Similarly, evaluation of sugarcane (*Saccharum officianarum*) and energy cane (*S. officianarum x spontaneum*) focused on the Imperial Valley, which has a year-round climate with sufficiently warm winter temperatures to sustain production of these tropical perennial grasses. All three types of feedstocks currently are of interest to diverse groups or established companies seeking to expand their in-state production of biofuels, or establish new biofuel/bioenergy businesses in California.

Both economic analyses of the potential for bioenergy crop adoption in diverse cropping systems throughout California and assessment of biomass transformation technologies were carried out. The economic conditions under which four new bio-energy crops (canola, camelina sweet sorghum, and sugarcane) could be adopted on farms in California were analyzed. The crops and land area displaced locally by the adoption of these four crops also were identified. For this purpose we applied a cropping system optimization model that was developed for California, the Bioenergy Crop Adoption Model (BCAM). BCAM uses principles of positive mathematical programming (PMP) to capture local marginal cost information to calibrate the model to previously observed cropping patterns in the region.

A range of currently available and well-demonstrated biomass transformation technologies are available for use with the energy crops evaluated here. They could be deployed quickly if economic conditions were appropriate and policy stability is maintained.

Nature and structure of agronomic trials and demonstrations

A large number of empirical trials (65) were conducted during this project. These are identified in Table 1. Winter annual oilseed crops were carried out across California, while sugar producing crops were evaluated in the San Joaquin Valley and Imperial Valley where temperatures are most suitable. Being perennial, the number of trials with sugarcane and related genera were limited but carried out over two or more years.

Winter annual oilseeds include canola (*Brassica napa* and *Brassica juncea*), camelina (*Camelina sativa*), and meadowfoam (*Limnanthes alba*). Each is best planted in late fall or early winter, and in many locations in California may be grown on winter rainfall, or a combination of winter rainfall, stored or residual soil moisture, and limited irrigation. Where irrigation sources are limiting, winter annual crops that use little water may extend irrigation supplies while sustaining or improving farming system profitability. Each species evaluated 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 classified as edible oils in the US so they are not considered food crops. Canola, on the other hand, is a food-grade oil crop, but is identical to a non-food crop (rapeseed). Oilseed meals from canola and camelina have use as livestock feeds.

A large amount of variance in yield was observed among the canola varieties tested during these trials. 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 3). Average yields were slightly larger at WSREC site than at Davis, but average oil percent was slightly lower in most years, for approximately similar oil yields. In 2012-13, more than half the varieties at Davis and WSREC had yields greater than 3,000 lb/ac, while in two other 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 relatively high. Detailed results and discussion are presented in the body of the report.

Like canola, camelina yields varied considerably across the four years of the trials at WSREC and Davis. The effect of different years was highly significant. One apparent source of variation among years was exceptionally cold weather experienced in the 2010-11 growing season. In these trials, mid- to late November is the best planting period, effectively at the expected start of the winter rainy season in California's central valley. Harvest is generally 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. In contrast to differences among years, camelina variety differences were small and for the most part non-significant (Table 9). 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 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 so differences are primarily due to climate. Meadowfoam results are discussed in the body of the report.

Canola was always the highest yielding species among the three winter annual oilseeds tested across all sites and years. Oil content was also greater in canola than in camelina and meadowfoam. Because of its longer growing season and larger overall dry matter (DM) accumulation, canola uses more water, responds to larger amounts of nitrogen fertilizer, and has different effects on cropping systems in which it is included (Chapter 3). Camelina may be optimal for farming situations where moisture is limiting or where earlier harvest and removal is desired for double cropping purposes.

Sweet sorghum (*Sorghum bicolor*) has been identified repeatedly in recent years as a promising bioenergy crop. It is a warm season annual C4 grass that has traditionally been produced throughout the southeastern states as a source of sugar syrup. Sweet sorghum varieties with differing maturity requirements were grown from 2010-2012 at the University of California West Side Research and Extension Center near Five Points in western Fresno County. Three component studies were carried out: (1) planting date trials; (2) furrow irrigation studies; and (3) a nitrogen rate study. Biomass yields and sugar content were largely consistent across all three years and at the highest levels averaged between 11 to 12 t dry matter per acre, and 14 to 15 % Brix (sugar) content. Water stress reduced biomass and sugar yields in sweet sorghum so the best strategy is to produce sweet sorghum on fewer acres and irrigate it optimally, rather than reduce irrigation on more acres. Optimum nitrogen application rates were approximately 120 lb/ac in all three years. Lodging was a significant problem with sweet sorghum. Stalks were also evaluated each year for indications of disease occurrences (such as Fusarium presence) and none were found.

Sugarcane (*Saccharum officinarum*) is a tropical C4 grass that has been identified as a promising crop for the Imperial Valley, but may also have utility for the warmer areas of the San Joaquin Valley. In most regions, it issued for either sugar production (sucrose), or the sugar is fermented into ethanol or made into useful biochemicals. Related species in the Saccharum genera may have uses for cellulosic biofuel production or as a biomass source for combustion for electricity. Other Saccharum type grasses (especially *Saccharum sponteneum*) include crosses between sugarcane and other Saccharum genera that are called energy canes. These have high biomass yields but lower sugar contents than sugarcane and are seen primarily as sources of biomass for cellulosic ethanol production or simple combustion for power. Some *S. spontaneum* species or crosses have also been evaluated under this contract.

Saccharum clones were grown in the deep alluvial soil (42% clay, 41% silt, 16% sand) of the University of California, Desert Research and Extension Center in Holtville, southern Imperial County. The soils are not optimal for sugarcane, In the San Joaquin Valley, *Saccharum* clones were grown in the deep, fine sandy loam, soils at the University of California, Kearney Research and Extension Center in Parlier, southern Fresno County. The yield potential of better sugarcane varieties, and particularly of very high yielding Type II energy canes in the Imperial Valley, appears to be excellent. Yields were also excellent in the San Joaquin Valley, but the trials were performed on the east side of the Valley, where energy crops may not be economically viable. Nitrogen requirements were evaluated and appear consistent with literature values of 100 lb nitrogen for the plant crop, incorporated in the spring after substantial growth, and somewhat more (150 lb N/ac) for the rattoon crops. Further work with amount, timing, and composition of nitrogen fertilizer may be able to reduce the greenhouse footprint of energy cane production. Water was applied at less than expected crop requirements, potentially reducing yields in these studies. Based on calculations, high yielding sugarcane will require on average about as much water as the other current perennial crop, alfalfa (about 6.1 ac ft/year). Irrigation water requirements for sugarcane and energy canes are important considerations for farmers and biofuel businesses considering these crops in the Imperial Valley.

Economic analysis

The economic conditions under which four new bio-energy crops (sweet sorghum, canola, sugarcane and camelina could be adopted on farms in California were analyzed. The crops and land area displaced locally by the adoption of these four crops also were identified. For this purpose we applied a multi-region, multi-input and multi-output model that was developed for California, the Bioenergy Crop Adoption Model (BCAM), which uses principles of positive mathematical programming (PMP) to capture local marginal cost information to calibrate the model to previously observed cropping patterns in the region. The cropping pattern is based upon farmers' choices and behavior in the near recent past throughout California. By using farmers' actual crop choice data over time, this analysis reflects the diverse patterns of land use that have emerged in California as a consequence of the many and varying factors influencing farm management decisions at a local scale throughout the state. Using a calibrated model, scenarios related to the study's objectives were evaluated: conditions for the introduction of the three energy crops in California agricultural systems and any effects on land use within the state. Data used in this assessment on crop performance and response to management factors are based on research supported in this grant and reported here in Chapter 2.

We divided California into five production regions (Figure 71) as a way to capture and summarize the great variability of farming conditions and systems in the state. Cluster analysis was also used to determine nine production clusters for each of the five regions. The major crops within each crop cluster were determined by identifying the fewest number of crops that accounted for 95 percent of the crop frequency. Those crops that fit this criterion established the cropping pattern for each of the nine clusters in each of the five California regions and were assumed to be grown on all acres in the cluster. BCAM was used to identify the profit level required for new crop adoption in each region. In this study, more specifically, the entry price range was defined as the minimum range price at which it is expected that the region will dedicate between 5,000 and 100,000 acres to the production of any of the crops evaluated.

In all cases, crop yields identified in the agronomic trials are high enough and costs of production are competitive enough to suggest that farmers would produce these crops if new bioenergy businesses create sufficient in-state demand. The exception is meadowfoam, which produces high quality oils, but is too low-yielding and variable to be of interest to growers. The technology needed to use these crops for energy purposes is well-known and already established within the state for oilseeds, or in other locations (sweet sorghum and sugarcane), and could be established here based on models for successful systems.

Technical prospects

The characteristics of biodiesel fuels derived from vegetable oils or fats and greases depend on the fatty acid composition of the feedstock source. 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 the Fatty Acid Methyl Ester process (FAME). Alternatively, they are subject to hydrocracking in which they are converted to esters with the addition of hydrogen and are made into green diesel or renewable diesel. These fuels are largely indistinguishable from conventional petroleum diesel. In a similar manner, they can serve as a source for bio-jet fuel. 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 and degrade over time due to oxidative instability.

Canola oil, camelina oil, and meadowfoam are useful feedstocks for biodiesel production via FAME processes. However, the compositional difference between these three oils results in different corresponding qualities of biodiesel when the fatty acid profiles in the oils transfer to biodiesels. Instead of the esters that comprise biodiesel, renewable diesel or jet fuels can be made by hydrogenation and deoxygenation of vegetable oils, resulting in hydrocarbons that can be added to petroleum-based fuels with mostly similar properties. Low-cost H_2 is needed to produce biodiesel esters. H_2 is commonly available at petroleum refineries, but to date there is no such facility operating in California.

Biofuel and biochemical production from non-oilseed agricultural crops are based on the production of the monomeric sugars from biomass. Sweet sorghum and sugarcane store in their stems soluble carbohydrates produced from photosynthesis primarily as six-carbon sugars and, in the case of sweet sorghum, additional five-carbon sugars. These are removed by crushing and expressing plant juices, which are either purified and crystallized as sugar, or fermented using years to ethanol. These crops also accumulate large amounts of lignified cellulosic biomass as stems and leaves. Converting lignified cellulosic compounds to simple sugars requires additional treatments. Both C6 and C5 sugars can be derived from lignified crop residues by decomposing cellulose. Depending on the conversion technology used, different mixes of C5 and C6 sugars of varying purity can be produced.

Lignocellulosic technology is just beginning to enter the commercial phase at a small scale. The end-product, EtOH, may change to (e.g.) butanol, as the broader liquid transport issues are more fully considered, but several technologies are in development in California and elsewhere. Candidate technologies for production of advanced biofuels in California include deconstruction using thermophilic bacteria (maximum growth temperatures of ~70˚C (158˚F). Alternative technologies include chemical deconstruction by hydrodeoxygenation (dehydration-hydrogenation) processes.

Environmental considerations

All of the proposed bioenergy feedstock crops evaluated here are adapted and can be grown in California or are produced elsewhere in agricultural regions with sufficiently similar climates. In no case assessed in this analysis would land in California be converted from a more natural condition (less intensive management) to the more highly modified character of farmland. In general, after urbanization, the most significant ecological intervention in landscapes is the conversion from natural or low intensity management landscapes to ones suitable for intensive crop farming. Such conversion occurred in large areas of California during the late 19th and early 20th centuries, and has largely ceased since that time. There are approximately 10 million irrigated acres in farm use in California, out of a total of approximately 100 million acres of all landscape types.

The adoption of the bioenergy crops analyzed here would not require new land and water resources, but instead cause farmers to adjust their complex cropping systems to accommodate new crop enterprises. The effects of new crop adoption vary by crop and region and are discussed in the report. Environmental effects from crop shifting associated with new crop adoption are expected to be minimal if not marginally positive. A number of wildlife species inhabit managed landscapes, and some thrive in such landscapes. Altering annual crops produced in a given area of the state where a large range of crop species already are in production will not alter the character of the landscape with respect to wildlife or other relevant aspects of biodiversity for the most part. The introduction of perennial grasses into largely annual crop dominated landscapes may provide some features favorable to species benefitting from grassland type habitats where these are missing.

Prospects and barriers

The state's Low Carbon Fuel Standard and the federal Renewable Fuel Standard create demand for compliant alternative fuels. The state of California has adopted an ambitious set of goals, legislation and supporting regulations to reduce greenhouse gas (GHG) emissions for energy use in the state. Bioenergy, including biomass for electricity, biogas and biofuels has been identified as part of the state's renewable portfolio standard (RPS), and the use of biofuels is essential for the success of the state's Low Carbon Fuel Standard (LCFS). In addition, the state must comply with federal alternative fuel requirements embodied in the Renewable Fuel Standard. The state has updated its Bioenergy Action Plan. The goals of this plan are to: increase environmentally and economically sustainable energy production from biomass residues and biogenic wastes; to encourage development of diverse bioenergy technologies that increase local electricity generation; to combine heat and power (CHP), renewable natural gas, and renewable liquid fuels for transportation and fuel cell applications; to create jobs and stimulate economic development, especially in rural regions of the state; and to reduce fire danger, improve air and water quality, and reduce waste. The State Alternative Fuels Plan has ambitious goals for biomass-based fuels, including their use for up to a quarter of all fuels by 2022. The state also has a goal of having an increasing share of its transportation fuels produced within the state by 2050.

Formal life cycle analysis was not conducted as part of this analysis, but based on current reported standards, it appears likely that alternative fuels produced from the feedstock crops analyzed here would meet the standards required by both regulations. Prospects for new bioenergy businesses in California based on these crop feedstocks and potential environmental effects are discussed. The stability of both policies in their present form is essential to secure confidence that investments in expanding existing facilities, and especially in new types of biorefineries, are prudent. California's well-known high costs for regulatory compliance, and financial conditions affecting the cost and availability of capital all remain obstacles to the successful development of new bioenergy enterprises in the state.

CHAPTER 1: Introduction and Project Overview

1.1 Problem Statement

The state of California has adopted an ambitious set of goals, legislation and supporting regulations to reduce greenhouse gas (GHG) emissions for energy use in the state. Bioenergy, including biomass for electricity, biogas and biofuels has been identified as part of the state's renewable portfolio standard (RPS), and the use of biofuels is essential for the success of the state's Low Carbon Fuel Standard (LCFS). In addition, the state must comply with federal alternative fuel requirements embodied in the Renewable Fuel Standard. The state has updated its Bioenergy Action Plan[1]. The goals of this plan are to: increase environmentally and economically sustainable energy production from biomass residues and biogenic wastes; to encourage development of diverse bioenergy technologies that increase local electricity generation; to combine heat and power (CHP), renewable natural gas, and renewable liquid fuels for transportation and fuel cell applications; to create jobs and stimulate economic development, especially in rural regions of the state; and to reduce fire danger, improve air and water quality, and reduce waste. The State Alternative Fuels Plan[2] has ambitious goals for biomass-based fuels, including their use for up to a quarter of all fuels by 2022. The state also has a goal of having an increasing share of its transportation fuels produced within the state by 2050[3].

California's agriculture is the most productive in the world and yields for most crops tend to be above the average achieved in many other regions where similar crops are grown. Agriculture can contribute to the state's transportation and alternative energy supplies, with associated economic, employment and GHG benefits. However, there is also a need to better understand potential displacement of food crops and any potential environmental effects from increased production of crop-based transportation fuels. These effects have not been evaluated or quantified. Agricultural residues of various types are already under active development as feedstocks for biofuel conversion processes, as part of overall plans to develop fuels from California's biomass wastes and residues. Beyond biomass wastes and residues, which have been well quantified and geographically inventoried and are estimated to supply potentially up to 10% of the state's current motor fuel use, energy crops cultivated specifically for biofuel production may have additional, and perhaps greater, capacity to support an in-state biofuels industry in the longer term. However, the prospective role for cultivated energy crops in California as feedstocks for biofuel production has not yet been well quantified, including its impacts on food supply, if any. There is a need to identify, evaluate and demonstrate the production of new energy crops that could prove most suitable for production in California, and to better determine the energy, environmental and economic implications of using crops as part of California's transportation energy strategy.

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[1] http://www.energy.ca.gov/bioenergy_action_plan/
[2] http://www.energy.ca.gov/2007publications/CEC-600-2007-011/CEC-600-2007-011-CMF.PDF
[3] http://www.energy.ca.gov/2011publications/CEC-100-2011-001/CEC-100-2011-001-CMF.pdf

1.2 Goals of the Agreement

The goal of this Agreement was to advance the scientific understanding of crop-based biofuel production options suitable for application across California's diverse cropping regions and growing conditions. The results of the Agreement will support sound public and private sector decision-making about some likely purpose-grown biofuel feedstock crops, identified by the project's Technical Advisory Committee as potentially suitable for farms in California. For this purpose, the California Department of Food and Agriculture (CDFA) has supported a three-year research project conducted by scientists in the Department of Plant Sciences at UC Davis and in the Department of Natural Resources at UC Riverside to provide empirical data and related simulation and economic modeling efforts to determine the yield, resource use and economic potential of energy crops suitable for biofuels production in California, and to determine whether they can complement or interfere with current crops produced within the state.

1.3 Objectives of the Agreement

The objectives of this Agreement are:

1. to demonstrate potential energy and industrial crops under commercial conditions (focusing on crops that may use marginal lands and that minimize environmental externalities);
2. familiarize growers with these crops,
3. determine the suitability of these crops for various energy and industrial markets;
4. determine costs,
5. estimate energy production potential, and
6. identify barriers to commercialization

Field trials and demonstrations, plant material and soil analyses, environmental implications, and assessment of economic performance have been carried out. Results of these diverse efforts are reported here. Reports, articles, field days, and oral presentations have been and will be used to disseminate the results.

The experience of California based companies pursuing these feedstock options are also summarized where information is available, as well as their progress to developing actual businesses, and obstacles to that development they have experienced.

1.4 Project Overview

The Technical Advisory Panel created for this project identified three distinct crop classes for evaluation: winter annual oilseed crops, sweet sorghum, and sugarcane.

Winter annual oilseeds include canola (*Brassica napa* and *Brassica juncea*), Camelina (*Camelina sativa*), and Meadowfoam (*Limnanthes alba*). Each is best planted in late fall or early winter, and in many locations in California may be grown on winter rainfall, or a combination of winter rainfall, stored or residual soil moisture, and limited irrigation. Where irrigation sources are limiting, winter annual crops that use little water may extend irrigation supplies while sustaining or improving farming system profitability. Each species evaluated has different oil quality characteristics that make them variably suitable for biodiesel use or as feedstocks for other industrial uses including cosmetics and chemicals (Knothe, 2005). Camelina and Meadowfoam are not considered to be edible oils in the United States so they are not considered food crops. Canola, on the other hand, is a food grade oil crop, but is identical to a non-food crop (rapeseed), except for differences in some fatty acid content (erucic acid) and secondary compounds called glucosinolates. From the perspective of crop agronomy, these are meaningless differences. Oilseed meals from all three species have use as livestock feeds. Some varieties of Brassica oilseeds (oilseed rape, also *B. napus*) have higher levels of glucosinolates, secondary compounds in the oilseed meal, which might find use as natural pesticides (Mora and Borek, 2010; Chew, 1988).

Sweet sorghum (*Sorghum bicolor*) has been identified repeatedly in recent years as a promising bioenergy crop. It is a warm season annual C4 grass that has traditionally been produced throughout the southeastern states as a source of sugar syrup. It stores six carbon (hexose) sugars in its stems as it grows. These sugars can be converted to ethanol in a way similar to the sugar in sugarcane, and residual biomass (bagasse) may have diverse uses, including as an energy source via combustion for electricity, as a second feedstock for cellulosic ethanol, or for fermentation of wastewater (stillage from the ethanol process) in an anaerobic digester (AD) to make biogas (methane). There is potential for products made from fibers removed from stems, for cuticular waxes, and for feed for cattle from particular portions of the residues.

Sugarcane (*Saccharum oficinarum*) is a tropical C4 grass that has been identified as a promising crop for the Imperial Valley, but may also have utility for the warmer areas of the San Joaquin Valley. In most regions where it is grown, it issued for either sugar production (sucrose), or the sugar is fermented into ethanol or made into useful biochemicals. Related species in the Saccharum genera may have uses for cellulosic biofuel production or as a biomass source for combustion for electricity. Other Saccharum type grasses (especially *Saccharum sponteneum*) include crosses between sugarcane and other Saccharum genera that are called energy canes. These have high biomass yields but lower sugar contents than sugarcane and are seen primarily as sources of biomass for cellulosic ethanol production or simple combustion for power. Some *S. spontaneum* species or crosses have also been evaluated under this contract.

A large number of empirical trials (65) were conducted during this project. These are identified in Table 1. Winter annual oilseed crops were carried out across California, while sugar producing crops were evaluated in the San Joaquin Valley and Imperial Valley where temperatures are most suitable. Being perennial, the number of trials with sugarcane and related genera were limited but carried out over two or more years.

Table 1: Locations and types of trials.

		Year			
		2009/2010	2010/2011	2011/2012	2012/2013
Type	Species				
Variety Trial	Canola	Davis/WSREC	Davis/WSREC/McA	Davis/WSREC/McA	Davis/WSREC
	Camelina	WSREC	Davis/WSREC	Davis/WSREC/PMC	Davis/WSREC
	Meadowfoam	Davis/WSREC	Davis/WSREC		
	Sweet Sorghum	WSREC	WSREC	WSREC	
	Sugarcane	KREC/DREC	KREC/DREC	KREC/DREC	
N Response	Canola	Davis/WSREC	Davis/WSREC	Davis/WSREC	
	Camelina	Davis/WSREC	Davis/WSREC	Davis/WSREC/PMC	
	Meadowfoam	Davis/WSREC	Davis/WSREC		
	Sweet Sorghum	WSREC	WSREC	WSREC	
	Sugarcane				
Irrigation	Canola	Davis/WSREC	Davis/WSREC	Davis/WSREC	
	Camelina	Davis/WSREC	Davis/WSREC	Davis/WSREC	
	Meadowfoam	Davis/WSREC	Davis/WSREC		
	Sweet Sorghum	WSREC	WSREC	WSREC	
	Sugarcane	DREC	DREC	DREC	DREC
Date of Planting	Canola		Davis/WSREC/McA	Davis/WSREC	
	Camelina			Davis/WSREC	
	Meadowfoam				
	Sweet Sorghum				
	Sugarcane				
Seeding Rate	Canola		Davis/WSREC/McA	Davis/WSREC	
	Camelina				
	Meadowfoam				
	Sweet Sorghum				
	Sugarcane				
Herbicide Tolerance	Canola				
	Camelina			WSREC	
	Meadowfoam				
	Sweet Sorghum				
	Sugarcane				

Davis: UC Davis Research Farm; WSREC: UC Davis Westside Research and Extension Center; McA: McArthur (Lassen County) on-farm locations; PMC: NRCS Plant Materials Introduction Center (Lockeford, San Joaquin County); KREC: Kearney Research and Extension Center; DREC: Desert Research and Extension Center.

Crop Assessment Report

During the period from fall 2009 to spring 2013, variety trials and agronomic studies of three different oilseed species were carried out. The majority trials of these were conducted at the UC WSREC and the UC Davis campus. Other locations included McArthur in Shasta County and Lockeford in San Joaquin County (Table 1). Most trials were conducted using randomized complete block designs, usually with four replications, although partially replicated designs were used in the final season. The varieties tested varied between seasons, depending on what cooperating seed companies were willing to provide. Over the course of the five years, trials were able to test a representative sample of the varieties being offered for sale in California, or being developed for sale in California. In the 2012-13 season, varieties from Australian breeding programs were tested for the first time.

The project focused on winter annual oilseeds, rather than spring types, based on the recommendations of the project research leaders and a consensus of the project's Technical Advisory Committee. 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 per unit dry matter is less than in summer. The fall-planted crops can also take advantage of the winter rains that characterize the climate in most of the state, rather than being reliant solely on irrigation. This is similar to the way wheat, barley and oats are treated, and the seasons for these cereals largely overlap with the Brassica oilseeds. However, in northern-interior locations, like McArthur, 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 consequently 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.

1.5 Canola

Canola (*Brassica napus*) 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). Canola and rapeseed are the primary feedstocks within the European Union for biodiesel.

Rapeseed (*B. napus*) is the original source for canola, but has higher levels of erucic acid and glucosinolates, which are both anti-nutritional factors (Ebberlint et al., 1999; Chew, 1998 ; Fenwick, 1983), although glucosinolates in oilseed meals have reported uses as natural pesticides and may be valuable by-product of some varieties (Mora and Borek, 2010). Indian Mustard (Brassica *juncea*) is a related species also used for cooking and transportation fuels. Canola and rapeseed 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 California intermittently since the late 1970s there is little 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

Although canola has been evaluated in California intermittently since the late 1970s, there is little 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. Paul Knowles at the University of California, Davis, evaluated canola germplasm and related Brassica oilseed crops in the late 1970s and early 1980s in California (Knowles, 1980; Knowles et al., 1981; Knowles et al., 1983). Yields of between 1.2 and 2.1 Mg/ha were reported from these trials (Knowles et al., 1981), but the work was 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 canola trial was conducted in Yolo and Fresno Counties evaluating varieties, nitrogen response, and response to late season irrigation by Kaffka, Brittan and Hutmacher in 2006-07 (unpublished). They planted a number of commercial varieties, and evaluated the response of selected varieties to differing rates of fertilizer nitrogen, and supplemental irrigation in spring (approximately 6 ac in). Maximum yields were higher in Yolo than in Fresno County (Fig. 1, 4), supplemental irrigation in Yolo County in spring resulted in a significant yield increase (Fig. 2), and canola responded to increasing nitrogen rates linearly across the range of nitrogen levels applied (Fig. 3), indicating that the crop's nitrogen demand was not satisfied at 150 lb of nitrogen per acre that year.

Figure 1: Variety yields in Yolo County in 2006.

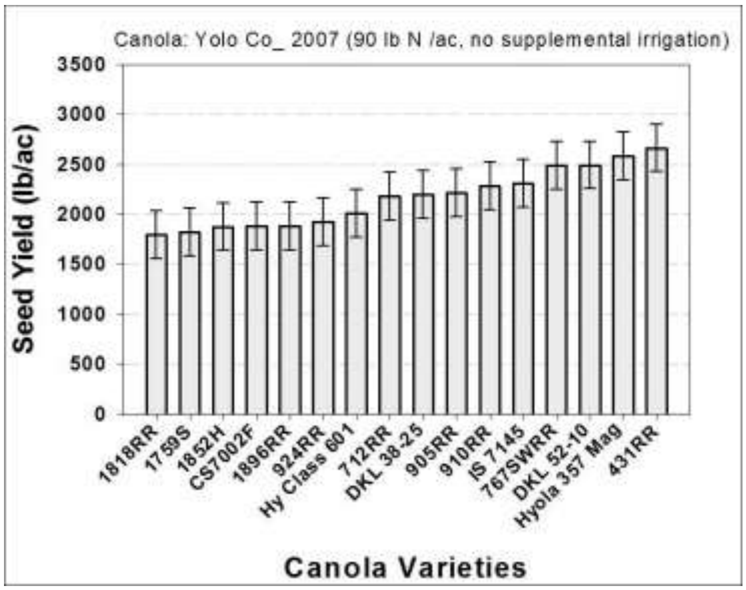


Figure 2: Supplemental irrigation effects in spring in Yolo County in 2007. Approximately 6 ac-in of water were applied.

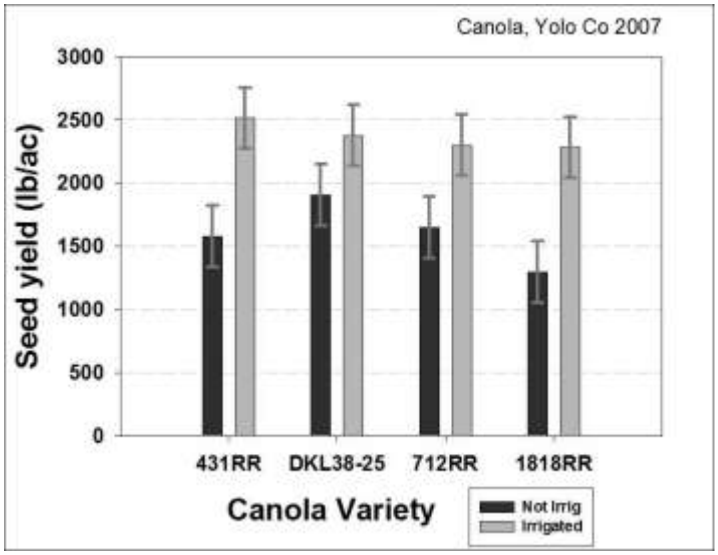


Figure 3: Nitrogen response of canola in Yolo County in 2007.

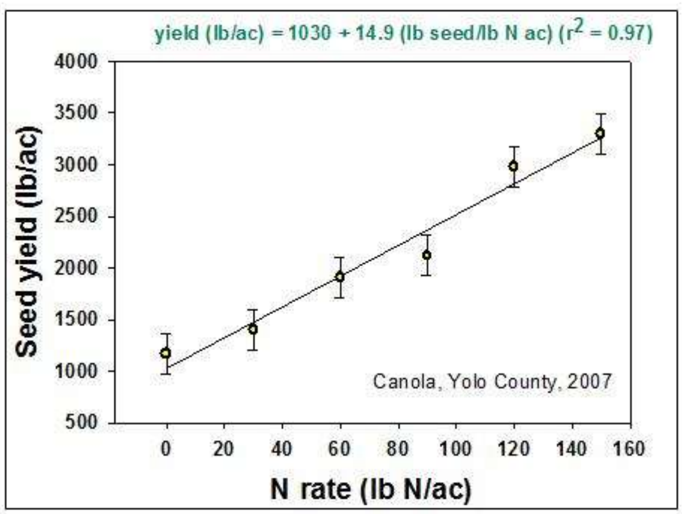
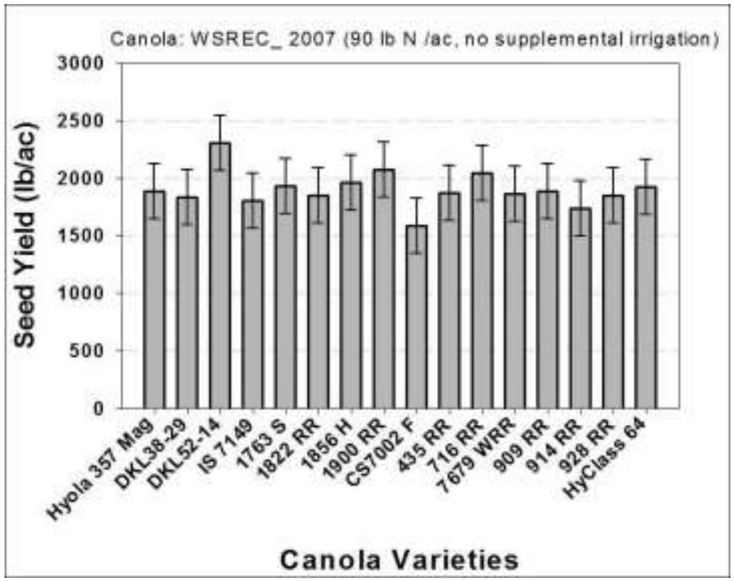


Figure 4: Variety yields in Fresno County in 2007 (WSREC).



Trials: 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)[4]. 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 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 (Fig. 5). The highest yields at WSREC were achieved with 160 lb of nitrogen 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 (Fig. 6). Supplemental irrigation (approximately 6 ac in) in spring had no effect on yield at either location (Fig. 7). We believe this is because 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 (Fig. 8). Winter and spring temperatures in Davis are cooler than at WSREC 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.

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

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 Indian mustards 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 (Fig. 10). Similarly, oil content was not influenced by nitrogen fertilizer level (Fig. 9). The protein content of the residual meal left after oil crushing and extraction is likely to be influenced by fertilizer nitrogen levels, but this was not tested in these trials. Oil yields by variety are reported in Fig. 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 using a FAME process (see below).

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

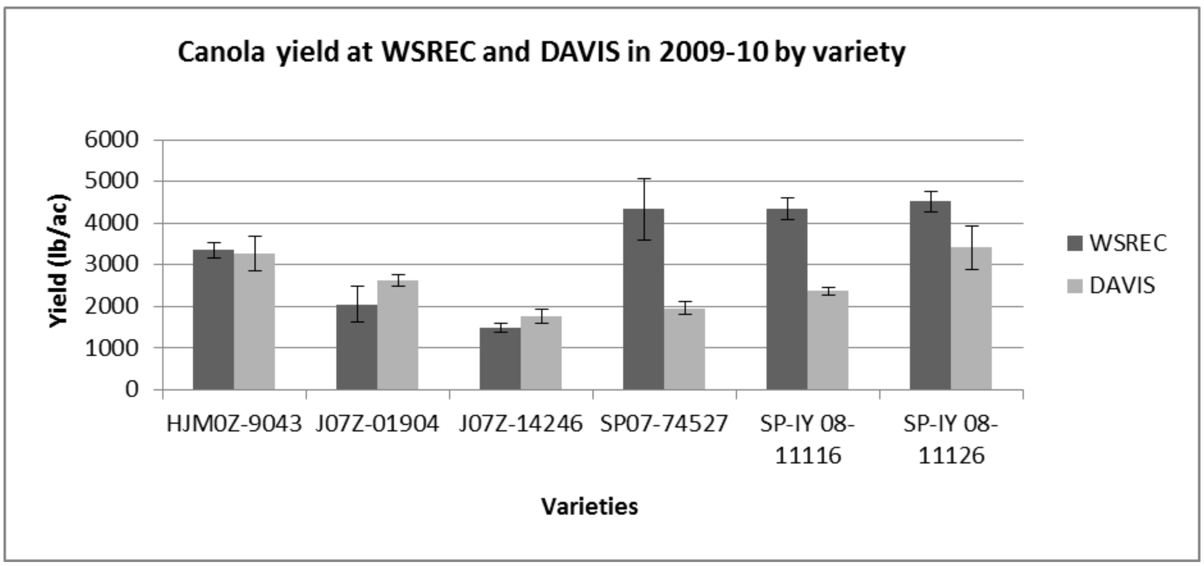


Figure 6: Canola response to nitrogen (SP07) at WSREC and Davis in 2009-10.

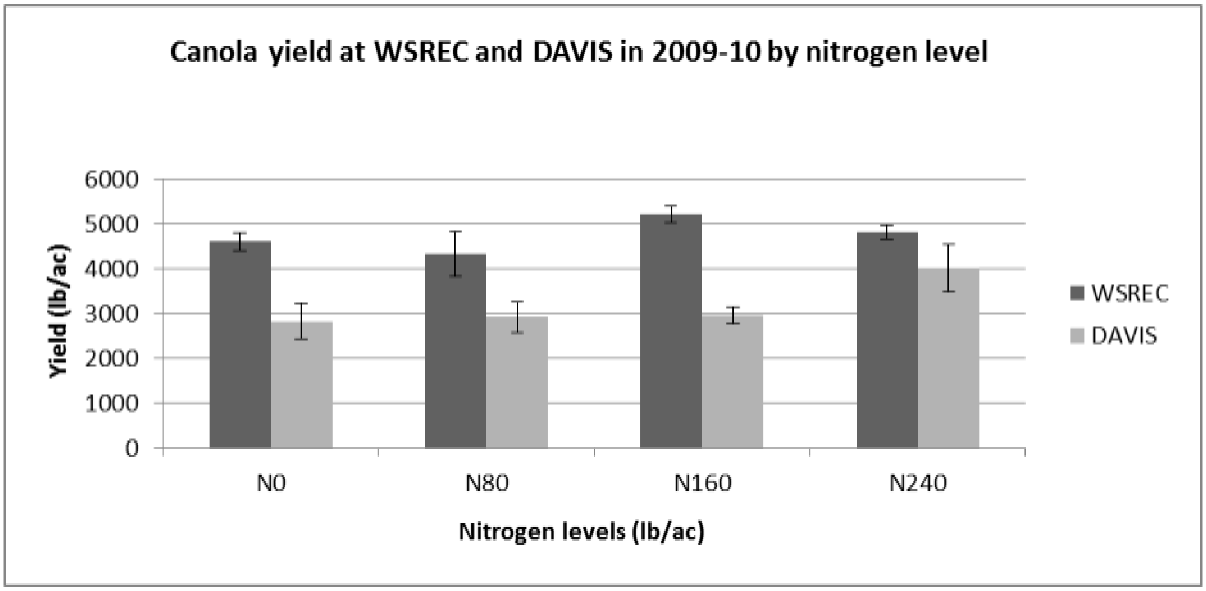


Figure 7: Canola response to supplemental spring irrigation plus rainfall (I) compared to treatments that were not irrigated in spring (NI) at WSREC and Davis in the 2009-10 growing season.

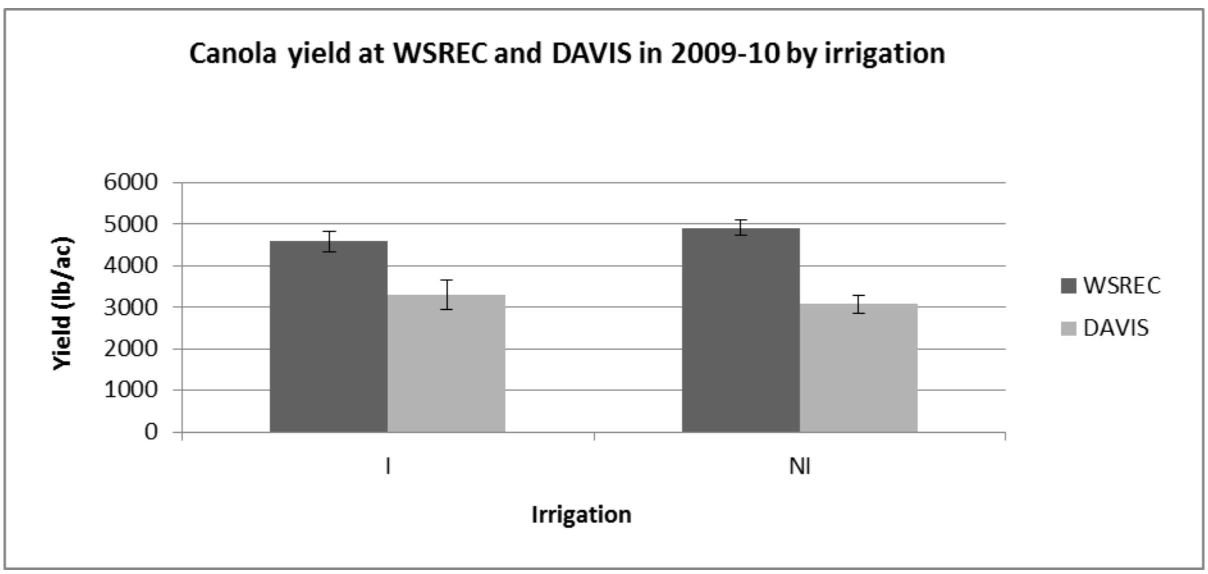


Figure 8: Canola seed oil contents by variety at WSREC and Davis in the 2009-10 growing season.

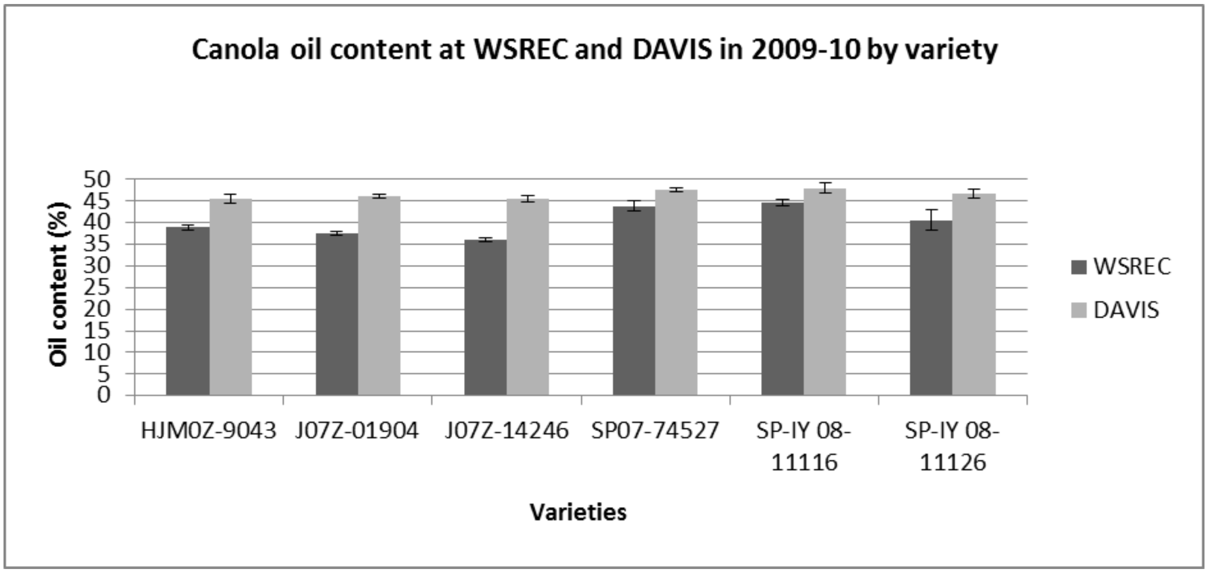


Figure 9: Canola oil content in response to nitrogen fertilizer in SP07 at WSREC and Davis in the 2009-10 growing season.

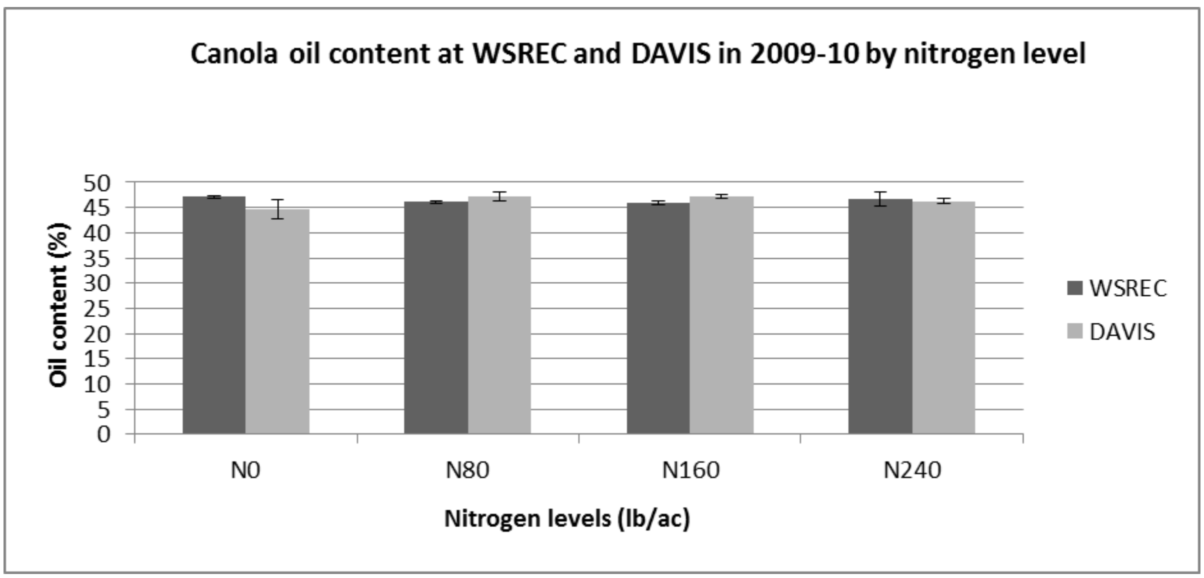


Figure 10: Canola oil content in response to supplemental spring irrigation in SP07 at WSREC and Davis in the 2009-10 growing season.

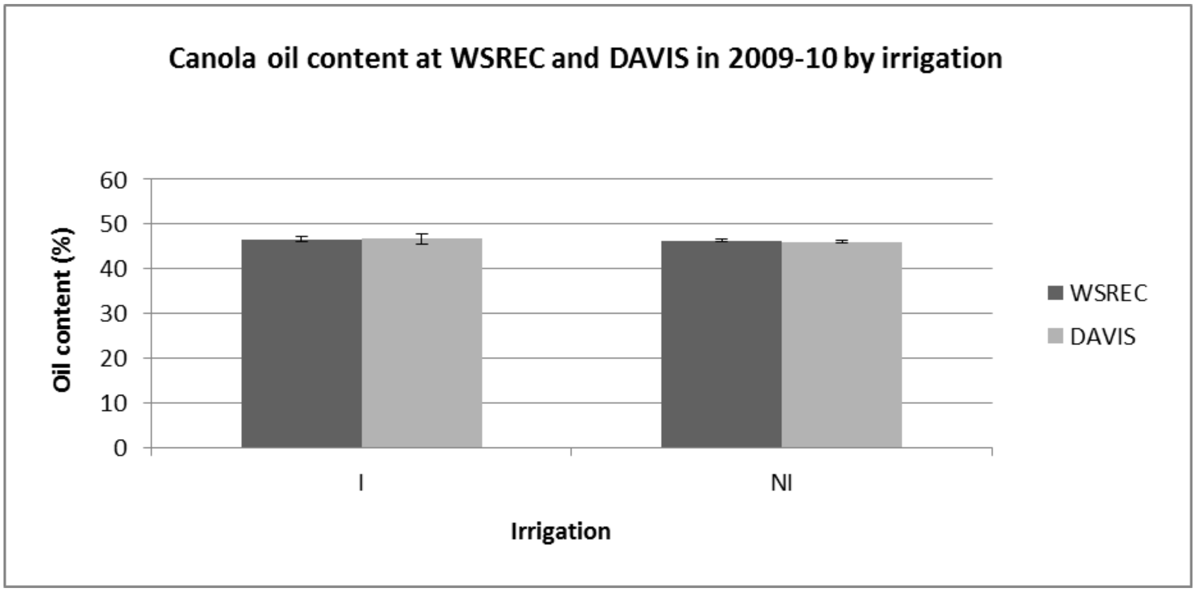
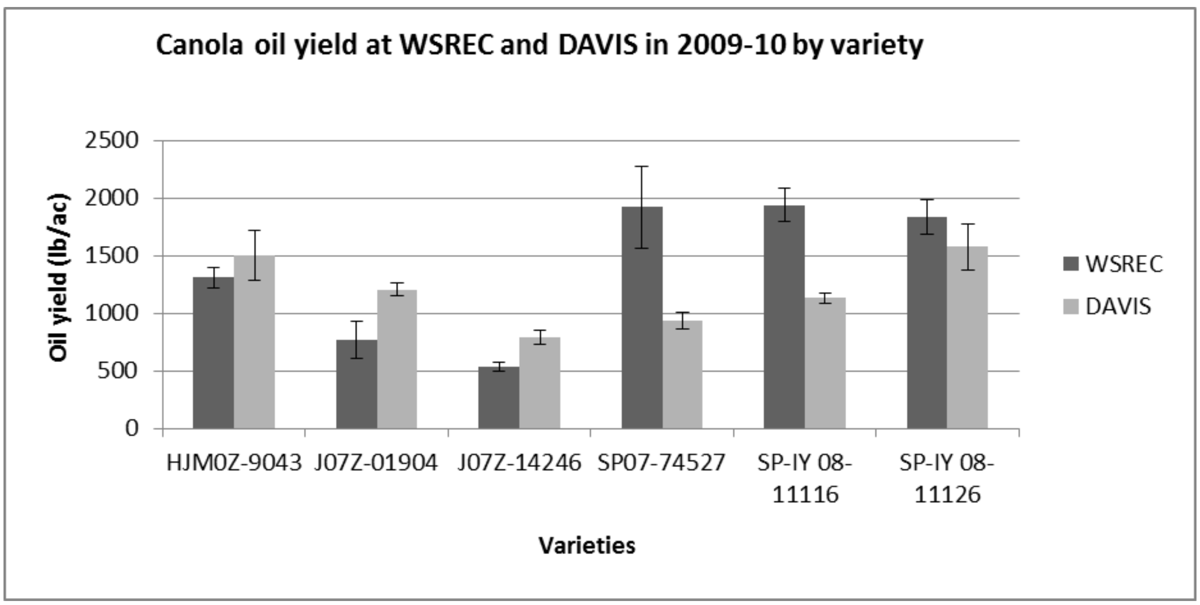


Figure 11: Canola oil yield at WSREC and Davis in the 2009-10 growing season.



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. In 2010-11, Cibus, Inc. submitted varieties for testing, as did Viterra. HJM1Z-0029 was a *B. juncea* variety, all others were *B. napus*. This was an unusually cold and wet year in the central valley (Appendix Fig. A.1). At Davis, significant rainfall occurred into June and there were a large number of freezing nights, especially in February (See Table 8 below). 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 Fig. A.2). 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 (Fig. 12). Nitrogen response was minimized due to lower overall yields (Fig. 13). A single spring irrigation increased seed yield at WSREC (Fig. 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 (15). Nitrogen application did not affect oil content at either location (Fig. 16). Similarly, oil yields were not affected by nitrogen application at WSREC (Fig. 17), but supplemental irrigation in spring did improve oil yields modestly (Fig. 18).

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

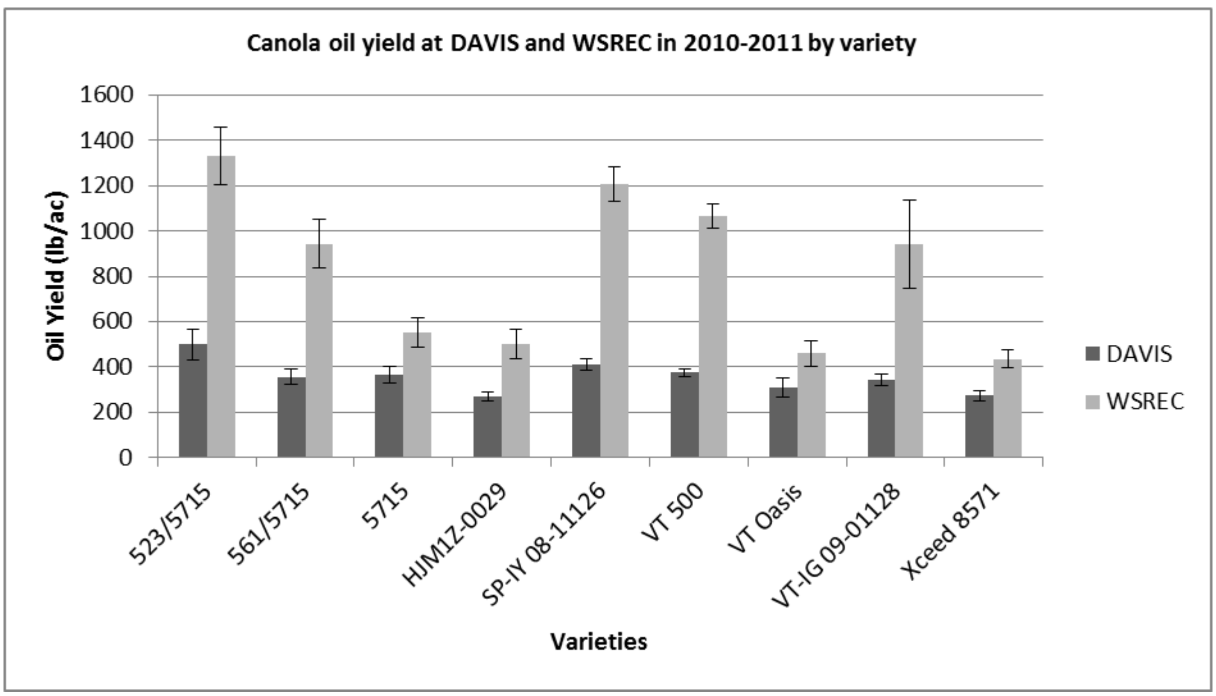


Figure 13: Canola yields (VT 500) in response to nitrogen fertilizer rates at Davis and WSREC in the 2010-11 growing season.

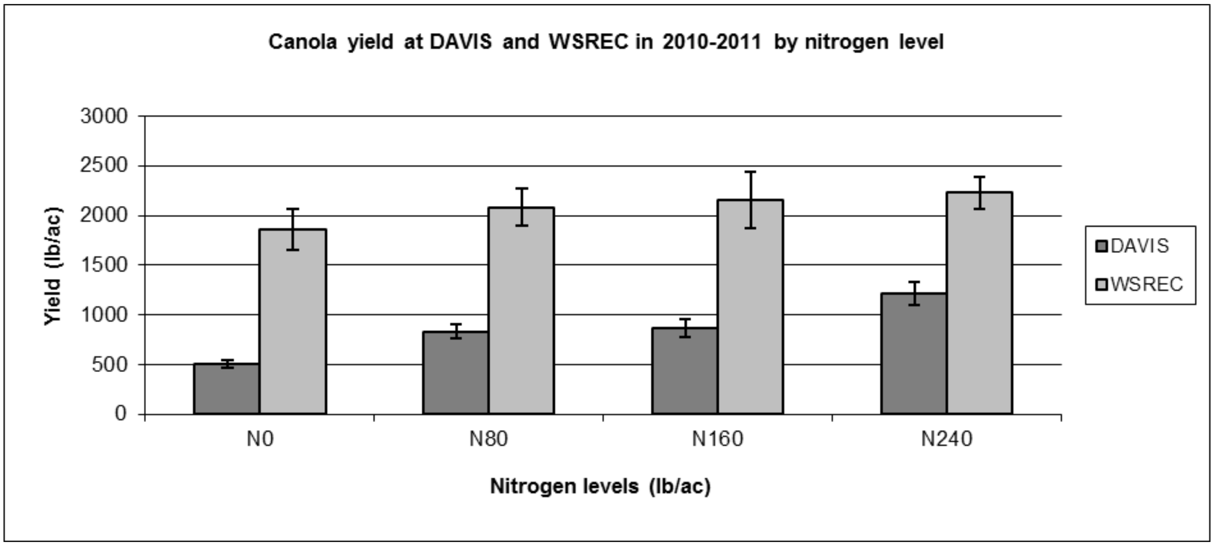


Figure 14: Canola yields (VT 500) in response to supplemental spring irrigation at WSREC in the 2010-11 growing season. There was no supplemental irrigation at Davis due to late season rainfall.

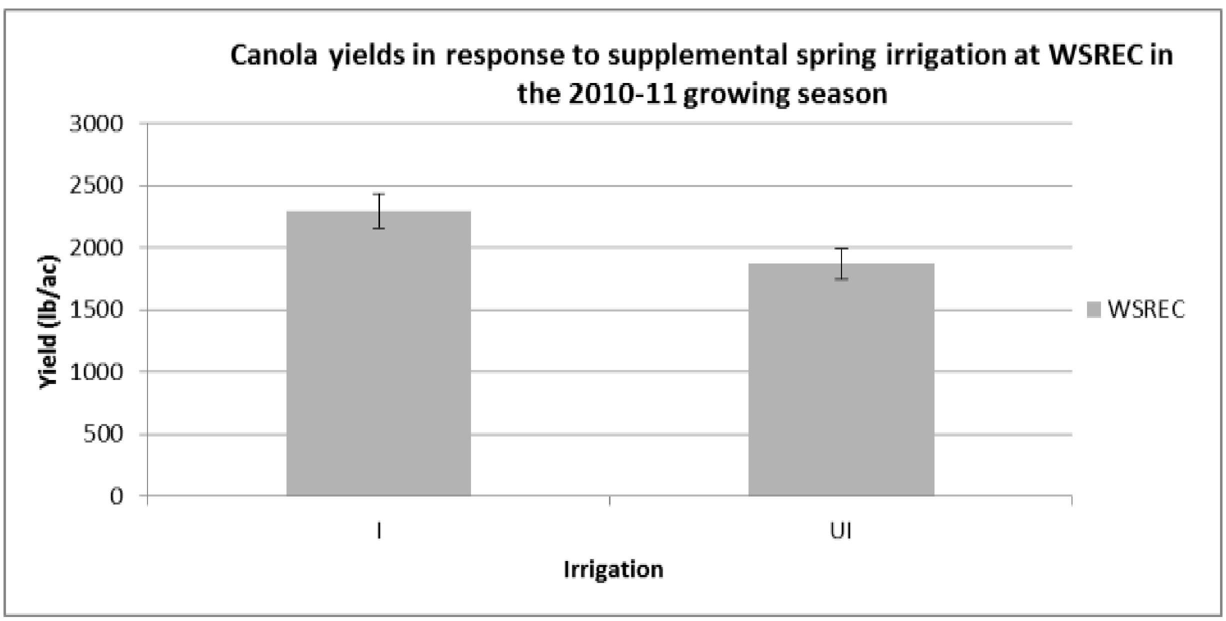


Figure 15: Canola oil content by variety at Davis and WSREC in the 2010-11 growing season.

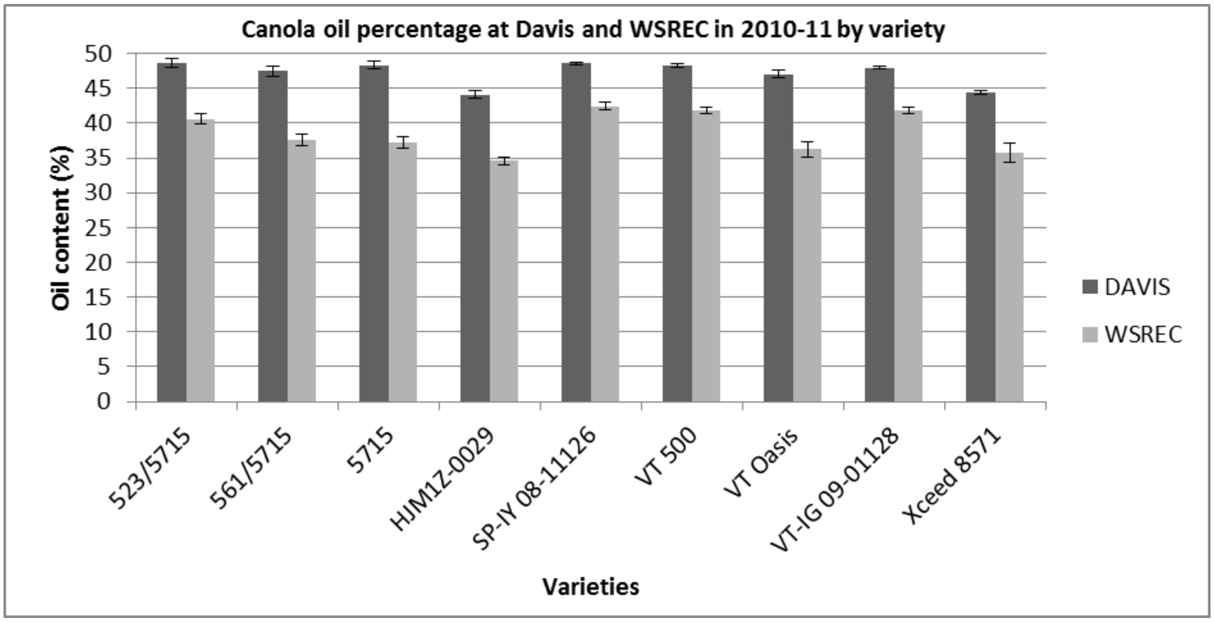


Figure 16: Canola oil content (VT 500) in response to nitrogen fertilizer rates at Davis and WSREC in the 2010-11 growing season.

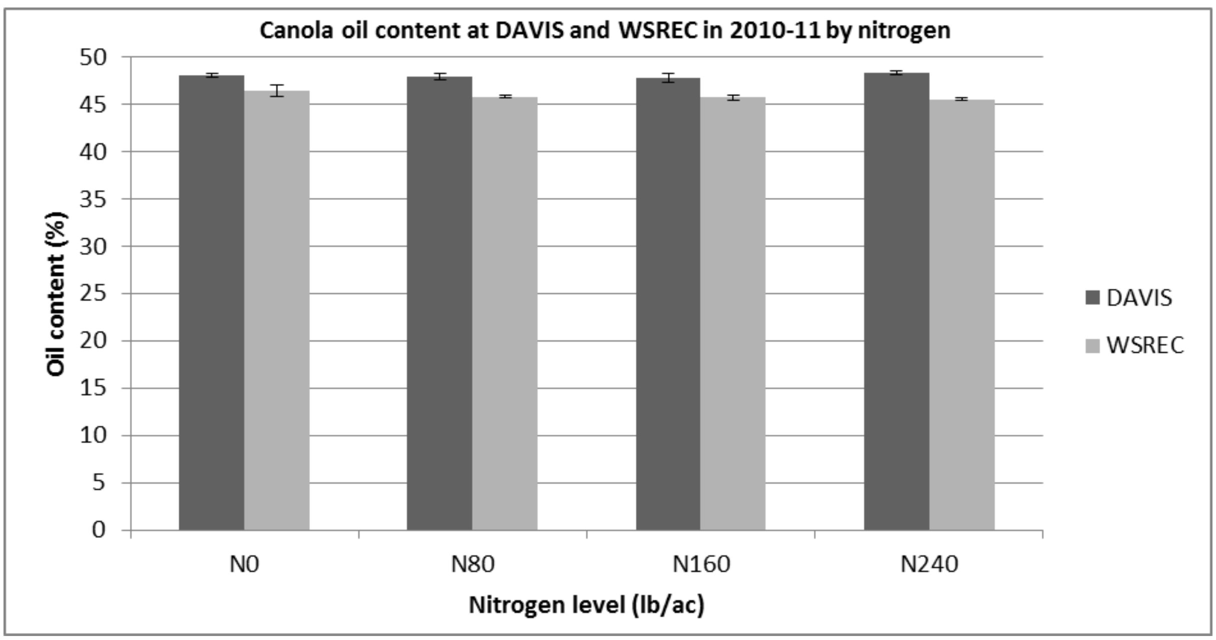


Figure 17: Canola oil yields (VT 500) in response to nitrogen fertilizer rates at Davis and WSREC in the 2010-11 growing season.

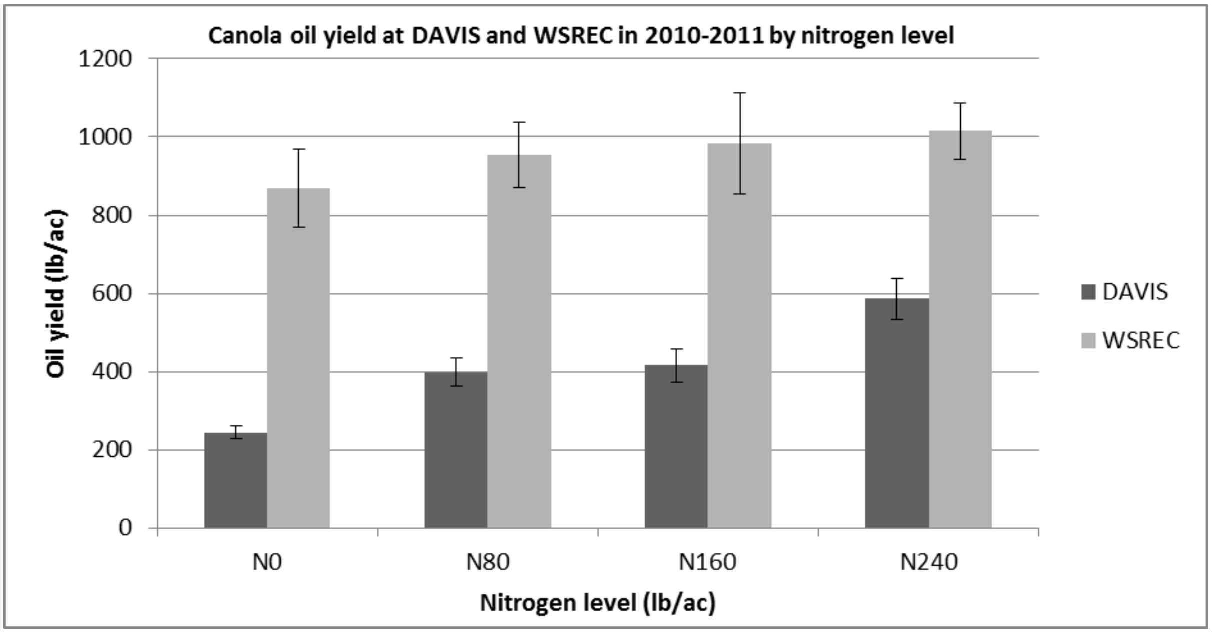
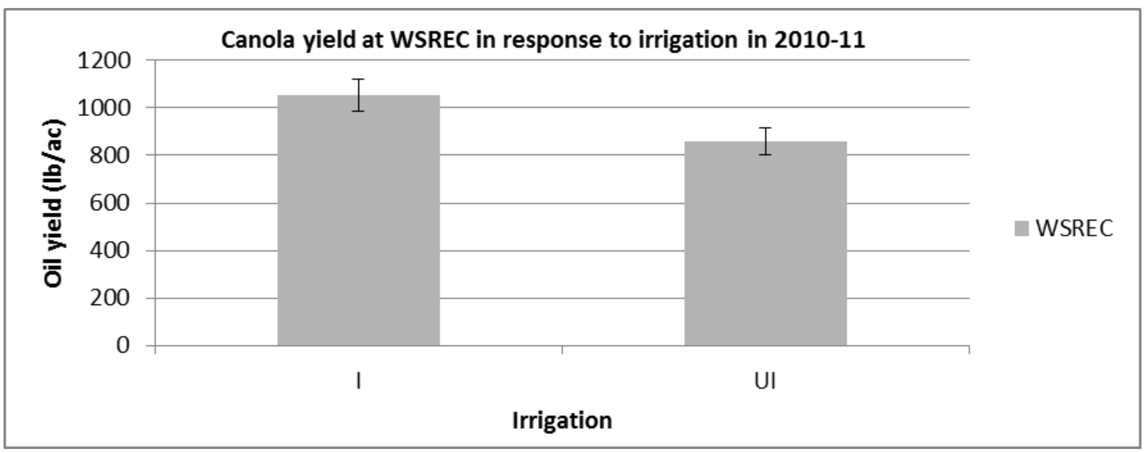


Figure 18: Canola yields (VT 500) in response to nitrogen fertilizer rates at WSREC in the 2010-11 growing season. There was no supplemental irrigation at Davis due to late season rainfall.



2011-12 Trials.

Fewer companies collaborated in 2011, and therefore fewer varieties were available for testing. 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 nitrogen fertilizer levels at Davis were between 160 and 200 lb nitrogen per acre. Lower levels of fertilizer nitrogen 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 lb per acre. No response was observed at Davis with late season rains. Assuming a similar oil percent to other years, oil yields will be comparable.

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

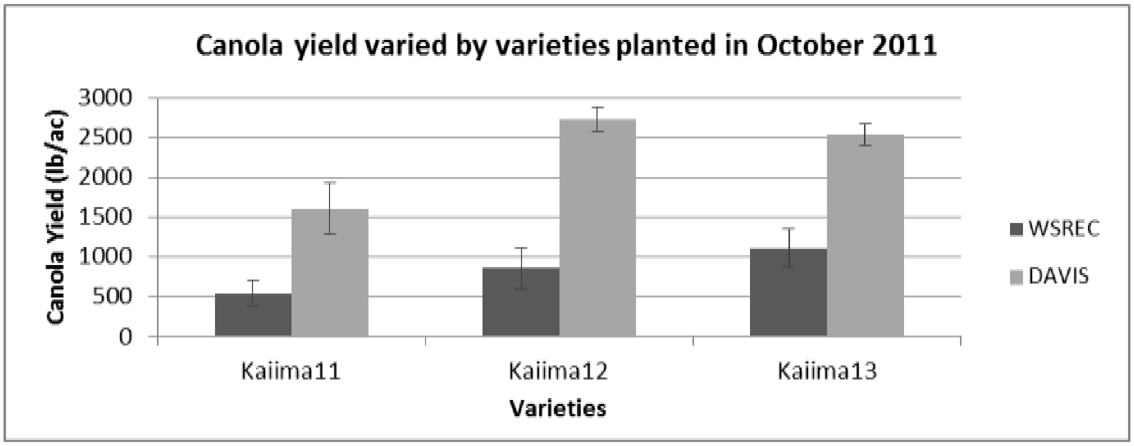


Figure 20: Variety trial yields (lb/ ac) in the 2011-12 growing season.

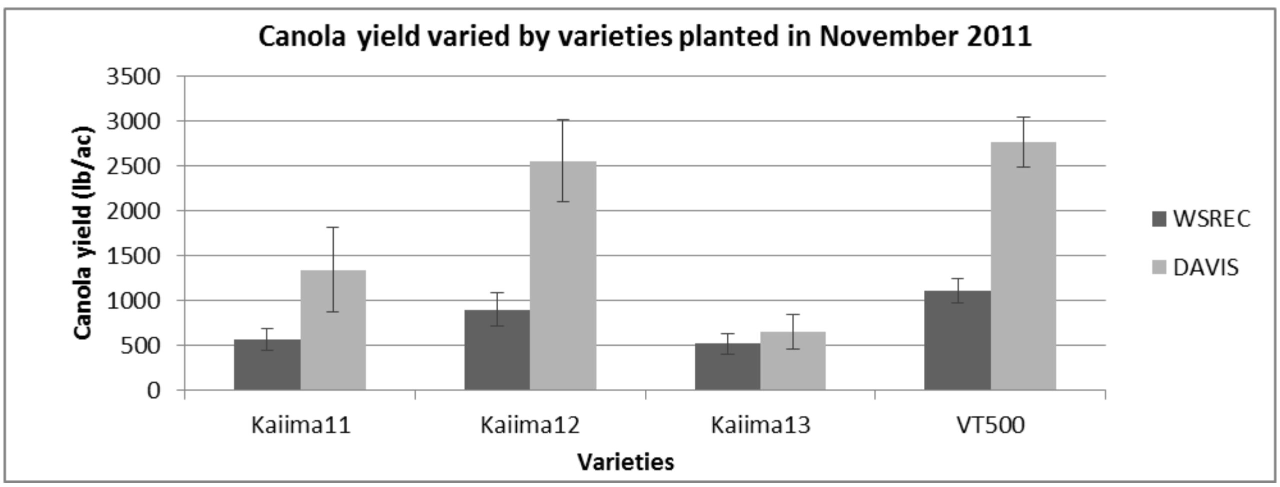


Figure 21: Canola response to nitrogen in the 2011-12 growing season. Residual herbicide damage may have limited canola response at WSREC location.

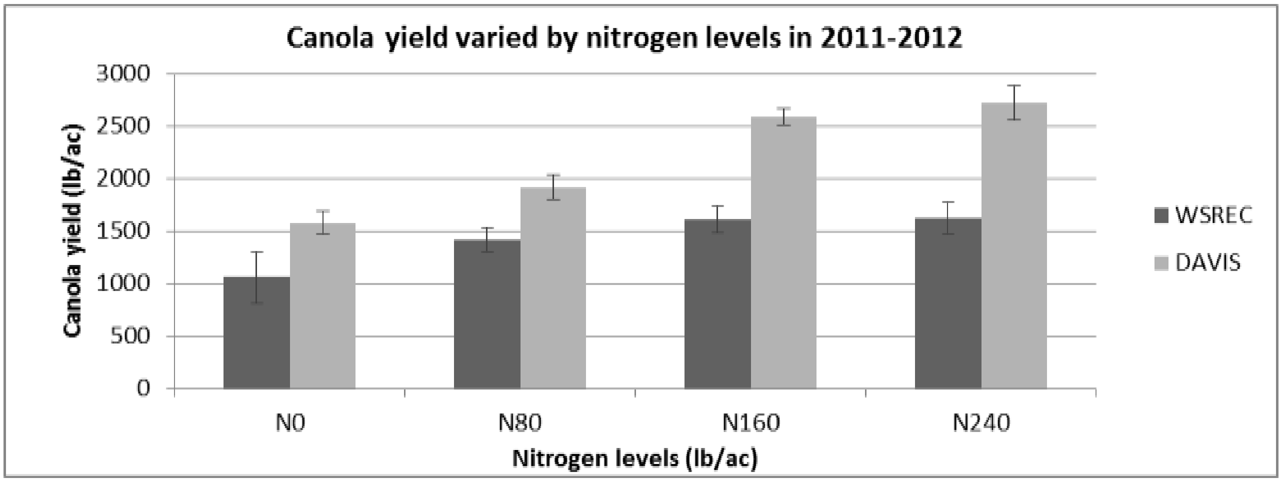
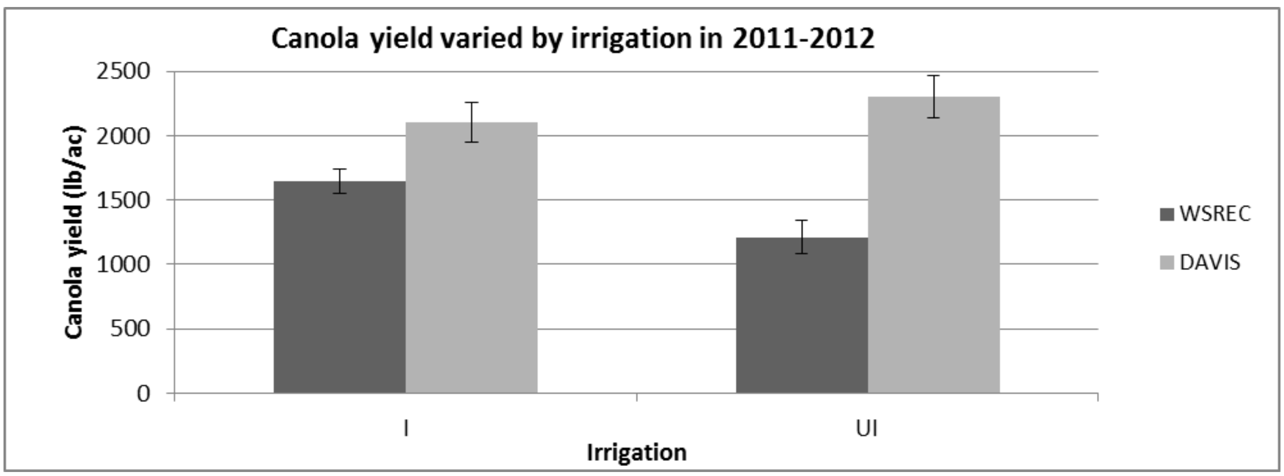


Figure 22: Canola response to late season irrigation at WSREC in the 2011-12 growing season.



2012-13 Trials

Canola variety trials using newer varieties sourced from several different companies, including new entries submitted by Australian companies (Pacific Seeds and Canola Breeders Western Australia) for the first time in trials in California, were planted at Davis and WSREC as before (Table 2). The Davis site was not given any supplemental irrigation. The WSREC was grown with initial irrigation applications at establishment but otherwise was un-irrigated for the remainder of the season.

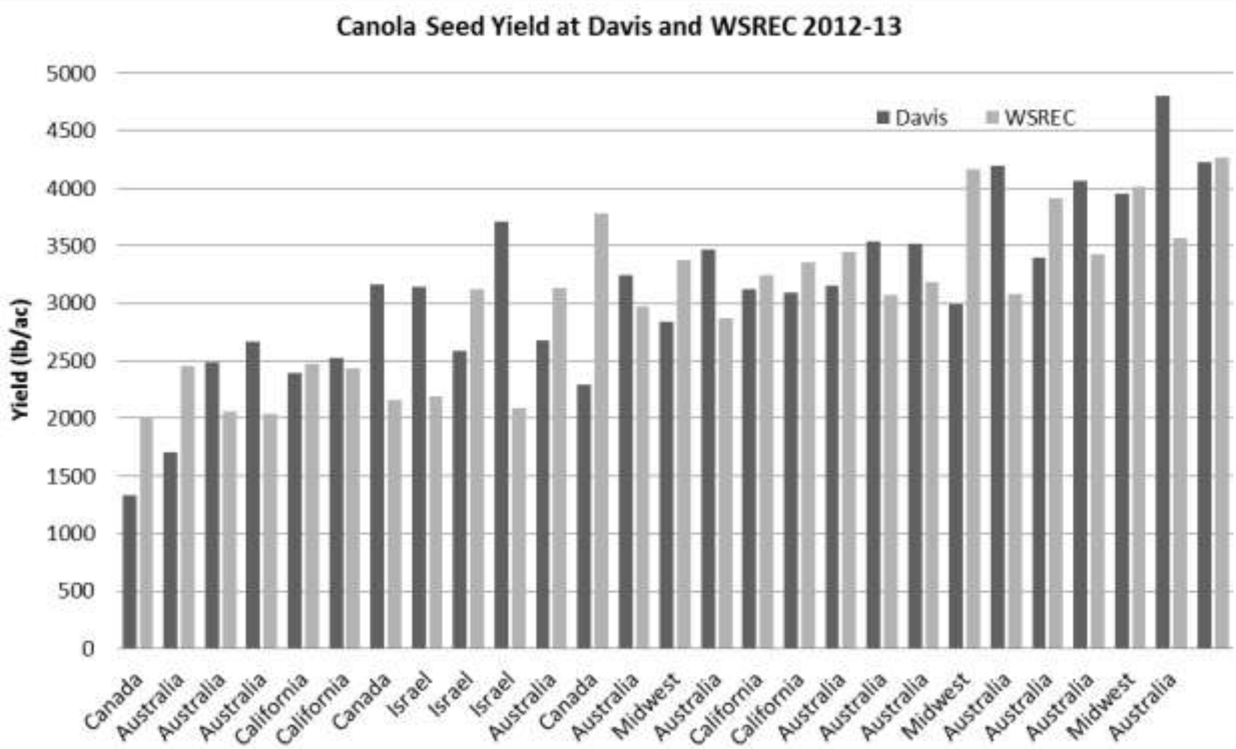
Canola seed yields in 2012-13 were similar to the very high yields observed in the 2009-10 growing season at both Davis and WSREC. On average, yields were slightly larger at Davis than WSREC, but not significantly so. Several entries produced more than 2 t/ac of seed.

Table 2: Canola varieties and origin for 2012-13 trials.

Source	Variety
CBMA	Agamax
(Australia)	AtomicHT
	JardeeHT
	TangoC
	TumbyHT(J+G)
Cibus	C1511
(California)	V1
	V2
	V3
DL Seeds	DL5001
(Canada)	DL5002
	DL5003
Kaiima	Kaiima9
(Israel)	Kaiima11
	Kaiima12
Pacific Seeds	H4722
(Australia)	I4403
	I6654
	K9317
	K9319
	T2522
	T98022
	T988060
Winfield	HyClass 930
(Canada)	HyClass 947
	HyClass 955
	HyClass 988

CBWA (Canola Breeders of Western Australia); Pacific Seeds (Australia); DL Seeds (Canada); Winfield Seeds (Canada); Kaiima (Israel); Cibus (California)

Figure 23: Canola yields in Davis and WSREC in the 2012-13 season. At the time of writing, we have not received approval to release yields with varieties.



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 earlier planting dates 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 planting in fall 2010 resulted in larger yields. This is commonly observed in canola plantings in Australia.

Figure 24: Planting dates and seeding rates comparisons in Davis in the 2010-11 growing season.

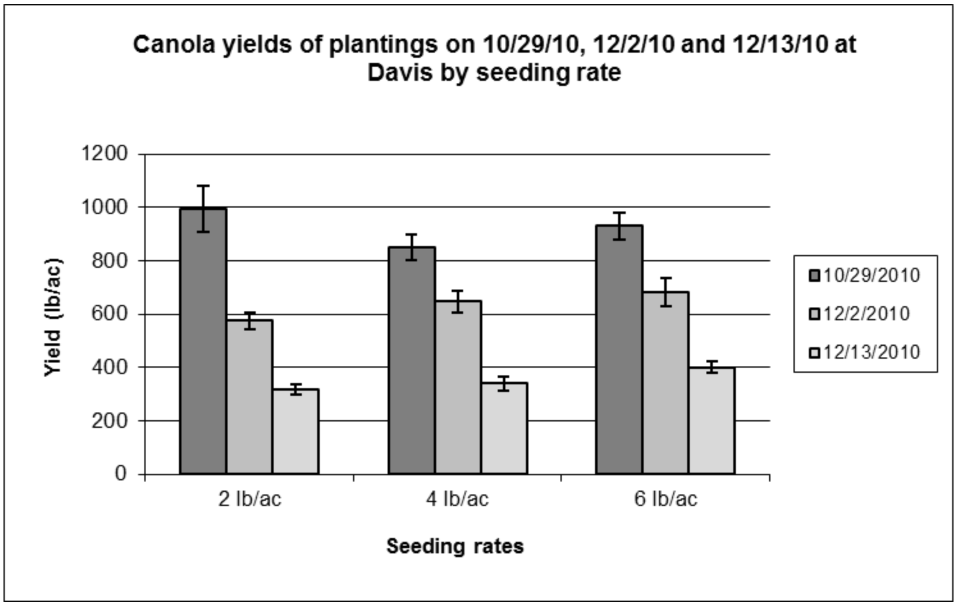
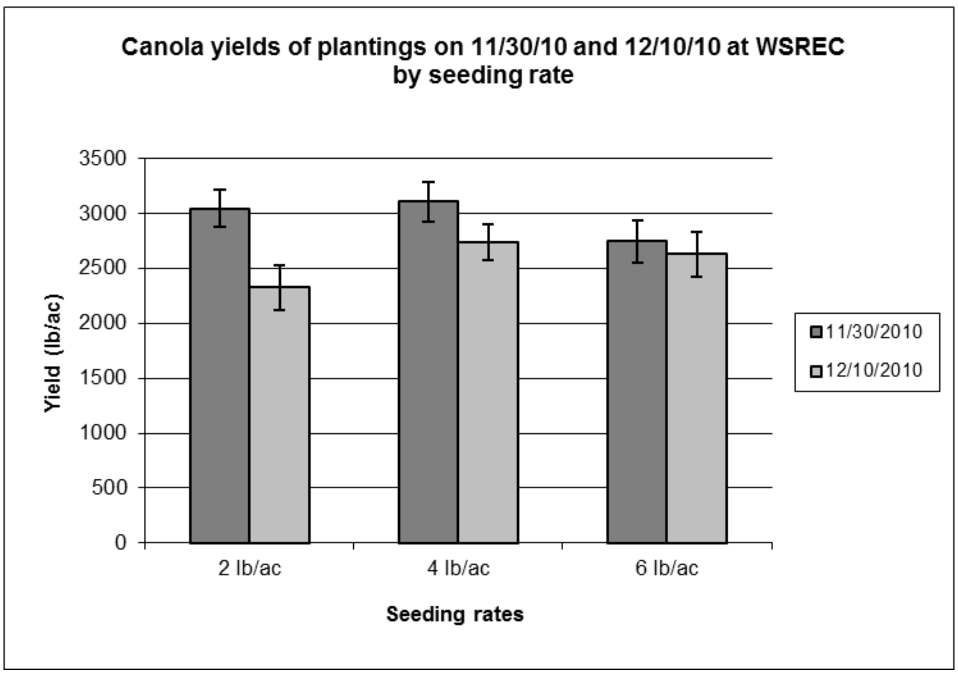


Figure 25: Planting dates and seeding rates comparisons at WSREC in 2010-11.

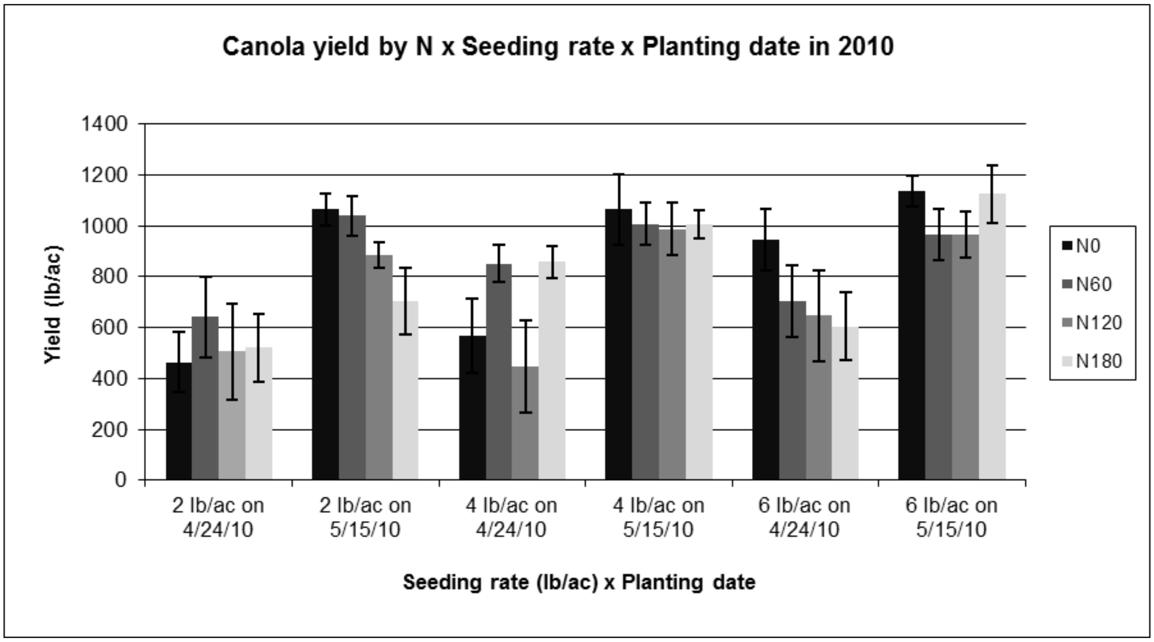


McArthur results (2010) (Dan Marcum-UCCE, Shasta County).

McArthur is located in Shasta County and has a continental climate with freezing temperatures in winter and mild summers (Appendix A). Brassica oilseed crops are spring-planted annuals at this location. In 2010, two planting dates were compared and three seeding rates. Higher seeding rates were hypothesized to compensate for weed pressure and a short growing season at that location. Four different nitrogen rates were compared (0, 60, 120, and 180 lb of nitrogen per acre). Plots were irrigated and hand-harvested. Yields were larger when planted in mid-

May than in late April. Yields were higher at 4 and 6 lb per acre rates than at 2 lb/ac rates, and there was no response to nitrogen above 60 lb nitrogen per acre at the observed yield levels. At the yield levels observed in this trial, there was no response to increasing nitrogen rates above 60 lb per acre.

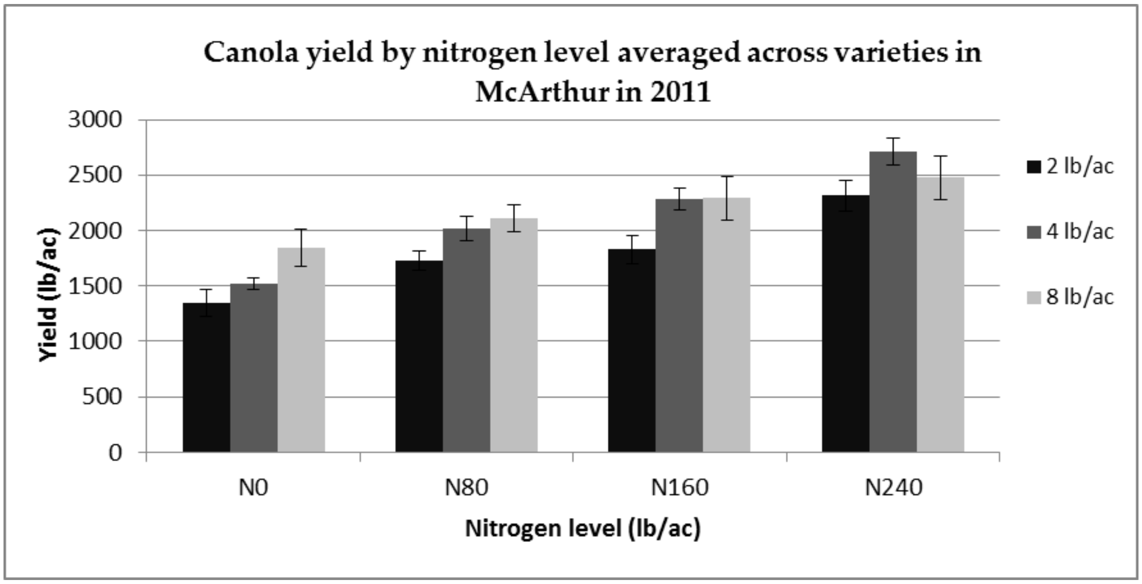
Figure 26: Canola response to nitrogen by planting date and seeding rate in McArthur in 2010.



McArthur (2011) (Dan Marcum-UCCE, Shasta County).

A similar set of trials was carried out in McArthur in 2011, except that all plots were planted in mid-May, and the highest seeding rate was increased to 8 lb per acre. 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 nitrogen application up to 240 lb N/ac in this year.

Figure 27: Yield by seeding rate and nitrogen rate in McArthur in 2011.



Crop water use

In the 2012-2013 season, soil water depletion was record at all the sites. This was done using a combination of soil water sensors and volumetric soil water measurements taken at the start and end of the growing season. This work is ongoing, however preliminary results suggest that soil water depletion by both species is between 9" and 10". This is lower than was anticipated and therefore requires further analysis and repetition of the experiment in subsequent seasons.

Discussion: Multi-year comparisons and general conclusions.

A large amount of variance was observed among the varieties tested during these trials. In most years, canola yields in the lower Sacramento Valley location at Davis averaged 2.25 t/ac of seed, with an average oil content greater than 46%. The best yielding varieties had yields greater than 3.0 t/ac (3,000 lb of seed) (Table 3). In 2012-13, more than half the varieties at Davis and WSREC had yields greater than 3,000 lb/ac, while in two other 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 relatively high.

Statistical analyses were complicated by differences in varieties between years and by variance differences between sites and years. For these reasons, the significance of site by variety interactions could not be examined. Main effects with non-parametric analyses were investigated and showed that yield varied significantly between seasons and sites. These results suggest that to develop a more reliable understanding of long term mean yields, variety evaluation will need to continue at multiple locations throughout California.

Regardless of this, 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 nitrogen remaining from previous crops and fertilization practices. This is in line with fertilization recommendations in other canola-growing regions.

Canola planted in spring and harvested in fall in Shasta County resulted in yields greater than 1 t/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 in that region as well.

The place of canola in cropping systems in diverse locations in California and the potential for its adoption based on these results is discussed in Chapter 3. Potential biodiesel yields from differing transformation technologies are also discussed in Chapter 3.

Table 3: Canola variety trial yields (2009-13) in 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	
2012-13	63	3120	900	126	1670	4540	
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
2012-13	1241	2050	2550	3130	3530	4270	6230

Table 4: Canola variety trial yields (2009-13) in 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

1.6 Camelina

Camelina (*Camelina sativa*) is a member of the mustard family that is related to canola. It is sometimes referred to as false flax, given the species' superficial resemblance to true flax. Although it has been grown for millennia, interest in camelina as an alternative oilseed crop has increased in recent years. It is currently 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 also reported to exist.

Camelina originated in central Europe and 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: 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[5].

Previous work in California

To our knowledge, there has been no previous work in California apart from one 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.

Yields at WSREC were comparatively good in May 2010, with some varieties producing more than 2000 lb/ac in small plots (Fig. 28). There was no response to nitrogen fertilizer in this trial (Fig. 29). Seed oil content varied little among the varieties tested (Fig. 30), with average oil content in seeds (36.8%) being similar to others reported in the literature. Oil yields varied from

[5]http://www.renewableenergyworld.com/rea/news/article/2012/08/flying-on-woody-biomass-and-camelina-consortium-seeks-biofuel-answers

700 to approximately 1000 lb per acre (Fig. 31), which would result in 100 to 130 gallons of biodiesel per acre using the Fatty Acid Methyl Ester (FAME) process. Oil content and oil yield did not respond to increasing fertilizer nitrogen levels (Fig. 32/33). Supplemental irrigation in spring also had no effect on oil content or oil yield in 2009-10 at WSREC (Fig. 34, 35).

Figure 28: Camelina variety trial seed yields in 2009-10 at WSREC.

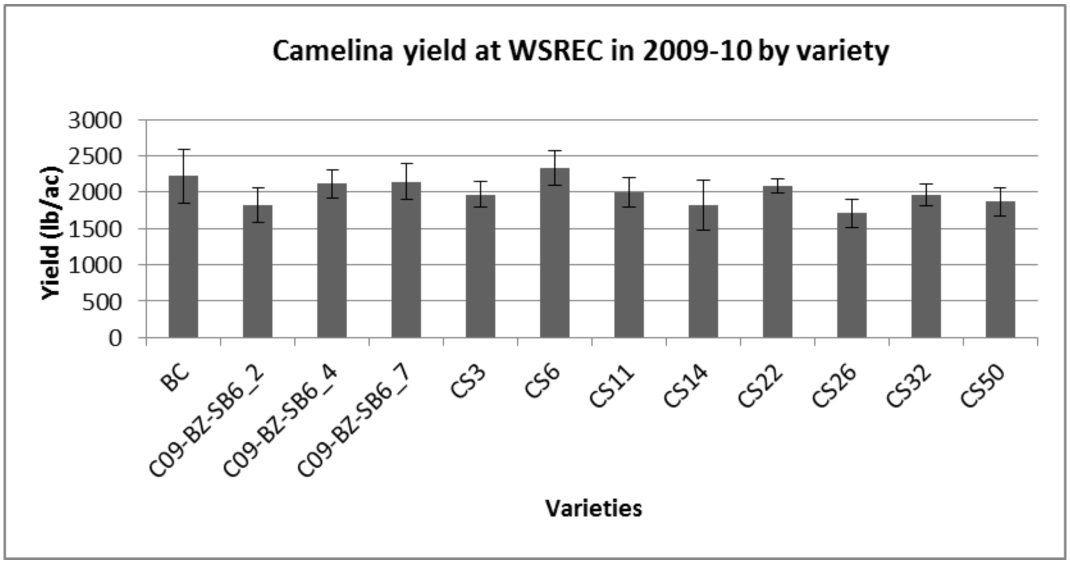


Figure 29: Camelina response to nitrogen in 2009-10. There was no significant response.

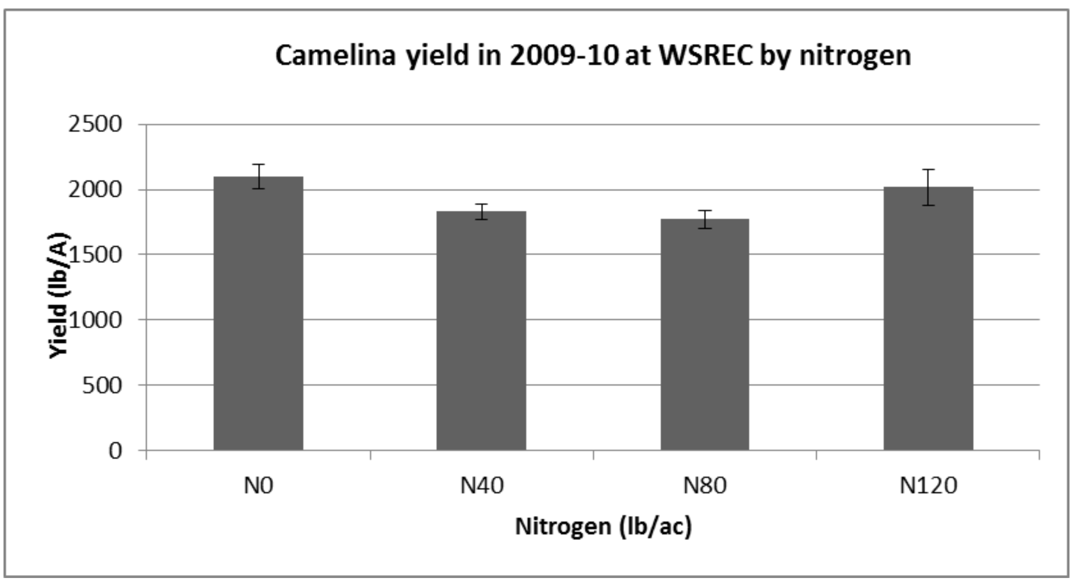


Figure 30: Oil content (%) of camelina varieties at WSREC.

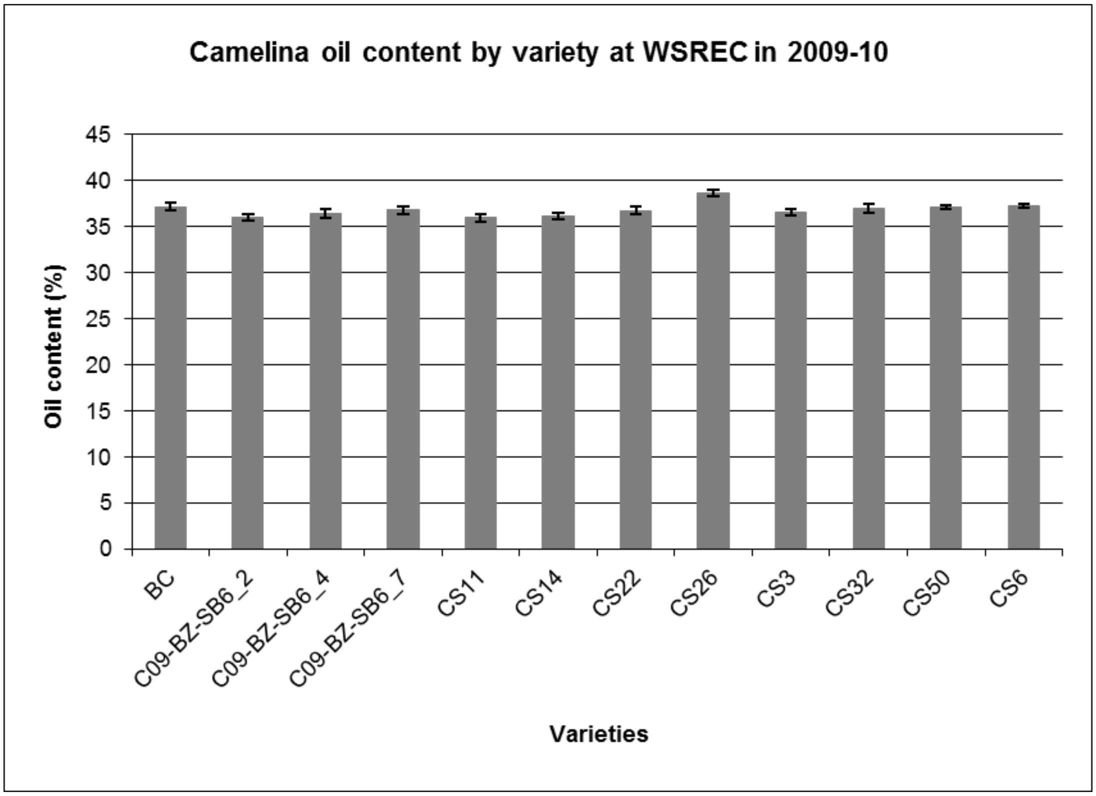


Figure 31: Oil yield (% oil x seed yield) at WSREC in 2009-10.

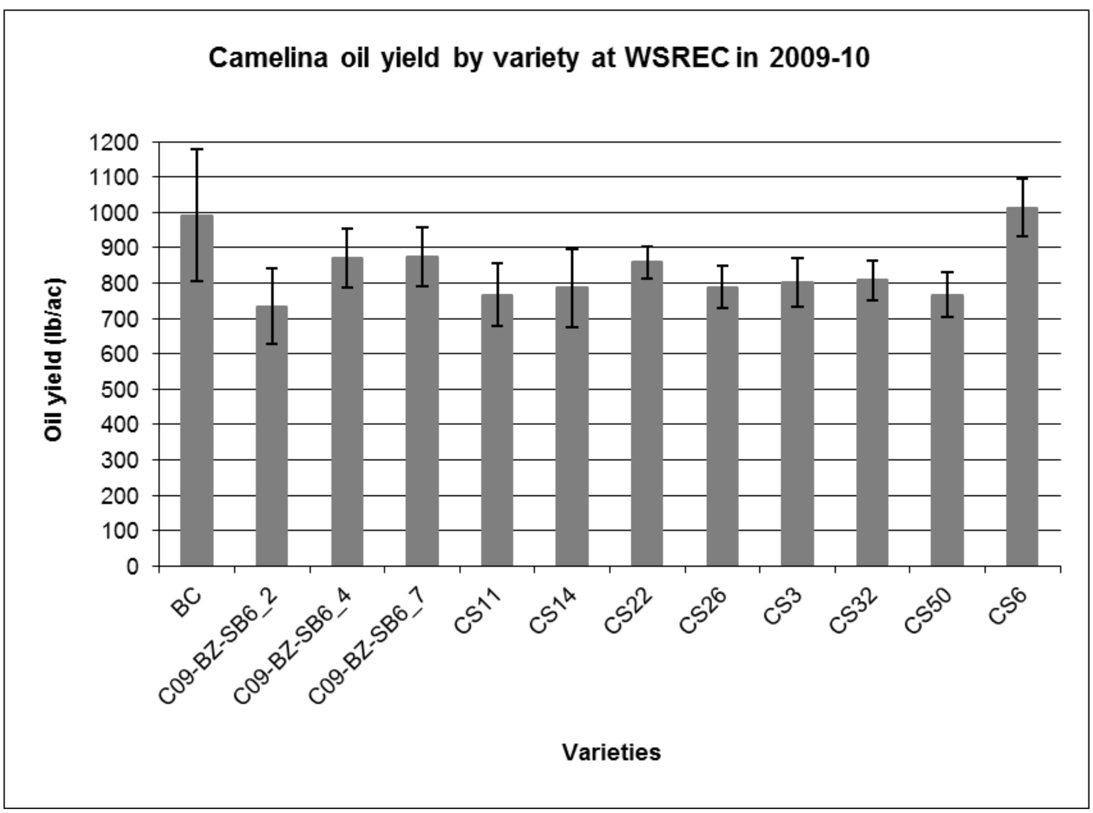


Figure 32: Oil content (%) in response to nitrogen fertilizer at WSREC in 2009-10. There was no response to increasing rates of nitrogen.

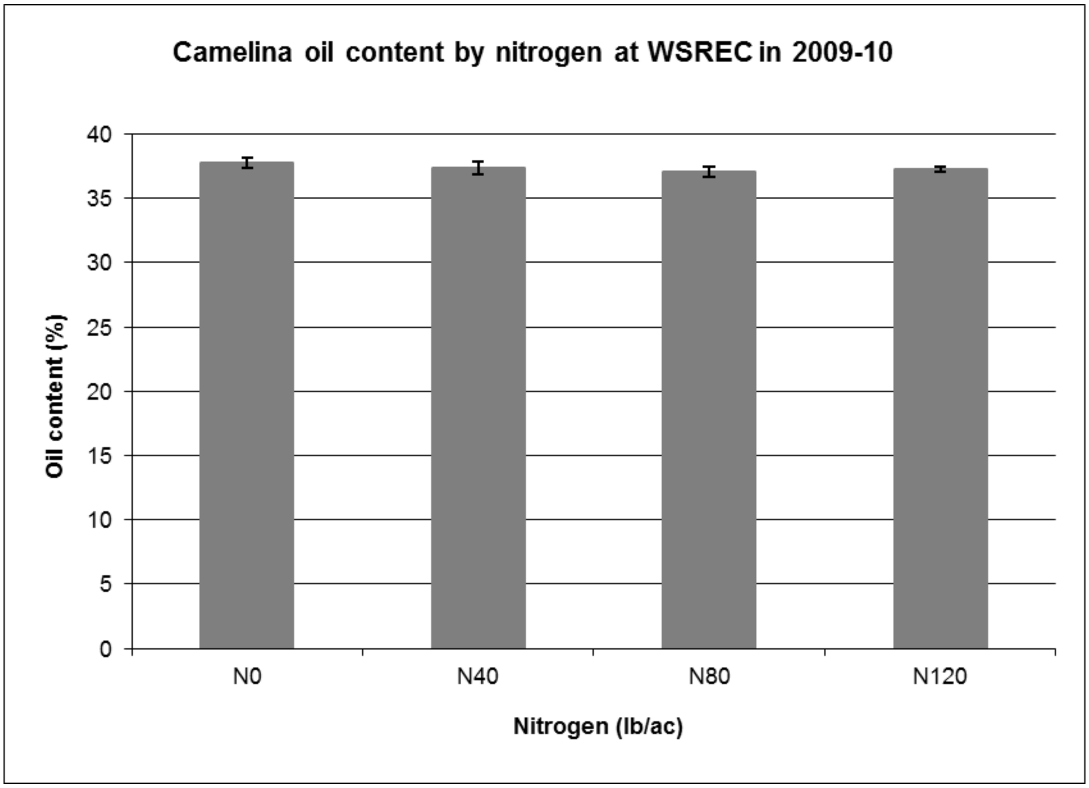


Figure 33: Oil yield in response to nitrogen fertilizer at WSREC in 2009-10.

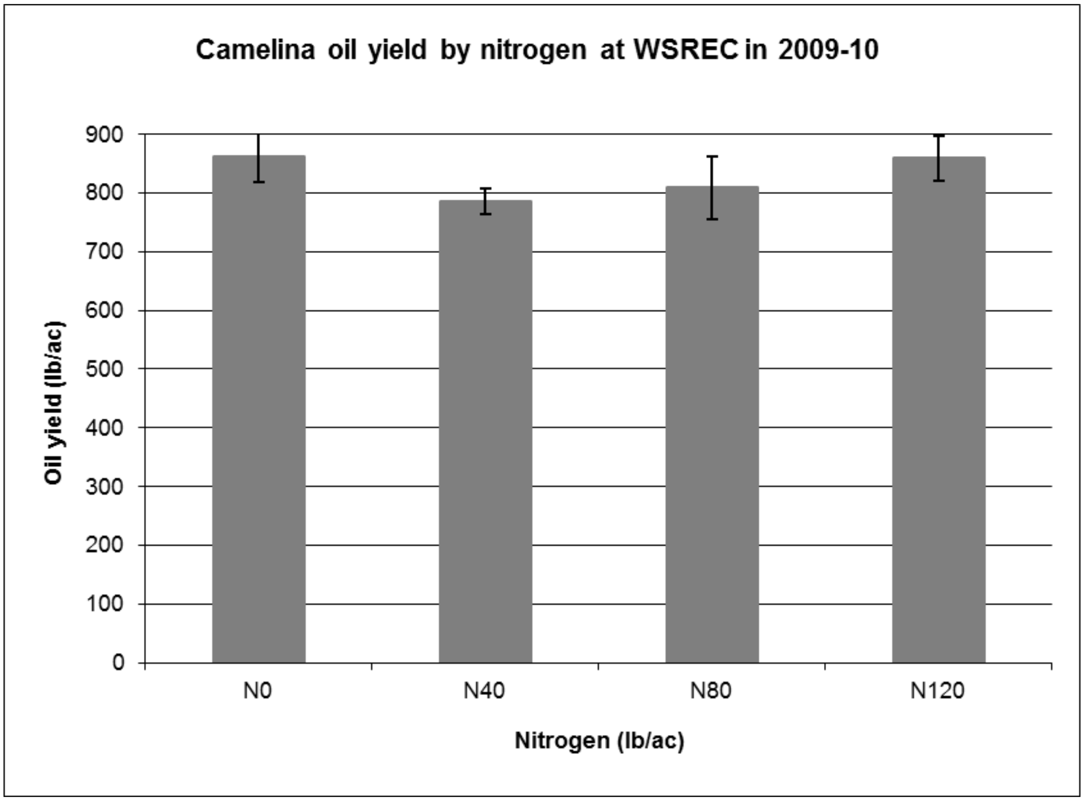


Figure 34: Oil % in response to supplemental spring irrigation at WSREC. There was no significant difference between the treatments.

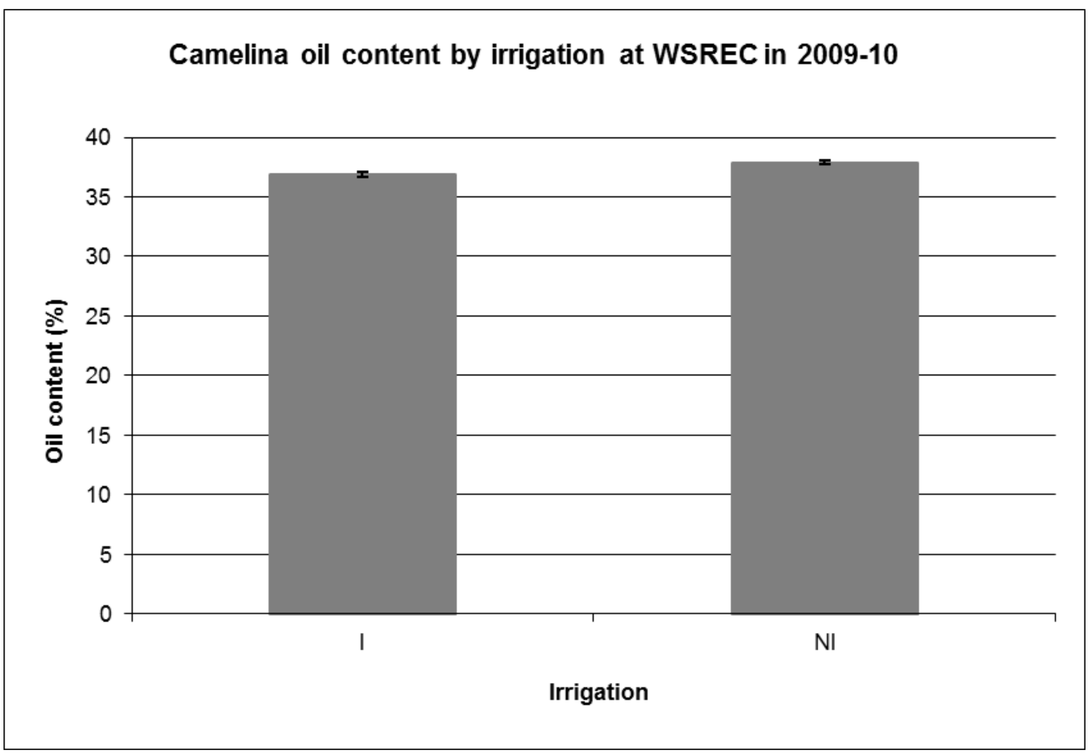
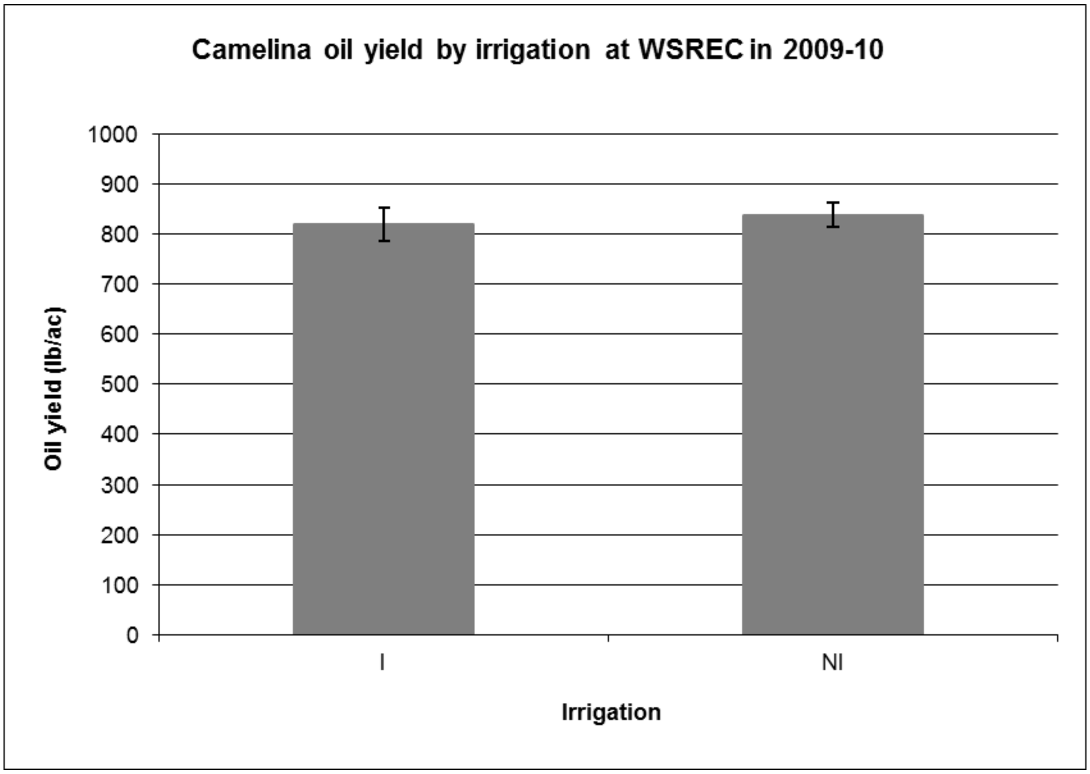


Figure 35: Oil yield in response to supplemental spring irrigation at WSREC in 2009-10. There was no significant increase in oil yield in response to treatments.



2010-11 Trials.

Camelina was grown at both Davis and the WSREC in 2010-11. Yields were less than half those observed at WSREC during 2009-10. Variety yields at WSREC were higher on average than at Davis (Fig. 36). Unlike 2009-10, there was a response to nitrogen fertilizer, with maximum yields observed at 80 lb N/ac at both locations. Maximum yields in the nitrogen trial were larger than in the variety trial by 600 lb/ac at WSREC and approximately 200 lb/ac at Davis (Fig. 37). Supplemental irrigation had no effect on yield at either location (Fig. 38). Seed oil content was higher in 2010-11 than in 2009-10 at both locations, but there were no significant differences among varieties (Fig. 39). 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 (Fig. 40). Similar to 2009-10, there was no significant difference in oil yield in response to fertilizer nitrogen at WSREC, but nitrogen applied at both 40 and 80 lb N/ac increased seed oil yield at Davis (Fig. 41).

Figure 36: Variety trial seed yields at Davis and WSREC in 2010-11.

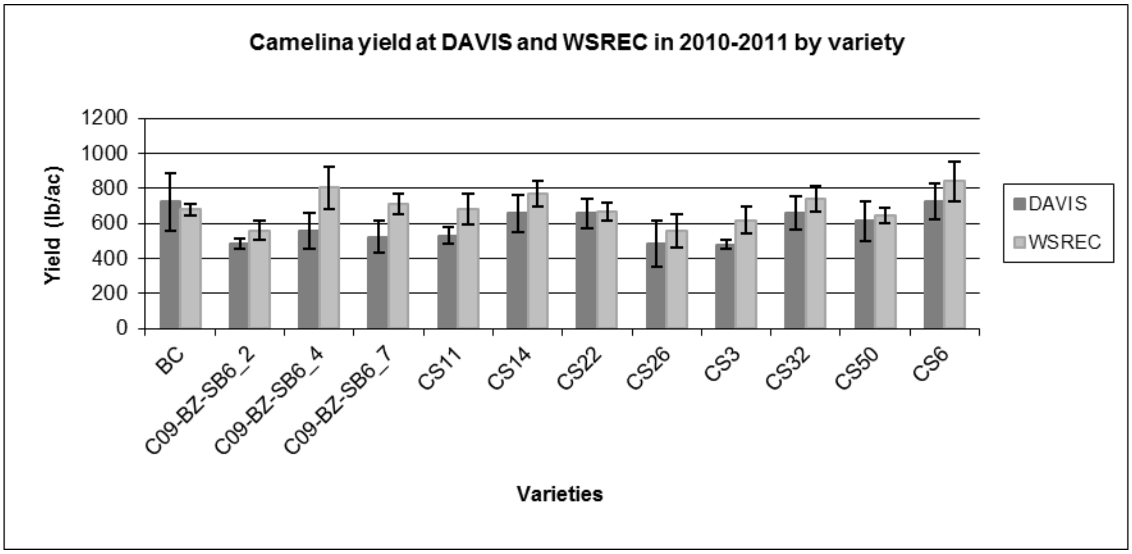


Figure 37: Camelina seed yield response to fertilizer nitrogen in 2010-11. In both trials, the highest yields were achieved at 80 lb N/ ac.

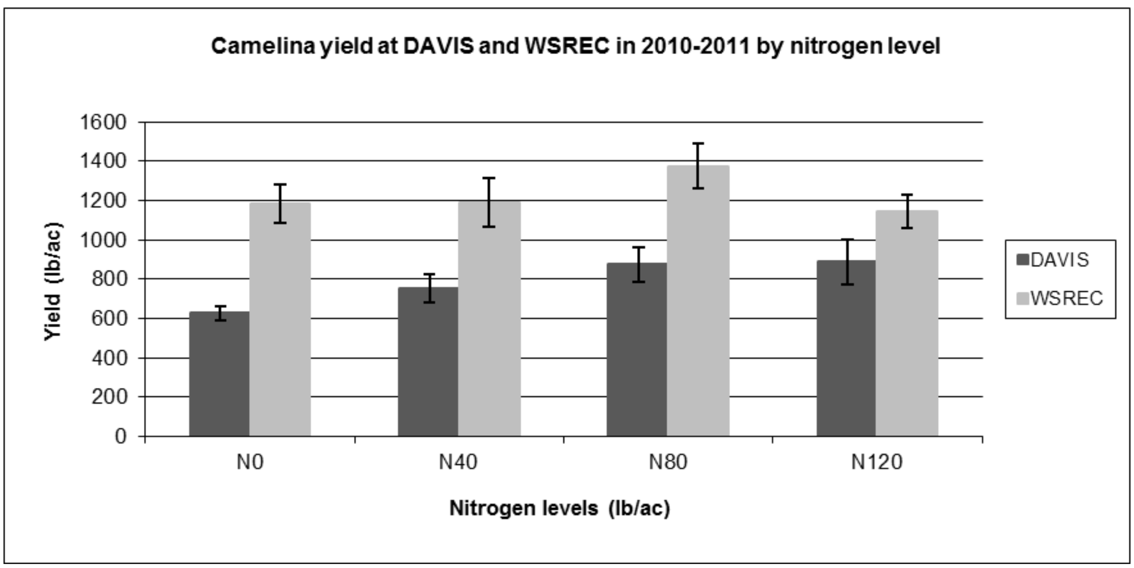


Figure 38: Seed yield response to supplemental spring irrigation at Davis and WSREC. Differences were not significant.

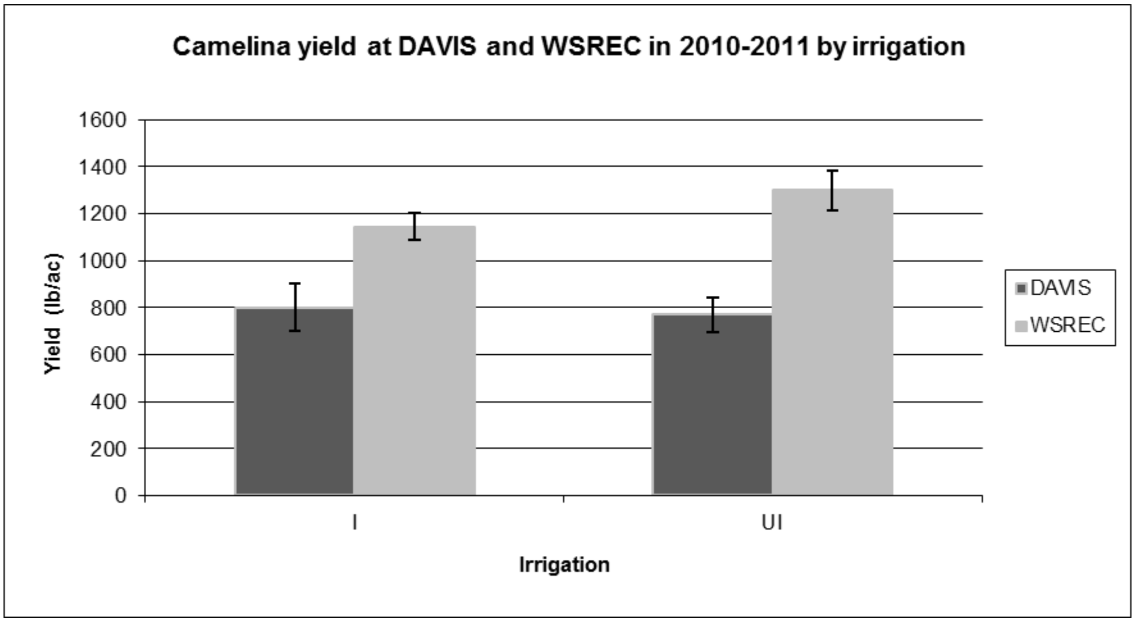


Figure 39: Oil content in variety trials at Davis and WSREC in 2010-11. There were no significant differences among the varieties, but average oil contents were greater in Davis than at WSREC.

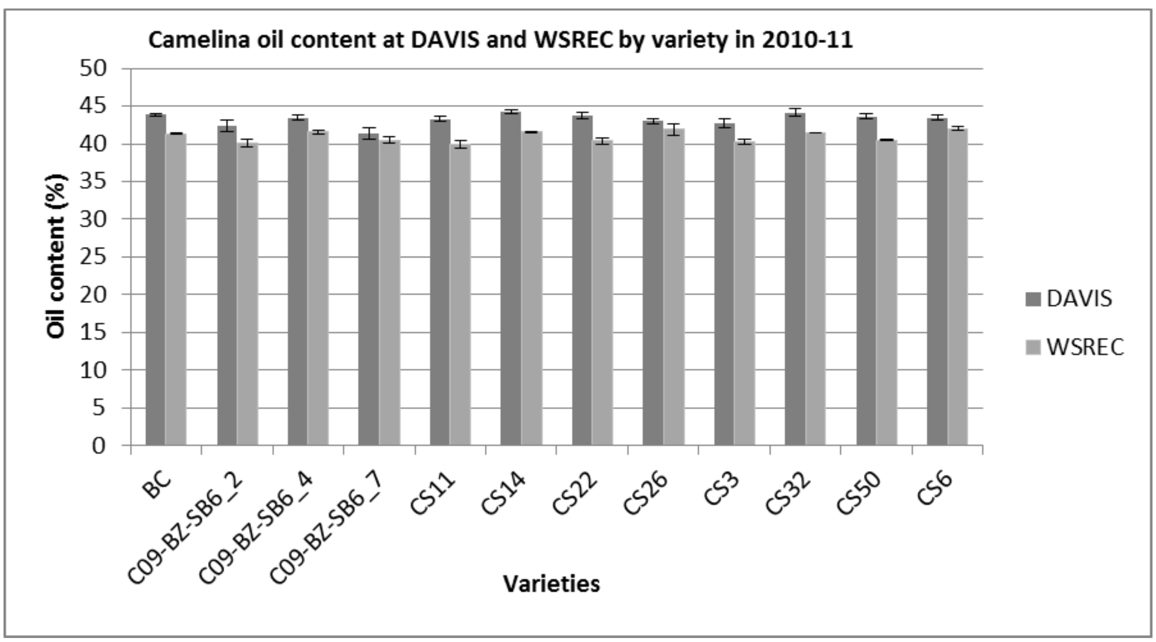


Figure 40: Oil yields at Davis and WSREC in 2010-11.

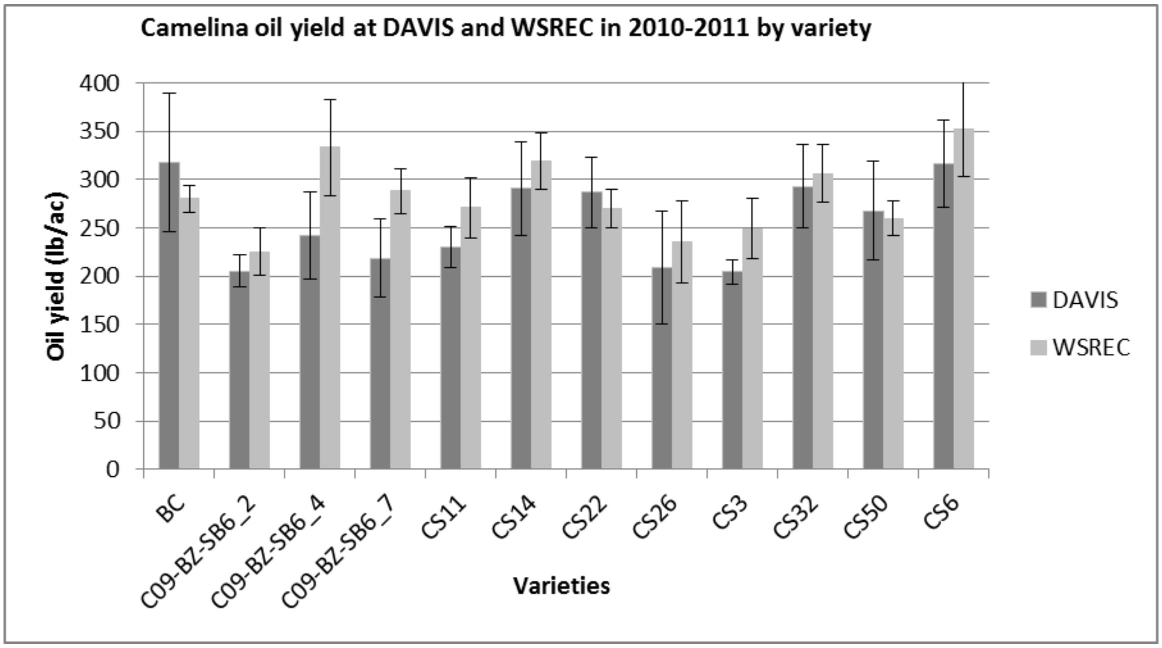
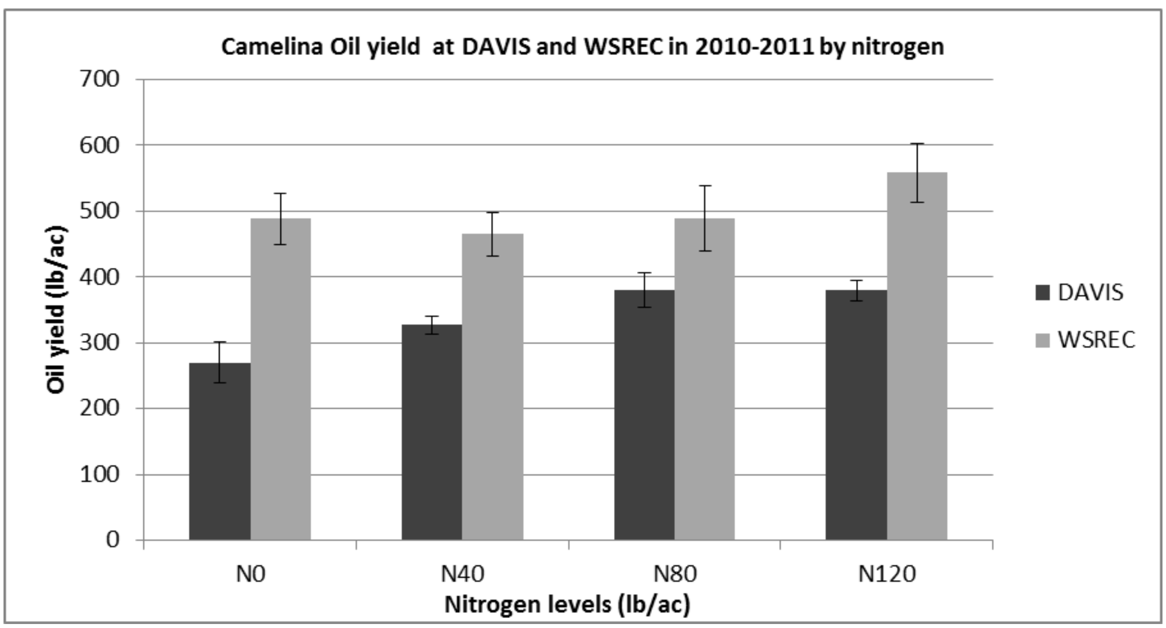


Figure 41: Oil yield (lb / ac) in response to fertilizer nitrogen. Maximum yields at Davis were observed at the 80 lb / ac rate. There was no significant response to nitrogen at WSREC, similar to 2009-10.



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 USDA NRCS Western Plant Materials Center (PMC). The PMC is immediately adjacent to the Cosumnes River, on alluvial, coarse-textured soils. Yields for individual planting dates are summarized in Figures 42-44. A comparison of variety means across all four planting dates is provided in Fig. 45. 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 Fig. 46. Seed oil yields for Davis and the PMC are compared in Fig. 48. In general oil percent was lowest at the PMC compared to the other locations, and oil yields were lower than at Davis. Nitrogen response was similarly suppressed at WSREC in 2011-12, while at Davis, maximum yields were observed at 80 kg N/ac (Fig. 48). 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 (Fig 49).

Figure 42: Variety trial seed yields at WSREC and Davis in 2011-12 for an October planting date.

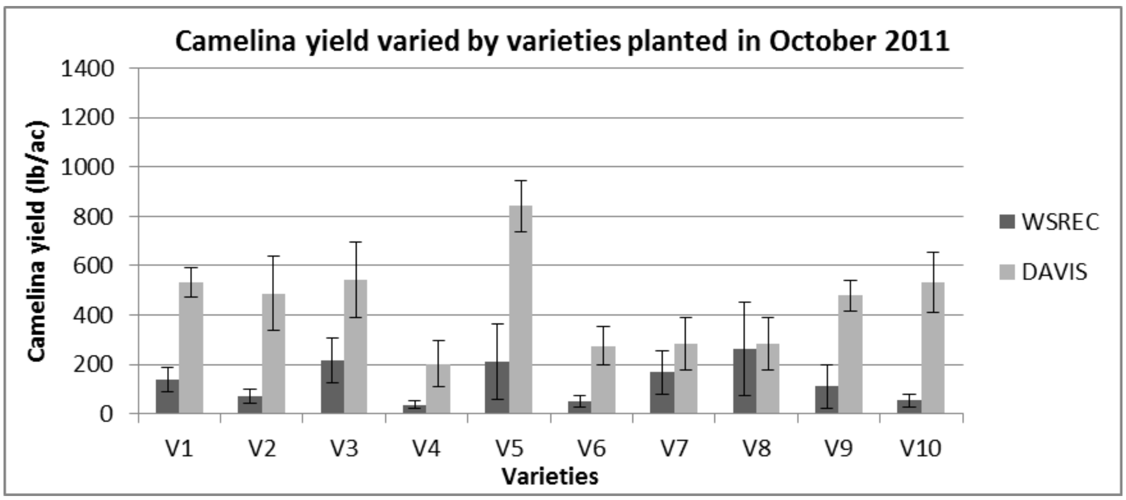


Figure 43: Variety trial seed yields at WSREC, Davis, and the Plant Materials Center near Lockeford. Yields were highest at Davis. Plots at WSREC were adversely affected by residual herbicides.

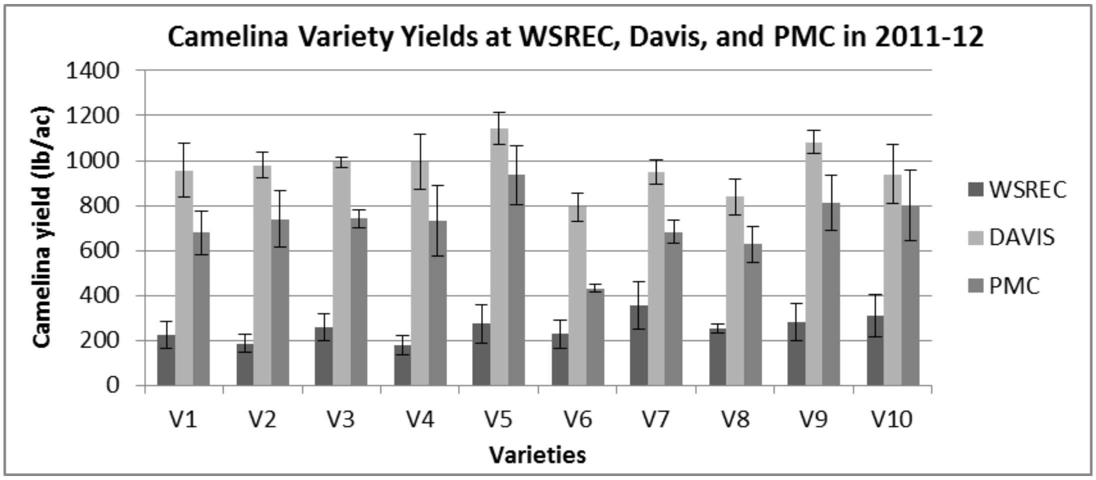


Figure 44: Variety yields at WSREC and Davis for a January planting date at WSREC and Davis in 2011-12.

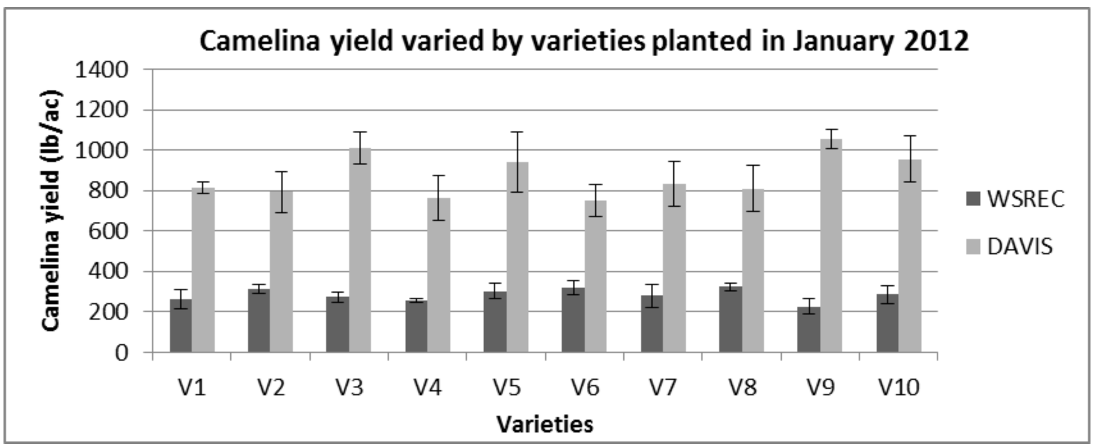


Figure 45: Comparison of seed yields at differing planting dates in 2011-12 at WSREC and Davis. The best planting date was in November.

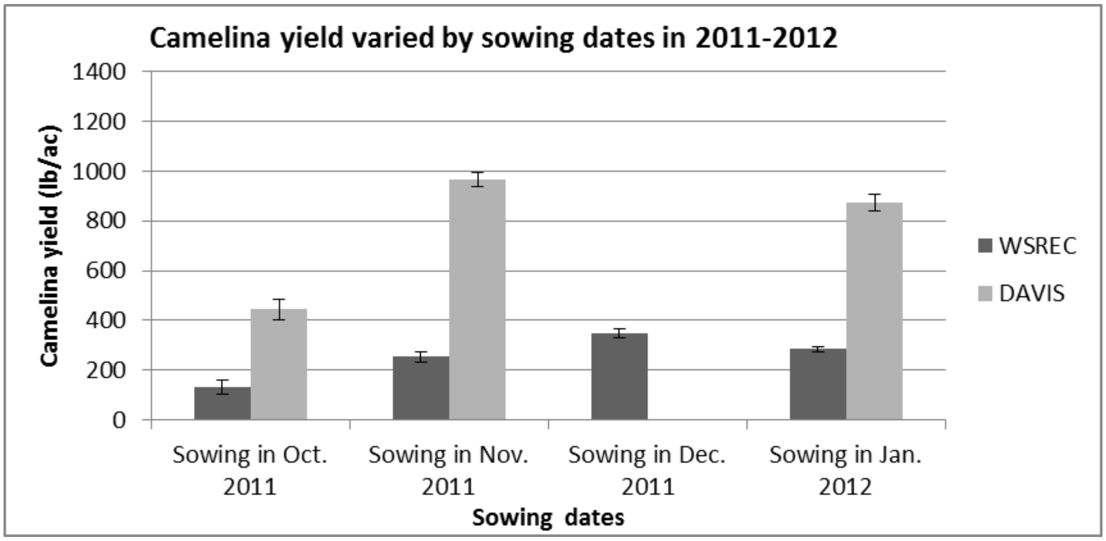


Figure 46: Oil content by variety, November planting date (2011-12).

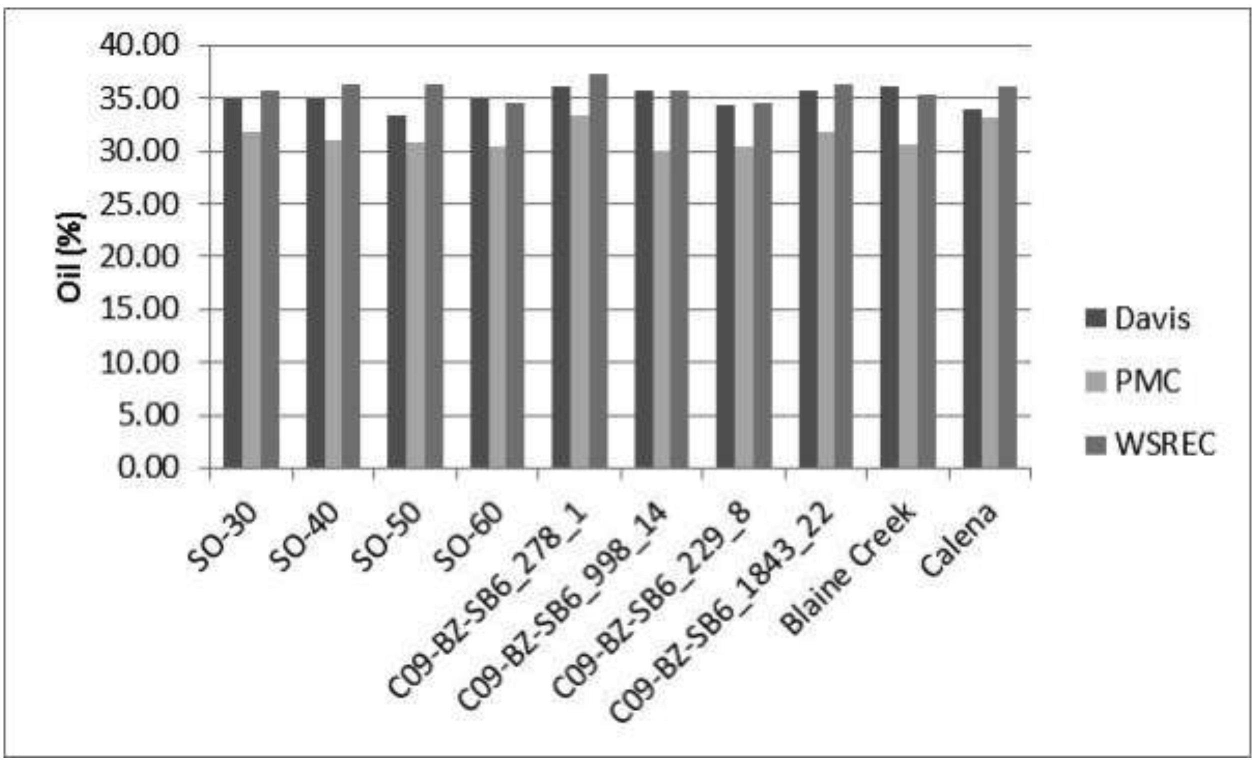


Figure 47: Oil yield by variety in 2011-12.

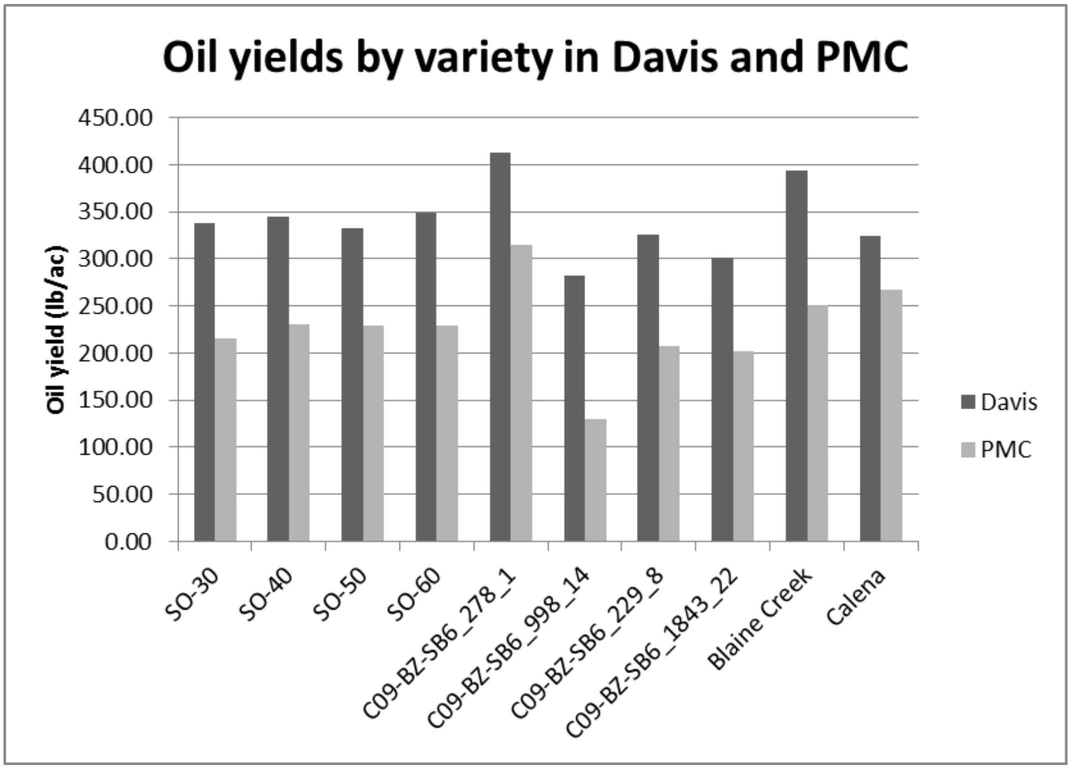
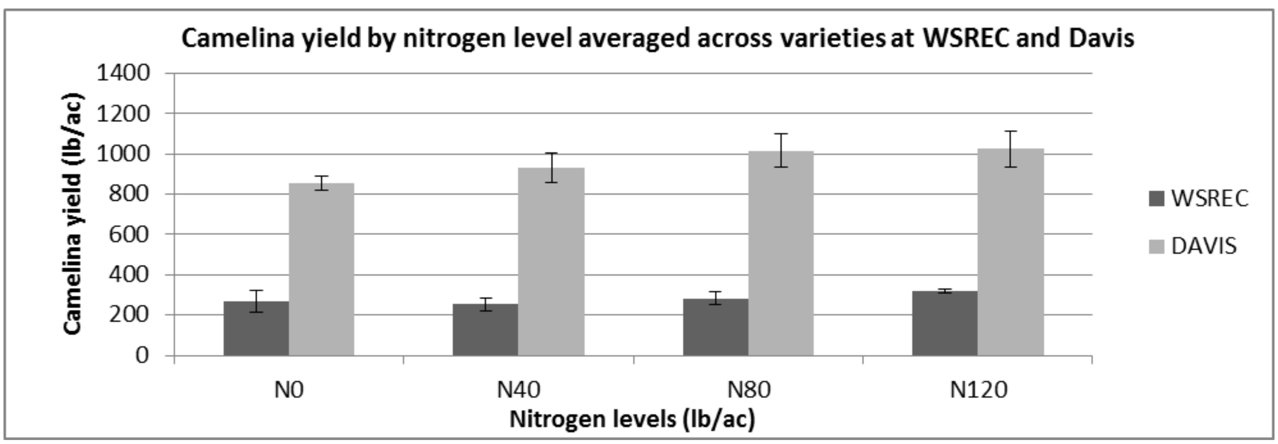


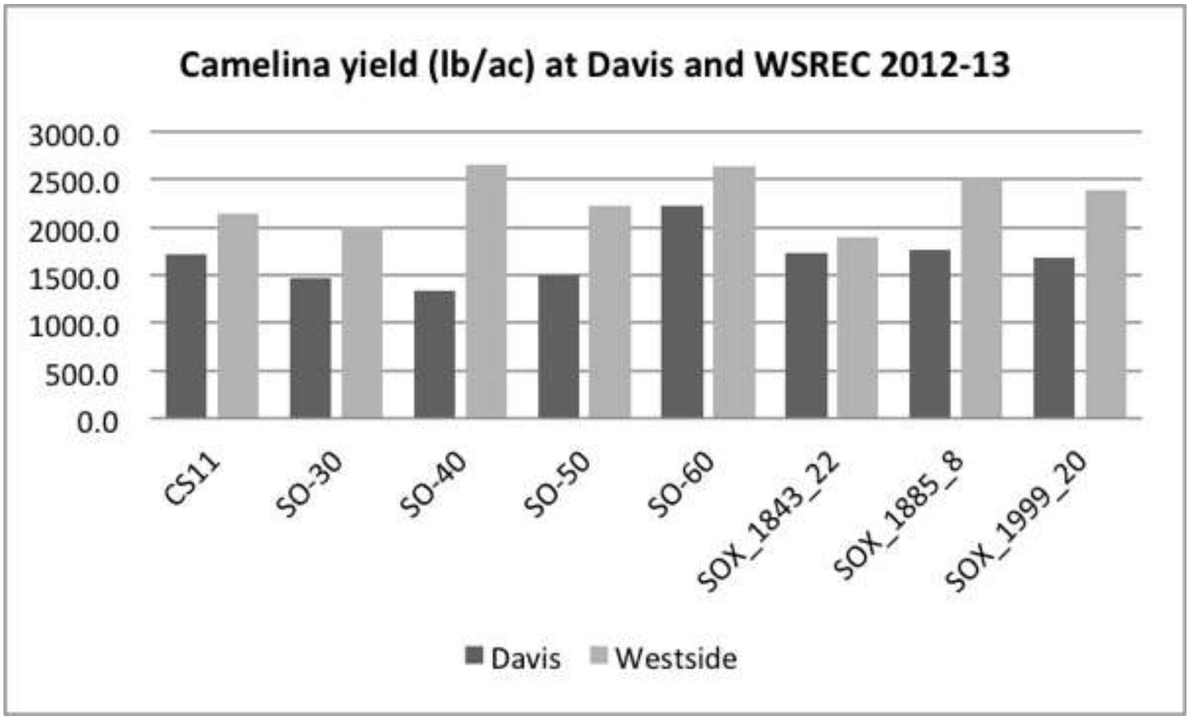
Figure 48: Response to nitrogen at WSREC and Davis in 2011-12. There was no response at WSREC, but maximum yields occurred at Davis at lb N / ac.



2012-13 trials

Camelina variety trials were planted at Davis and WSREC again in fall 2012 and harvested in late May 2013. Average yields were the highest observed in the four years of trials and most similar to those observed at WSREC in 2009-10. Higher yields were observed in Davis than in previous years. Camelina yields equal to or greater than 1 t/ac are similar to the highest yields reported in other locations under ideal conditions.

Figure 49: Camelina yields at both Davis and WSREC during the 2012-13 growing season.



1.6.1 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.

Results are presented in Fig. 47. 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-methyl-4-chlorophenoxyacetic acid), 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 even those that are difficult to control, such as burning nettle. 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 50: Camelina seed yields after pre-plant or post-emergence herbicide treatments. The herbicides evaluated are identified in Table 3.

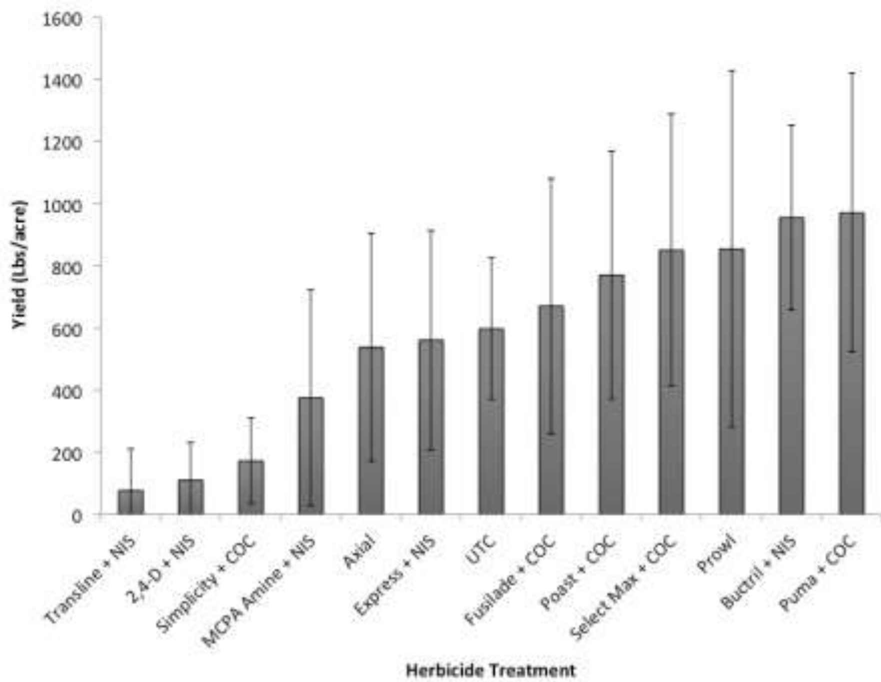


Table 5: List of herbicide treatments, their common names, and the rate dispersed.

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 across the four years of the trials at WSREC and Davis. Similar to the case for canola, statistical analysis to investigate variety by site interaction was challenging, given unequal variance between sites. Non-parametric analysis found the effect of different years was highly significant (Tables 6, 7). 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 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 7), and were also larger than in previous years at Davis (Table 6). 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 8). January through March was unusually cold in Davis as well. Freezing or near freezing temperatures while flower buds were forming, or during early blooms, reduced camelina yield, compared with years with more normal temperature patterns (Appendix A). Freezing temperatures during bud formation also produced lower camelina yield as compared to freezing temperatures earlier in the crop's development, as experienced in December 2009, when high yields were observed.

In contrast to differences among years, camelina variety differences were small and for the most part non-significant (Table 9). 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 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 so differences are primarily due 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, mid to late November is the best planting period, effectively at the expected start of the winter rainy season in California's central valley. Harvest is generally 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 the 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 carbohydrate in the form of oil to seed sooner. Warm, dry temperatures in early spring also cause camelina to be more prone to seed shatter than at Davis, where it was not observed.

Table 6: Camelina variety trial yields (lb / ac) at 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 7: 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 8: 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 9: Variety differences and probability level for significant differences among varieties (2009-2011 only). Data analysis for 2012-13 is not yet complete.

	WSREC				Davis	
Variety	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	

1.7 Meadowfoam

Meadowfoam (*Limnanthes alba*) is a California native annual 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.

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[6] (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 nitrogen x irrigation treatment. Plots were 30 feet in length and 4 feet in width. The variety trial was fertilized with 40 pounds per acre nitrogen, 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 nitrogen 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. Trial dates are in Table 1.1. 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 at the Davis location in spring 2010 (APPENDIX). Rainfall amounts and distribution precluded supplemental spring irrigation at

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

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 than at Davis. Figure 51 and 52 summarize average yield at each location. Meadowfoam yield at Davis is larger than at WSREC either variety trail and 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 (Fig. 51). Meadowfoam yield increased with nitrogen level at Davis with a longer and lower temperature growing season, but there was no response under more moisture-limited conditions at WSREC, despite supplemental irrigation (Fig. 53). Yield increased with supplemental irrigation at WSREC, but irrigation treatment differences at Davis were not significant (Fig. 53).

Figure 51: Meadowfoam yield by variety, 2009-10.

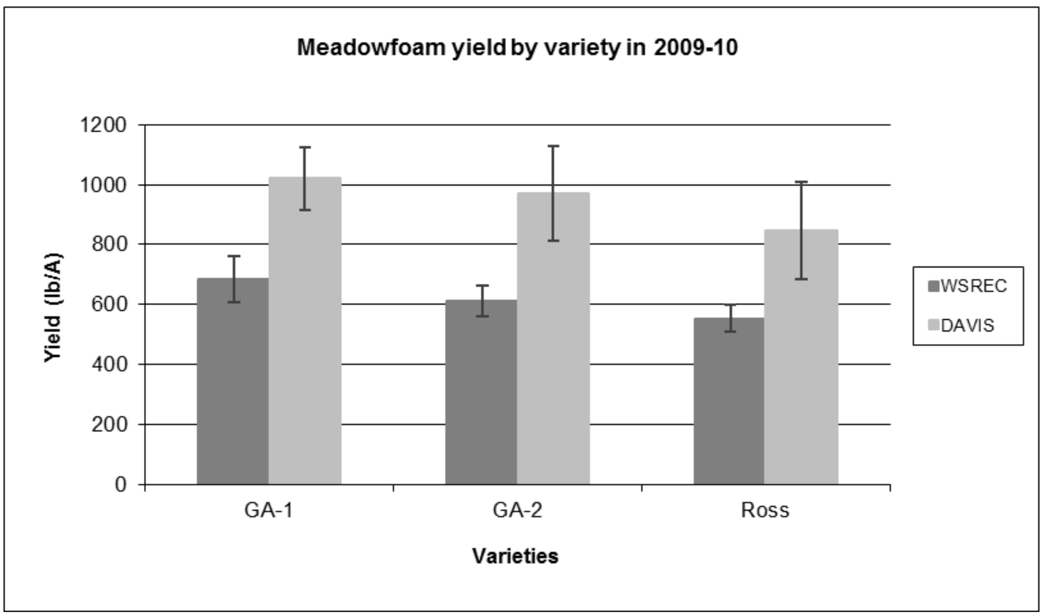


Figure 52: Meadowfoam yield by nitrogen level (2009-10).

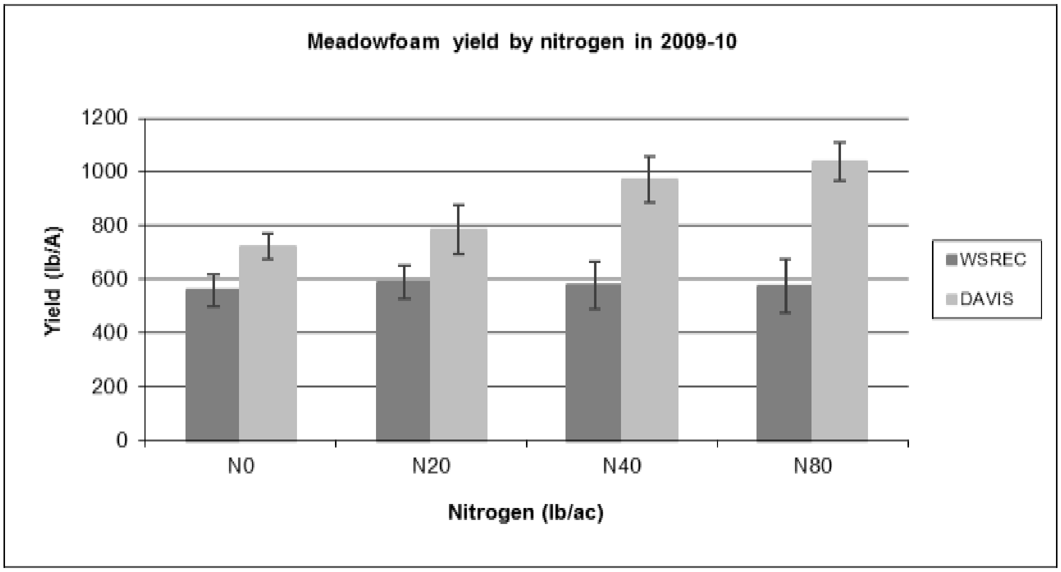


Figure 53: Meadowfoam yield by irrigation treatment (2009-10). At the lower rainfall site (WSREC) in a normal rainfall year, meadowfoam benefited from supplemental irrigation in spring.

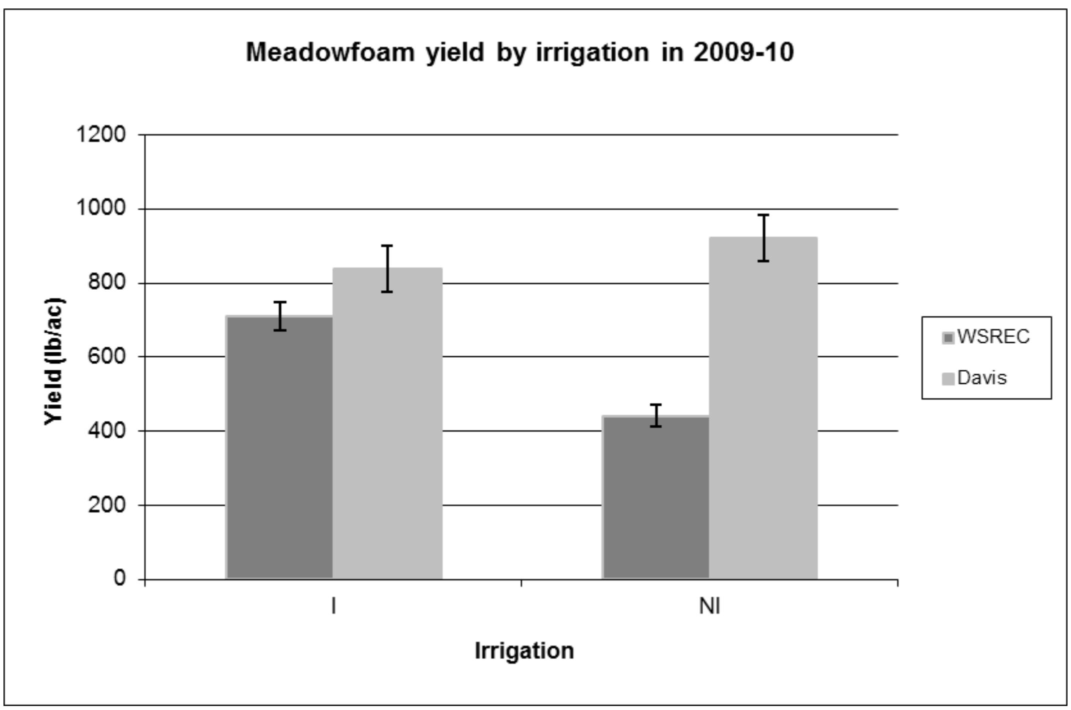
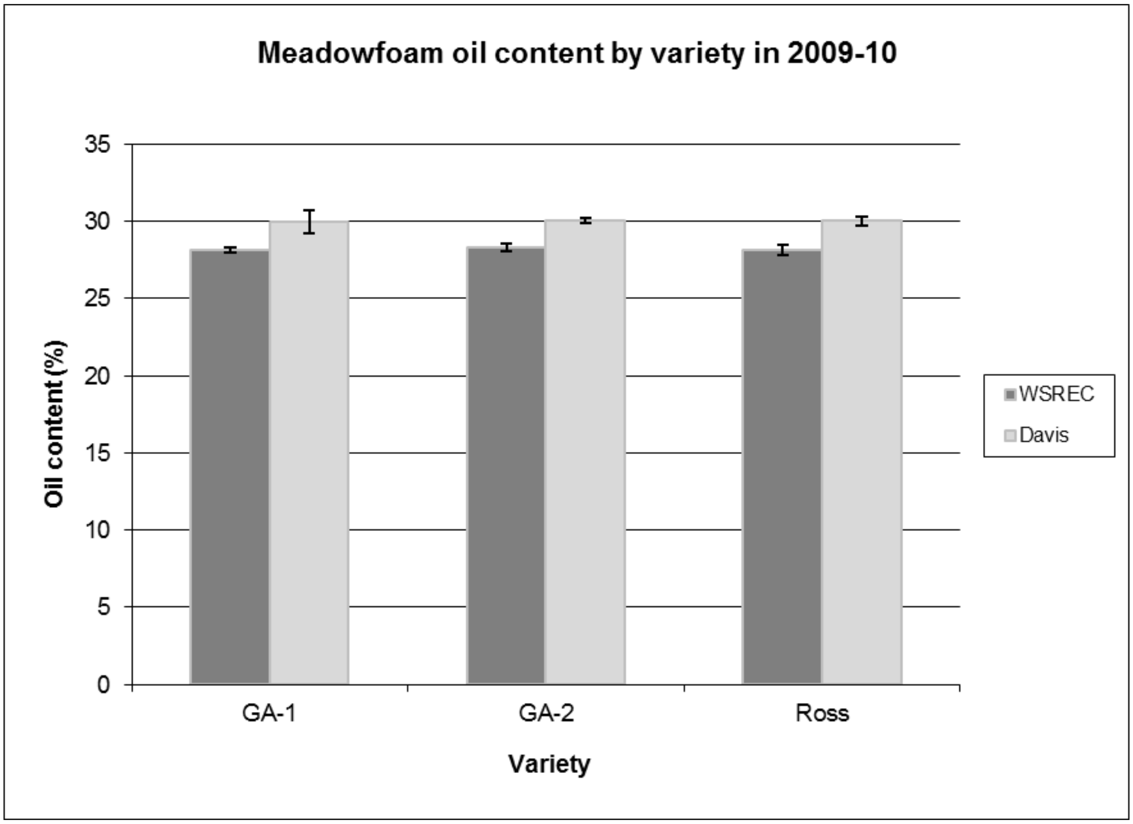


Figure 54: Oil content by variety. Nitrogen fertilization did not influence oil content in any of the trials (data not shown).



2010-11 Results

As in 2009-10, all cultivars matured earlier at WSREC than at Davis in 2010-11. Figure 55 and 56 summarize average yield at each location. 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 (Fig. 55). Under the unusually cold conditions experienced during the winter of 2010-11, Meadowfoam yield did not respond to fertilizer nitrogen at either location. Yield increased with supplemental irrigation at both locations (Fig. 57).

Figure 55: Meadowfoam yield by variety. (Error bars are standard errors.)

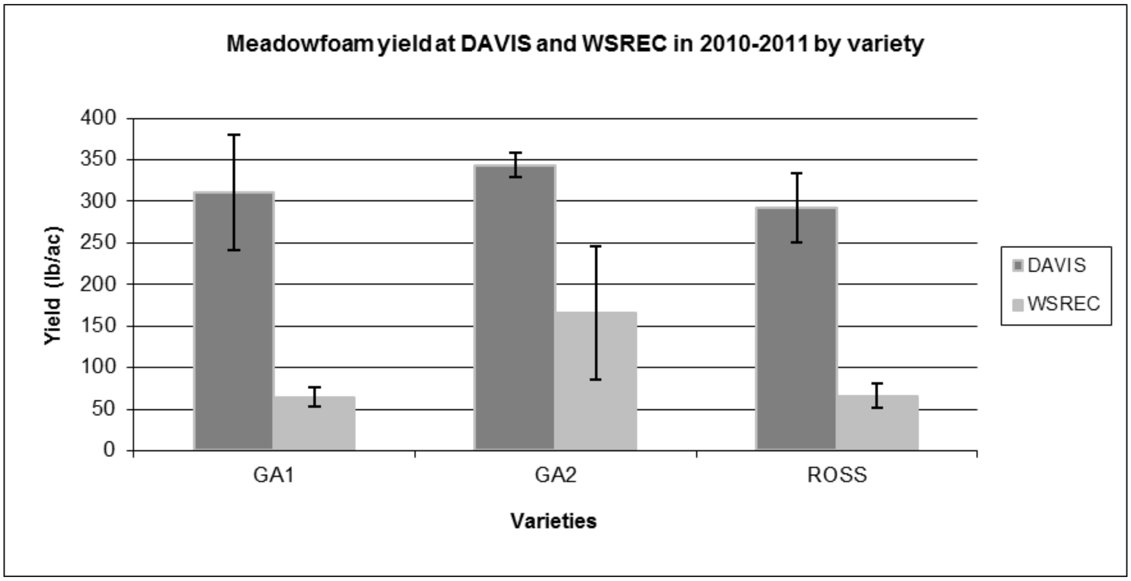


Figure 56: Meadowfoam yield by nitrogen level. (Error bars are standard errors.)

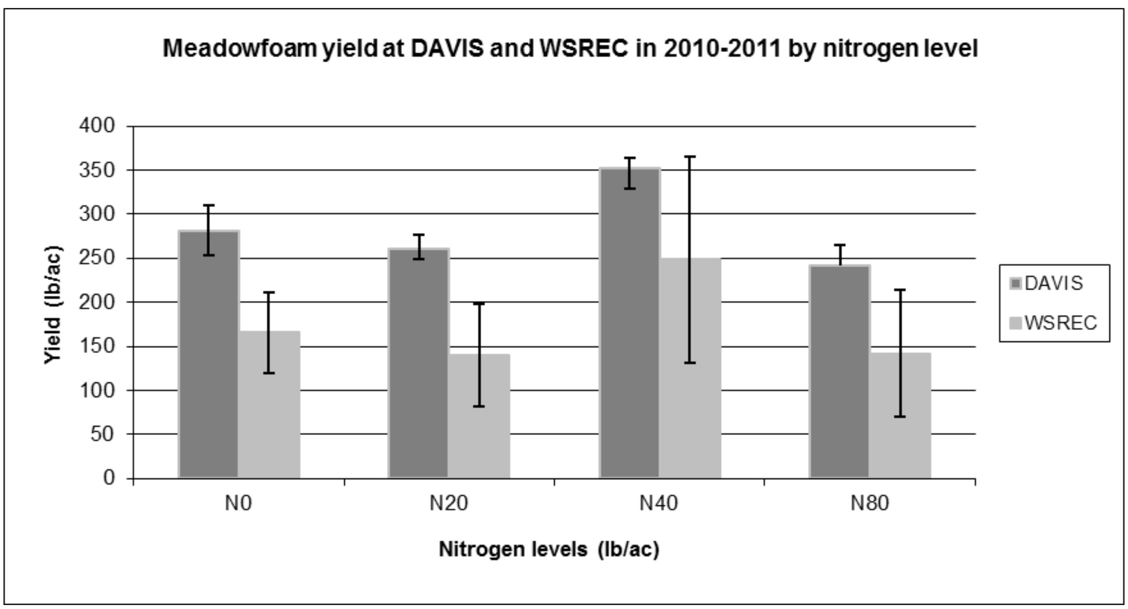


Figure 57: Meadowfoam yield by irrigation treatment. (Error bars are standard errors.)

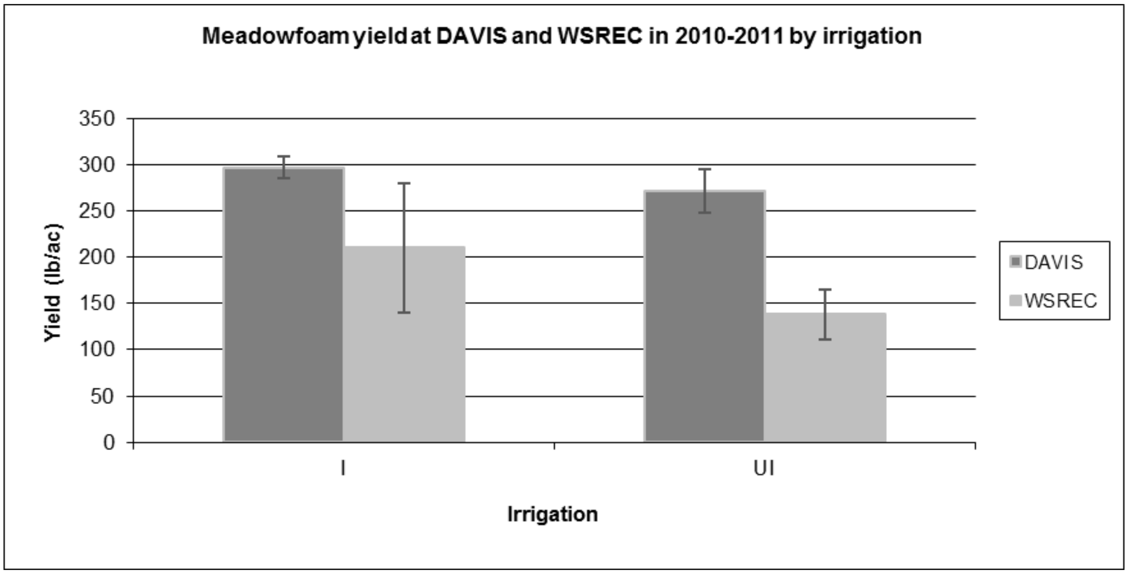
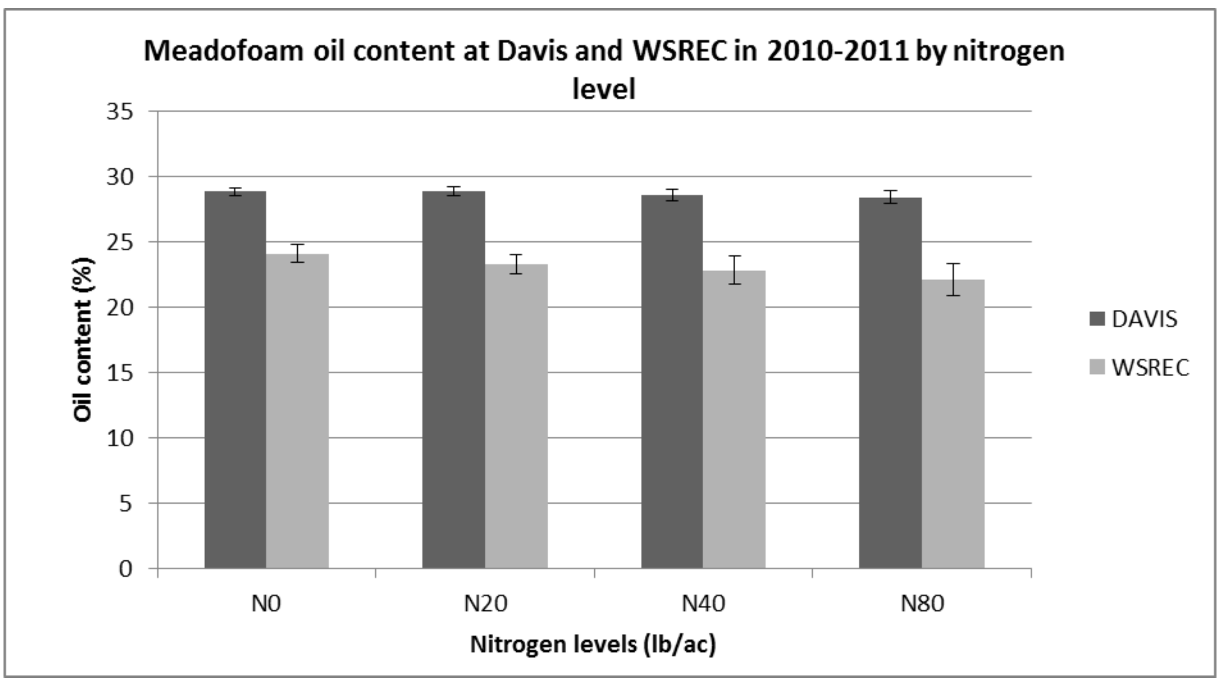


Figure 58: Meadowfoam oil percent by nitrogen level. There were no significant differences in oil content among varieties at either site (data not shown).



1.8 Discussion: Multispecies Comparisons

Canola was always the highest yielding species among the winter annual oilseeds tested across all sites and years. Oil content was also greater in canola than in camelina and meadowfoam. Because of its longer growing season and larger overall DM accumulation, canola uses more water, responds to larger amounts of nitrogen fertilizer, and has different effects on cropping systems in which it is included (Chapter 3). 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 3.6), but it is unlikely to be of use in the cropping systems in California due to its very low and variable yields.

Table 10: Comparison of oilseed crop performance (variety trial data) among species and locations (2009-2013). 2013 data is incomplete.

Species		2009-10		2010-11		2011-12			2012-13	
		Davis	WSREC	Davis	WSREC	Davis	WSREC	PMC	Davis	WSREC
Canola	**Yield (lb/ac)**	2563	3348	749	2004	1829	773		3123	2714
	Oil content (%)	46.58	40.23	47.23	40.4	46.5	40			
	Oil yield (lb/ac)	1191	1385	356	826	1050	356			
Camelina	**Yield (lb/ac)**	N/A	2015	591	689	967	254	717	1500	2080
	Oil content (%)	N/A	36.8	43.3	40.9	36.5	35.5	31.3		
	Oil yield (lb/ac)	N/A	742	256.8	282.4	50	90	225		
Meadowfoam	**Yield (lb/ac)**	945	617	315	99					
	Oil content (%)	30	28	28	23					
	Oil yield (lb/ac)	283	174	91	22					

1.9 Sweet Sorghum

Sweet sorghum (*Sorghum bicolor*) has been grown for many years in the southeastern US for making sweet syrup. It originated in Africa and has long been grown there (Saballos, 2008). More recently, and in many locations around the world, sweet sorghum has attracted attention as an ethanol crop, with characteristics similar to sugarcane (Prasad et al., 2008; Zhang et al., 2010). In temperate regions, it acts as an annual crop. Sweet sorghum has received increasing attention in recent years as a bioenergy crop. It is genetically similar to both grain and forage sorghums and can be introgressed or crossed with them (Kuhlman et al., 2010). Plant breeding efforts to improve the agronomic characteristics of sweet sorghum as a sugar source for biofuel production are in their early stages (Murray et al., 2009, Murray et al., 2008 a&b). Sweet sorghum accumulates large amounts of soluble sugars in its stems, somewhat similarly to sugarcane. These sugars are predominantly hexose or 6 carbon sugars, but 5C sugars are also present (Wu et al., 2010). Unlike sugarcane, it is an annual, so can fit more readily into multi-species cropping systems. Sorghum crops in general are thought to be more drought tolerant (Hills et al., 1990; Geng et al., 1989; Smith et al., 1987) and nitrogen use efficient than the other significant C4 grass crop, corn (Saballos, 2008). Both these characteristics were evaluated in the trials reported here. For sweet sorghum to become the basis for an ethanol or other biofuel production system, it must be harvested over the longest period possible. Sorghums are reported to have an optimum soil temperature for emergence of 70˚F (21˚C) and a minimum soil temperature of 60˚F (15˚C) (Saballos, 2008). These temperatures occur in mid-to-late spring in the San Joaquin Valley, but earlier in the Imperial Valley. Alternatively, in locations like the Imperial Valley, it could supplement the use of sugarcane by extending the sugarcane harvest season.

Previous Work in California

As an annual with a shorter growing season than sugarcane, (120 to 180 days, compared to 12 months), sweet sorghum requires less water. Work on the sweet sorghum cultivars available in the 1980s at the University of California (Hills et al., 1990) at three locations (Davis, Salinas, and Brawley) showed that sweet sorghum produced about 23% more fermentable carbohydrate than the corn varieties available at the time, required 40% of the fertilizer nitrogen and about 17% less water than a comparison corn crop. Stalk fresh weight sugar concentration at the time was approximately 8 to 10%. A trial in the Imperial Valley planted in late June 2008 resulted in fresh weight yields of 25 to 40 t/ac, Brix measurements of 12 to 18%, and estimated fermentable sugar yields of up to 4.2 t/ac. A number of newer reports and press releases from elsewhere in the United States suggest that additional improvements in the amount of fermentable sugar in sweet sorghum have been achieved (Lau et al., and M. Rooney, Texas A&M[1]).

Table 11: Older trials in California (Hills et al., 1990).

Location	Gross yield (t/ac)	Stripped Stalk (t/ac)	DW stripped stalks (t/ac)	Hexose sugar equiv % DW*	Hexose sugar yield (t/ac)	Pot. Et-OH yield (gal/ac)
Davis (119 days)	49.9 (41-59)	41.0 (33-50)	10.2 (8.2-12.1)	32.6 (24-37)	3.29 (1.91-4.32)	473 (254-576)
Salinas (144 days)	36.8	299	7.7	40.3	3.12	415

Shaffer et al., (1992) reported sweet sorghum yields from a number of farm-based trials in the Sacramento Valley primarily over a two-year period averaging 19 and 23 t/ac of fresh weight biomass and 2.6 to 3.2 t/ac of hexose sugar equivalents.

Figure 59: Sweet sorghum yield in the Imperial Valley in 2008 (June planting, October harvest); Kaffka, unpublished.

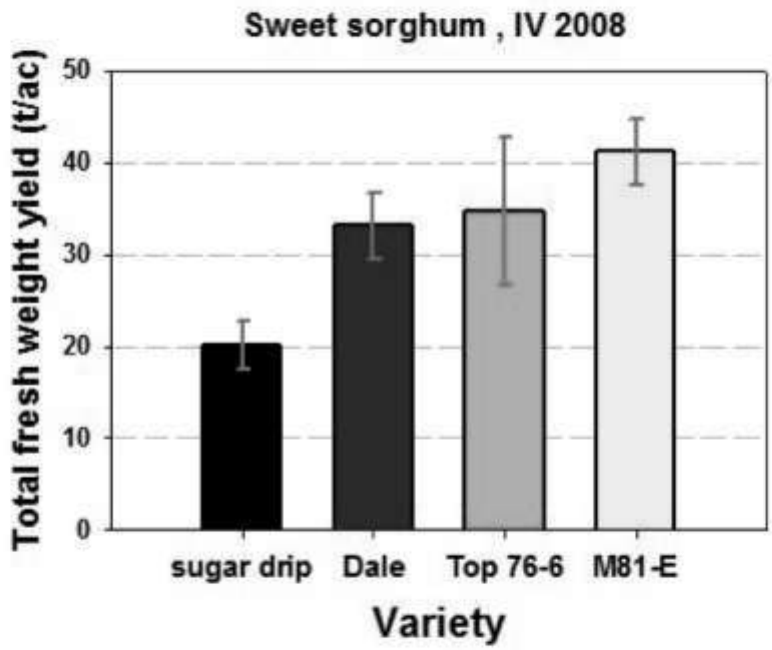
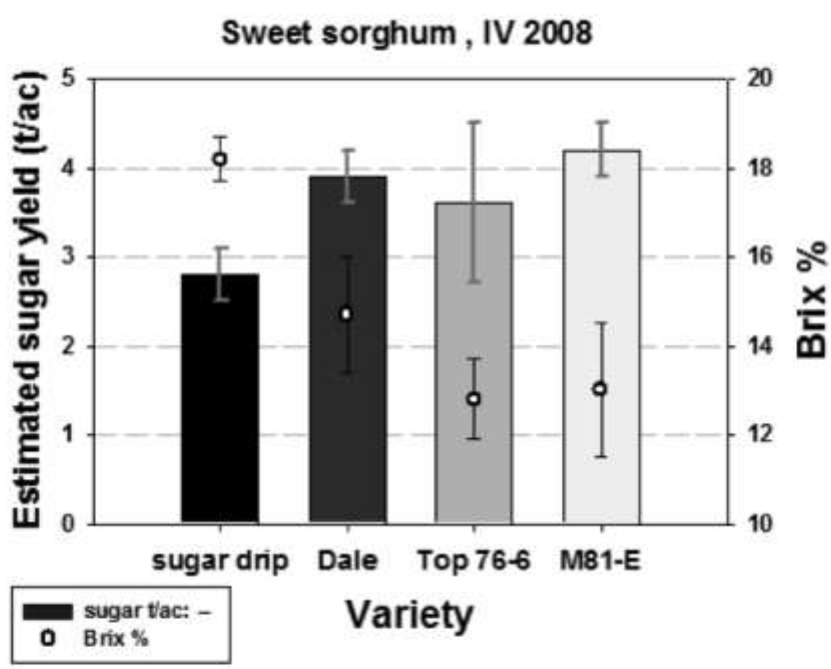


Figure 60: Sweet sorghum sugar yield and BRIX content in the IV in 2008 (June planting, October harvest). Kaffka, unpublished.



Sweet sorghum varieties with differing maturity requirements were grown during the 2010, 2011 and 2012 planting seasons at the University of California West Side Research and Extension Center near Five Points in western Fresno County. The soil type was a Panoche clay loam, a deep soil with high water holding capacity (approximately 1.8 to 2.1 inches available water per foot) and no restricting layers within the upper 8 feet of the soil profile. The overall experimental layout included three component studies:

(1) five to seven varieties (different depending on the year) that were included in the planting date trials, with the first planting in May followed by two additional plantings at approximately 3 week intervals after the first planting;

(2) irrigation studies using furrow irrigation and planted to the variety M81E, with four irrigation treatments ranging from close to full evapotranspiration replacement down to more severe deficit irrigation levels; and

(3) a nitrogen rate study with two varieties that was carried out in 2011 and 2012 only. Analyses of these data are still underway at the time of writing and will be included in a later version of the report.

Plots were planted in 30-inch rows and irrigated using gated pipe to direct water into furrows. Pre-plant irrigations were made to all plots, and additional supplemental sprinkler irrigations were made during the first three weeks after planting to maintain acceptable upper bed soil moisture content during the seedling germination and early development periods. These irrigations together brought stored soil water levels to field capacity within the upper 3 to 3 ½ feet of the soil profile in the time period corresponding to about 3 to 4 weeks post-planting. Residual estimated soil NO_3-N averaged about 39 (2010), 47 (2011) and 55 lb NO_3-N per acre (2012) in the upper 3 feet of the soil profile, and this was taken into account with subsequent fertilizer applications. In component studies (1) and (2), fertilizer (NPK 15-15-15) was applied at about 350 lb/acre along with 0-46-0 at 100 (2011, 2012) to 125 lb/acre (2010) either the same day or 1 day prior to the first furrow irrigation for each planting date treatment and irrigation treatment. An additional nitrogen fertilizer application of urea was made at layby timing to provide an additional 35 lb of nitrogen per acre in all planting date and irrigation trials.

Planting Date Treatments

In 2010 and 2011 in the planting date trials, the varieties included in all three planting dates were Umbrella, M-81E, Dale, and three experimental varieties from Dr. Bill Rooney of Texas A&M University, TX-09020, TX-09025, and TX-09026.

Due to lack of availability of seed of the experimental varieties from Texas, in 2012 in the planting date trial, the seven varieties included in all three planting dates were Umbrella, Keller, M-81E, Dale, KN Morris, and two commercially-available varieties from Ceres, EJ-7281 and EJ-7282, which are derived in part form Dr. Rooney's program. Planting dates in this trial (Table 12) were a May planting each year hereafter called planting date #1 (PD1), a mid-June planting date (PD2), and an early July planting date (PD3).

Irrigation Treatments

In the irrigation studies, all plots were planted in late May each year with the variety M-81-E at a seeding rate of approximately 50,000 to 60,000 seed/acre. The irrigation treatment receiving the most water was irrigated more frequently, receiving approximately 24.7 inches (2010), 23.2 inches (2011), and 23.1 inches (2012) of applied irrigation water, including early post-planting sprinkler irrigation), while the more severe deficit irrigation treatments received 13.6 inches (2010), 11.8 inches (2011) and 12.2 inches (2012) of irrigation water, including early post-planting sprinkler irrigation. Soil samples were collected near planting and again post-harvest in order to allow calculation of changes in stored soil water for use in water balance and total crop water use calculations.

Table 12: Planting and harvest dates as a function of treatment, study in 2010, 2011, and 2012.

Trial and Treatment	Planting Date-2010	Harest Date-2010	Planting Date-2011	Harvest Date-2011	Planting Date-2012	Harvest Date-2012
Irrigation Trial	5/19/10	9/28/10	5/20/11	9/19-20/11; 10/5-6/11	4/23/12	9/20/12; 10/9/12
Planting Date 1 Trial	5/19/10	9/29/10	5/20/11	9/19-22/11; 10/5-6/11	5/23/12	9/20/12; 10/9/12
Planting Date 2 Trial	6/16/10	10/19/10	6/9/11	10/5-6/11; 10/27-28/11	6/13/12	10/12/12; 11/1/12
Planting Date 3 Trial	7/7/10	11/7/10	7/1/11	10/27-18/11; 11/17-18/11	7/2/12	10/31/12; 11/21/12
N Fertilitiy Trial	Not done	Not Done	6/9/11	10/5-6/11; 10/27-28/11	6/13/12	10/12/12; 11/1/12

1.9.1 Results and Discussion

Applied Water and Evapotranspiration

2009-2010 Applied water and soil water use estimates as a function of irrigation treatments and planting date treatments in sweet sorghum trials at WSREC in 2010 are shown in Table 13.

Table 13: Total applied water and estimated soil water use between planting and harvest timing in irrigation and planting date treatments in 2010 trials.

Period of Time	Planting Date 1	Planting Date 2	Planting Date 3	Irrigation Trt 1	Irrigation Trt 2	Irrigation Trt 3	Irrigation Trt 4
Total all sprinkler plus furrow irrigations	17.9	17.2	17.5	13.6	17.2	20.7	24.7
Estim. Soil Water Use	-3.6	-2.7	-1	-6.1	-4.5	-3.3	-1.9
Total Estimated Plant Water Use	21.6	19.9	18.5	19.7	21.7	24	26.6

2010-2011: Estimated potential evapotranspiration from the WSREC station and rainfall are shown in Table 14, with values shown for each planting date and harvest date combination, including the two harvest dates used for each planting date. Potential evapotranspiration during these periods ranged from a low of 26.6 inches to a high of 34.5 inches. Irrigation amounts and dates for each of the four irrigation treatments are shown in Table 14. Rainfall totals for the periods are also shown, based on rain gauge readings at the California Irrigation Management Information System (CIMIS) station.

Table 14: Potential evapotranspiration from WSREC station in 2011 during periods from planting through harvest for different planting dates through the two harvest dates for each planting date.

Period of Time	Irrigation Trial Planting and Plant Date 1		Planting Date 2		Planting Date 3		Rainfall (inches)
	Harvest #1	Harvest #2	Harvest #1	Harvest #2	Harvest #1	Harvest #2	
May 20-31	3.05	3.05					0.03
June 1-30	7.81	7.81					0.66
June 9-30			6.3	6.3			
July 1-31	8.75	8.75	8.75	8.75	8.75	8.75	0
Aug 1-31	7.91	7.91	7.91	7.91	7.91	7.91	0
Sept 1-19	4.07						
Sept 1-30		6.27	6.27	6.27	6.27	6.27	0
Oct 1-6		0.69	0.69				
Oct 1-28				3.66	3.66		
Oct 1-31						4.01	0.44
Nov 1-18						1.49	0.78
TOTAL	31.59	34.48	29.92	32.89	26.59	28.43	1.91

Table 15: Estimated 2011 irrigation amounts per treatment in WSREC sweet sorghum trial (inches). Estimated soil water use is also shown.

Period of Time	Planting Date 1	Planting Date 2	Planting Date 3	Irrigation Trt 1	Irrigation Trt 2	Irrigation Trt 3	Irrigation Trt 4	Irrigation method
25-May	1.62	1.62		1.62	1.62	1.62	1.62	Sprinklers
11-Jun	2.15	2.15		2.15	2.15	2.15	2.15	Sprinklers
29-Jun	4.1	4.1		4.1	4.1	4.1	4.1	Furrow
1-Jul			1.9					"
17-Jul	4.4	4.4	4.4		4.4	4.4	4.4	"
2-Aug	3.9	3.9	3.9	3.9	3.9	3.9	3.9	"
23-Aug	3.6	3.6	3.6			3.6	3.6	"
8-Sep			3.4				3.4	"
Total Applied	19.8	19.8	17.2	11.8	16.2	19.8	23.2	
Estim. Soil Water Use	-2.8	-1.5	-2.3	-5.5	-3.6	-1.9	-1.1	
Total Estimated Plant Water Use	22.6	21.3	19.5	17.3	19.8	21.7	24.3	

Estimated soil water use overall during the period from planting through the second harvest for each date was not affected much by planting date, with net soil water use only ranging from 1.5 to 2.8 inches during this period. Irrigation water treatments, as might be expected, had greater impacts on net soil water use during the planting to harvest period, with much more water extracted (5.5 inches) in the lowest water application treatment when compared with the high water application treatment, with 1.1 inches net soil water use.

2011-2012: Estimated potential evapotranspiration from the WSREC station and rainfall are shown in Table 16, with values shown for each planting date and harvest date combination, including the two harvest dates used for each planting date. Potential evapotranspiration during these periods ranged from a low of 28.4 inches to a high of 38.0 inches. Irrigation amounts and dates for each of the four irrigation treatments are shown in Table 2.5.6.

Table 16: 2012 potential evapotranspiration from WSREC CIMIS station in 2012 during periods from planting through harvest for different planting dates through the two harvest dates for each planting date.

Period of Time	Planting Date 1	Planting Date 2	Planting Date 3	Irrigation Trt 1	Irrigation Trt 2	Irrigation Trt 3	Irrigation Trt 4	Irrigation method
25-May	1.62	1.62		1.62	1.62	1.62	1.62	Sprinklers
11-Jun	2.15	2.15		2.15	2.15	2.15	2.15	Sprinklers
29-Jun	4.1	4.1		4.1	4.1	4.1	4.1	Furrow
1-Jul			1.9					“
17-Jul	4.4	4.4	4.4		4.4	4.4	4.4	“
2-Aug	3.9	3.9	3.9	3.9	3.9	3.9	3.9	“
23-Aug	3.6	3.6	3.6			3.6	3.6	“
8-Sep			3.4				3.4	“
Total Applied	19.8	19.8	17.2	11.8	16.2	19.8	23.2	
Estim. Soil Water Use	-2.8	-1.5	-2.3	-5.5	-3.6	-1.9	-1.1	
Total Estimated Plant Water Use	22.6	21.3	19.5	17.3	19.8	21.7	24.3	

Estimated soil water use overall during the period from planting through the second harvest for each date was not affected much by planting date, with net soil water use only ranging from 1.5 to 2.8 inches during this period. Irrigation water treatments, as might be expected, had greater impacts on net soil water use during the planting to harvest period, with much more water extracted (5.5 inches) in the lowest water application treatment when compared with the high water application treatment, with 1.1 inches net soil water use. Heat units (base 60˚F) for the period from planting to first harvest date for each planting date treatment totaled 1934 heat units (planted 5/23), 1989 heat units (planted 6/13), and 1828 heat units (planted 7/02).

Table 17: 2012 estimated irrigation amounts per treatment in WSREC sweet sorghum trial (inches).

Period of Time	Planting Date 1	Planting Date 2	Planting Date 3	Irrigation Trt 1	Irrigation Trt 2	Irrigation Trt 3	Irrigation Trt 4	Irrigation method
25-May	1.2			1.2	1.2	1.2	1.2	
28 & 29-May	1			1	1	1	1	
8-Jun	1.15			1.15	1.15	1.15	1.15	
14-Jun		2						
18-Jun		1.4						
29-Jun	5.1	5.3		5.1	5.1	5.1	5.1	
3-Jul			1.6					
6-Jul			1.2					
11-Jul			1.2					
11-Jul	4				4	4	4	
18-Jul		4						
26-Jul			4.5					
2-Aug	3.7			3.7	3.7	3.7	3.7	
14-Aug			4.3					
23-Aug	3.7	3.7				3.7	3.7	
4-Sep			3.6					
7-Sep		3.6					3.3	
25-Sep			3.4					
Total Applied	19.85	20	19.8	12.15	16.15	19.85	23.15	
Estim. Soil Water Use	-3.47	-2.81	-2.09	-6.39	-4.37	-3.94	-2.02	
Total Estimated	23.32	22.81	21.89	18.54	20.52	23.79	25.17	
Plant Water Use								

Irrigation Trial Evaluations

Lodging Issues

In 2011, at the time of the first harvest (September 19), the first planting date data summaries showed plant populations averaging 42,800, 54,500, 65,700 and 68,200 plants per acre in irrigation treatments Trt. 1, Trt. 2, Trt. 3 and Trt. 4, respectively. Target plant populations at planting were about 50,000 to 55,000 plants per acre. Since the measured plant population averages shown above were determined close to harvest timing when it is somewhat difficult to differentiate between plants and tillers, the moderately higher populations in the higher irrigation water application treatments likely reflect more tillering, rather than differences in initial plant populations. Lodging was a significant issue in all irrigation treatments, even though in a prior year (2010) at the same research site we did not have significant lodging prior to harvest in any of the irrigation treatments with this same variety (M-81E). In 2011 there was little lodging in the field until relatively late in the season, with the majority of the lodging starting to occur soon after the September 8 field evaluations, at which time all treatments averaged less than 10 percent lodging (Table 18). Lodging intensified in the weeks after that, culminating in over 80 percent lodging in all treatments on the last measured date (October 12).

In 2012, at the time of the first harvest (September 19), the first planting date data summaries showed tiller per acre populations averaging 53361, 60,984, 69,696 and 71,148 plants per acre in irrigation treatments Trt. 1, Trt. 2, Trt. 3 and Trt. 4, respectively. Similar responses and treatment differences were observed in 2010 and 2011 trials (data not shown). In both 2011 and 2012, there was little lodging in the field until late August, with the majority of the lodging starting to occur the last ten days of August in 2012, about a week or two earlier than in 2010 or 2011 (Tables 17, 18). Lodging intensified in the weeks after that, culminating in over 50 percent lodging in most treatments by mid-October (Tables 2.5.8, 2.5.9).

Lodging can be a significant problem with sweet sorghum, and it is important to note several observations and findings associated with the lodging across years of the trial. First, there were no severe weather situations (rainfall events in excess of 0.25 inches, high wind periods with winds greater than 20 mph) that were associated with the extent of the lodging, the timing of the lodging, or any treatment differences in lodging percentages on measured dates. Second, stalks were evaluated each year for indications of disease occurrences (such as Fusarium presence) and no stalk rot, root damage or related disease incidence of any significance were identified in any of the treatments each year, at harvest time or when lodging first was observed.

Table 18: Lodging percentage in sampled areas as a function of date and irrigation treatment in sweet sorghum at WSREC, 2011.

Irrigation Treatment	Lodging (as a percent of the full plant population) - considered as "lodged" if plant at a 45 degree angle to the ground or less				
	8/23/2011	9/8/2011	9/19/2011	30-Sep	10/12/2011
1	0	8	28	74	86
2	0	6	31	73	88
3	0	7	31	74	90
4	0	1	35	78	90

Table 19: Lodging percentage in sampled areas as a function of date and irrigation treatment in sweet sorghum at WSREC, 2012.

Irrigation Treatment	Lodging (as a percent of the full plant population) - considered as "lodged" if plant at a 45 degree angle to the ground or less				
	8/20/2012	8/27/2012	9/9/2012	9/23/2012	10/8/2012
1	0	5	15	50	60
2	0	22.5	30	62.5	72.5
3	0	17.5	45	67.5	75
4	6	35	45	75	80

Yield Determinations – Fresh and Dry Weights – Irrigation Management Trial

For fresh weight and dry weight yield determinations, approximately 10 square feet of plot areas were cleared in each of three separate rows in each of four field replications per treatment. The samples were cut, removed from the field for fresh weight measurement, then subsamples of 5 plants were selected from each replication, run through a chipper, and placed in a hot greenhouse for about 5 to 7 days, then in a drying oven overnight (at 122˚F/50˚C) for determination of dry weights, moisture content at harvest and to allow yields to also be expressed on a dry weight basis. Yield information is shown in Tables 10 through 24.

Table 20: 2010 trial fresh weight yields as a function of irrigation treatment and harvest date (Harvest: Sept. 30) in sweet sorghum at WSREC.

Irrigation Treatment	Fresh Weight (T/acre)	
	Average	Std Dev
1	26.3	3.9
2	31.9	2.7
3	31.7	3.6
4	42.6	3.5

Fresh weight:dry weight ratios and dry weight yields were determined for treatments, but statistics have not been run and therefore are not shown here.

Table 21: 2011 trial fresh weights, dry weight fresh weight ratios, and dry weight yields as a function of irrigation treatment and harvest date (First harvest: Sept. 19) in sweet sorghum at WSREC.

Irrigation Treatment	Fresh Weight (T/ acre)		Dry Weight : Fresh Weight Ratio		Dry Weight (T/ acre)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
1	24.4	2.5	0.255	0.004	6.21	0.59
2	29.5	2.4	0.253	0.005	7.46	0.57
3	36.8	1.9	0.248	0.003	9.1	0.4
4	37.9	1	0.248	0.005	9.41	0.37

Table 22: 2011 fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of irrigation treatment and harvest date (Second harvest: Oct. 5-6) in sweet sorghum at WSREC.

Irrigation Treatment	Fresh Weight (T/ acre)		Dry weight : fresh weight Ratio		Dry Weight (T/ acre)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
1	26.9	1.7	0.264	0.007	7.1	0.42
2	33.1	1.1	0.262	0.003	8.64	0.362
3	42.6	1.7	0.257	0.004	10.94	0.4
4	44.2	3.2	0.254	0.005	11.2	0.76

In 2011 plant height averages within a week of the first harvest date (prior to widespread lodging) averaged 9.1 feet, 9.8 feet, 11.4 feet and 11.6 feet for irrigation treatments Trt. 1, Trt. 2, Trt. 3 and Trt. 4, respectively. Although not shown in the figures or tables, partitioning evaluations were done on 7 plant samples in all plot replications, separating the plants into stems, heads/panicles, and leaves (with leaves separated from leaf sheaths at the edge of the stem). Percent of total fresh weight as stems ranged from about 77.8 percent in the low water treatment (Trt 1) to a high of about 80 percent in higher water treatments (Trt 3, Trt 4). Percent of total fresh weight in leaves ranged from a low of about 18 percent in higher water application irrigation treatments to about 20 percent in the lowest water treatment (Trt 1), with percent of total fresh weight in the head/panicle averaging from a low of 1.6 percent in the lowest water treatment (Trt 1) to a high of about 3.1 percent in the highest water treatment (Trt 4).

Table 23: 2012 fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of irrigation treatment and harvest date (First harvest: Sept. 20) in sweet sorghum at WSREC.

Irrigation Treatment	Fresh Weight (T/ acre)		Dry weight : fresh weight Ratio		Dry Weight (T/ acre)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
1	22.45	1.34	0.324	0.006	7.29	0.5
2	29.31	1.17	0.284	0.007	8.33	0.26
3	37.93	2.22	0.273	0.013	10.34	0.71
4	41.56	1.26	0.261	0.005	10.85	0.39

Table 24: 2012 fresh weights, dry weight:fresh weight ratios, and dry weigh yields as a function of irrigation treatment and harvest date (Second harvest: Oct. 9) in sweet sorghum at WSREC.

Irrigation Treatment	Fresh Weight (T/ acre)		Dry weight: fresh weight Ratio		Dry Weight (T/ acre)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
1	22.69	0.76	0.336	0.01	7.63	0.47
2	28.71	2.12	0.305	0.01	8.77	0.74
3	39.31	1.17	0.277	0.01	10.89	0.6
4	42.37	2.04	0.27	0.006	11.44	0.49

In 2012 plant height averages during the last week of August (just prior to the start of significant lodging) averaged 7.6 feet, 9.6 feet, 10.6 feet and 11.2 feet for irrigation treatments Trt. 1, Trt. 2, Trt. 3 and Trt. 4, respectively. Although not shown in the figures or tables, partitioning evaluations were done on 7 plant samples in all plot replications, separating the plants into stems, heads/panicles, and leaves (with leaves separated from leaf sheaths at the edge of the stem). Percent of total fresh weight as stems ranged from about 72 percent in the low water treatment (Trt 1) to a high of about 74 percent in higher water treatments (Trt 3, Trt 4). Percent of total fresh weight in leaves ranged from a low of about 23 percent in higher water application irrigation treatments to about 26 percent in the lowest water treatment (Trt 1), with percent of total fresh weight in the head/panicle averaging from a low of 1.4 percent in the lowest water treatment (Trt 1) to a high of about 3.5 percent in the highest water treatment (Trt 4).

Refractometer (degree Brix) measurements for expressed stem sap

Since this crop is being evaluated for bioenergy potential in addition to other potential uses, simple sugar analyses were done as percent Brix using hand held, temperature compensated refractometers. Sap solution samples were taken from stem samples cut from sampled plants at specific locations described below, with sap expressed using a stem press to exert pressure until a minimum of 3 ml of liquid was expressed per sample. These measurements were made on the stem sections collected fresh in the field at harvest stage, with samples collected at about 1/4, 1/2 and 3/4 of plant height (following tables for different years and harvest dates shown.

Some averages for percent stem sugar will be presented, averaging the data summaries across multiple measurement locations on the plants (bottom, mid and upper zones as described above). A relatively consistent finding in this data is that Brix readings tended to increase significantly at sampling locations higher on the plant stems, as shown in the following tables.

Some standardization of this type of measurement will be needed in future evaluations, or alternatively it may be useful to consider some other ways to express sap to measure sugars from solutions expressed from the full length of sampled stem tissues rather than these sub-sections.

Table 25: 2010 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest timing from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") on the harvest date (Sept. 30) in 2010 sweet sorghum field trial at WSREC, variety M-81E.

Irrigation Treatment	Degree BrixLower stem section		Degree Brix Mid stem section		Degree Brix Top Stem Section		Degree Brix across all readings
	Average	Std dev	Average	Std dev	Average	Std dev	Average
1	8.67	0.37	10	0.61	10.4	0.23	9.7
2	9.42	0.24	10.96	0.37	13.83	0.29	11.4
3	10.58	0.51	11.83	0.22	13.92	0.38	12.11
4	11.61	0.21	14.25	0.17	15.34	0.44	13.74

Table 26: 2011 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest timing from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") on the first harvest date (Sept. 19) in 2011 sweet sorghum field trial at WSREC, variety M-81E.

Irrigation Treatment	Degree Brix Lower stem section		Degree Brix Mid stem section		Degree Brix Top stem section		Degree Brix across all readings
	Average	Std dev	Average	Std dev	Average	Std dev	Average
1	9.69	0.27	11.18	0.4	11.79	0.36	10.89
2	10.3	0.41	12.65	0.4	14.53	0.17	12.49
3	11.64	0.3	13.29	0.63	14.95	0.45	13.29
4	12.49	0.4	14.29	0.36	17.04	0.47	14.6

Refractometer data from both harvest dates indicated that in addition to the consistency with which the percent Brix values tended to increase in the mid to top stem sections, there also were consistent increases in percent Brix values going from the more water stressed, lower applied water treatments (Trt 1, Trt 2) when compared with the higher water application treatments (Trt 3, Trt 4). This was observed both in the first harvest data (Table 27) and in the second harvest date (Table 28).

Table 27: 2011 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest timing from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") on the Second harvest date (Oct. 7-9 readings date) in 2011 sweet sorghum field trial at WSREC, variety M-81E.

Irrigation Treatment	Degree Brix Lower stem section		Degree Brix Mid stem section		Degree Brix Top stem section		Degree Brix across all readings
	Average	Std dev	Average	Std dev	Average	Std dev	Average
1	11.16	0.53	12.43	0.74	13.15	0.54	12.25
2	11.46	0.52	13.84	0.4	14.58	0.47	13.29
3	12.26	0.34	13.68	0.6	15.5	0.47	13.81
4	13.37	0.72	15.27	0.55	17.4	0.28	15.35

Table 28: 2012 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest timing from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") on the first harvest date (Sept. 20) in 2012 sweet sorghum field trial at WSREC, variety M-81E.

Irrigation Treatment	Degree Brix Lower stem section		Degree Brix Mid stem section		Degree Brix Top stem section		Degree Brix across all readings
	Average	Std dev	Average	Std dev	Average	Std dev	Average
1	10.93	0.42	13.17	0.3	13.41	0.94	12.5
2	11.29	0.78	13.09	0.39	14.02	0.38	12.8
3	11.82	0.74	13.86	0.46	14.43	0.53	13.37
4	12.24	0.55	13.93	0.41	14.01	0.7	13.39

Refractometer data from both harvest dates indicated that in addition to the consistency with which the percent Brix values tended to go up in the mid to top stem sections, there also tended to be increases in percent Brix values going from the more water stressed, lower applied water treatments (Trt 1, Trt 2) when compared with the higher water application treatments (Trt 3, Trt 4), although the relative size of the differences varied some between years. These general observations were apparent both in the first harvest data (Tables 25, 27) and in the second harvest date (Tables 26, 28) in 2011 and 2012.

Table 29: 2012 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest timing from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") on the second harvest date (Oct. 7-9 readings date) in 2012 sweet sorghum field trial at WSREC, variety M-81E.

Irrigation Treatment	Degree Brix Lower stem section		Degree Brix Mid stem section		Degree Brix Top stem section		Degree Brix across all readings
	Average	Std dev	Average	Std dev	Average	Std dev	Average
1	12.63	0.19	14.05	0.44	13.73	0.77	13.47
2	12.15	0.41	14.27	0.56	14.92	1.13	13.77
3	12.58	0.51	14.44	0.55	15.55	0.86	14.19
4	12.62	0.54	14.87	0.53	15.55	0.41	14.35

1.9.2 Planting Date Evaluations

Planting dates and harvest dates for the three planting dates in the planting date trials for 2010, 2011 and 2011 are shown in Table 12. To demonstrate the differences in prevailing weather conditions for the periods represented by the growing periods (planting through harvest) in the planting date study, Table 30 (2011) and Table 31 (2012) also show potential evapotranspiration from a non-stressed grass surface, as estimated from a nearby weather station, and accumulated heat unit totals (with a 60˚F base) for the periods from planting through harvest for each planting date.

Table 30: 2011 planting dates, harvest dates for each planting date in 2011 sweet sorghum trial at WSREC.

Planting Date Treatment	Planting Date	Harvest Dates (two harvest dates shown per planting date)	Potential Evapotranspiration (inches water)		Heat Units or Degree Days (base 60 degrees F)	
			To first harvest date	To second harvest date	To first harvest date	To second harvest date
PD1	20-May	9/19; 10/05-06	31.59	34.48	1684	1881
PD2	9-Jun	10/05-06; 10/27-28	29.92	32.89	1784	1946
PD3	1-Jul	10/27-28; 11/17-18	26.59	28.43	1654	1685

Table 31: 2012 planting dates, harvest dates for each planting date in 2012 sweet sorghum trial at WSREC.

Planting Date Treatment	Planting Date	Harvest Dates (two harvest dates shown per planting date)	Potential Evapotranspiration (inches water)		Heat Units or Degree Days (base 60 degrees F)	
			To first harvest date	To second harvest date	To first harvest date	To second harvest date
PD1	23-May	9/20; 10/09	34.33	37.99	1934	2191
PD2	13-Jun	10/12; 10/31	31.84	34.31	1989	2099
PD3	2-Jul	11/01; 11/21	28.41	30	1828	1873

Plant populations and tillering

As an example of the type of additional data collected in the trials, some additional information will be shown for 2011 and 2012 below, with similar data collected for 2010 (data not shown).

In 2011, as measured about 3 weeks after planting, average plant populations for the varieties in the planting date study were recorded. Umbrella averaged 53,400 plants per acre, Dale averaged 49,200 plants per acre, M081E averaged 54,700 plants per acre; TX-09020 averaged 48,800 plants per acre, TX-09025 averaged 56,600 plants per acre, and TX-09026 averaged 53,700 plants per acre. At the time of the first harvest for each planting date, plant populations averaged 67,900 stalks per acre (averaged across all variety entries) for the first planting date (5/20), 70,400 stalks per acre (averaged across all variety entries) for the second planting date (6/09) and 61,200 stalks per acre (averaged across all variety entries) for the third planting date (7/01). Since earlier target plant populations at planting were about 50,000 to 55,000 plants per acre and the values shown above were determined close to harvest timing when it is somewhat difficult to differentiate between plants and tillers, the moderately higher populations in the harvest time stalk counts likely reflect relative levels of tillering rather than differences in initial plant populations.

In 2012, as measured about 3 weeks after planting, average plant populations for the varieties in the first planting date study were recorded. Umbrella averaged 46,900 plants per acre, Dale averaged 47,500 plants per acre, M-81E averaged 50,200 plants per acre, Keller averaged 47,300 plants per acre, KN Morris averaged 51,600, EJ-7281 averaged 46,800 plants per acre, and EJ-7181 averaged 53,600 plants per acre. At the time of the first harvest for each planting date, total plant / tillers larger than 0.5 cm diameter counts averaged 74,100 stalks per acre (averaged across all variety entries) for the first planting date (5/23), 68,900 stalks per acre (averaged across all variety entries) for the second planting date (6/13), and 63,300 per acre (averaged across all variety entries) for the third planting date (7/02). Since earlier target plant populations closer to planting were about 45,000 to 54,000 plants per acre and the values shown above were determined close to harvest timing when it is somewhat difficult to differentiate between plants and tillers, the moderately higher populations in the harvest time stalk counts likely reflect relative levels of tillering rather than differences in initial plant populations.

Lodging issues – planting date studies

2009-2010: As in the irrigation treatment studies, lodging was a significant issue in all varieties and all three planting dates, with the lightest levels of lodging observed in the first year (2010). In the first year (2010) the variety Umbrella showed a high level of lodging close to harvest timing, and the variety Dale moderate lodging. Lodging averages in 2010 planting date treatment plots at approximately harvest timing (soft dough stage) in the following varieties averaged:

(1) Umbrella: Planting date 5/19 = 85%; 6/16 = 60%; 7/07 = 30%

(2) Dale: 5/19 = 20%; 6/16=10%; 7/07 = 5%

(3) The experimental varieties were only included in 2010 in the 7/07 planting (due to limited seed) and the average observed lodging at harvest time were:

  a. TX-09020 = 5%

  b. TX-09025 = 25%

  c. TX-09026 = 45%

2011-2012: In 2011, lodging was a significant issue in all varieties and all three planting dates. In the first year (2010) studies, only the varieties Umbrella and TX-09026 showed a high level of lodging, and the varieties Dale and TX-09025 showed moderate lodging. There was little lodging in the field until relatively late in the season, with the majority of the lodging starting to occur soon after the September 8 field evaluations, at which time all treatments averaged less than 10 percent lodging (Table 32). There was some light rain in early September, but also several periods of some winds in excess of 25 mph gusts in early September, and the lodging started at a time corresponding with that higher wind and light rain period. Lodging intensified in the weeks afterwards, culminating in over 80 percent lodging in all treatments on the last measured date (October 19).

Table 32: Lodging percentage in sampled areas as a function of Planting Date and variety in sweet sorghum at WSREC, 2011.

Planting Date	Variety	Lodging (as a percent of the full plant population) - considered as "lodged" if plant at a 45 degree angle to the ground or less					
		23-Aug	8-Sep	19-Sep	30-Sep	12-Oct	19-Oct
20-May	Umbrella	13	22	45	83	90	93
	M-81E	0	3	23	53	78	85
	Dale	0	8	37	62	69	84
	TX-09020	0	3	24	62	76	84
	TX-09025	3	12	29	57	72	86
	TX-09026	12	7	31	63	73	86
9-Jun	Umbrella	5	8	36	65	75	89
	M-81E	0	0	15	36	72	84
	Dale	0	3	26	50	75	84
	TX-09020	0	3	25	46	80	87
	TX-09025	0	0	28	61	71	88
	TX-09026	0	0	31	53	74	84
1-Jul	Umbrella	8	8	29	64	87	84
	M-81E	0	0	8	27	63	85
	Dale	0	0	20	43	69	90
	TX-09020	0	0	14	42	68	87
	TX-09025	0	0	19	32	69	80
	TX-09026	8	8	18	27	66	86

In 2012, there were several periods of some winds gusted to about 15-20 mph in the last week of August and again in mid-September, but no rain, and the lodging started at timing that corresponded with those higher wind periods. Lodging intensified in the weeks after that, culminating in over 80 percent lodging in multiple cultivars and planting dates by late September and October evaluations (Table 33).

Table 33: Lodging percentage in sampled areas as a function of Planting Date and variety in sweet sorghum at WSREC, 2012.

Planting Date	Variety	Lodging (as a percent of the full plant population) - considered as "lodged" if plant at a 45 degree angle to the ground or less				
		August 20	31-Aug	23-Sep	12-Oct	
23-May	Umbrella	17	57	60	87	
	Keller	0	17	27	40	
	M-81E	0	23	50	73	
	Dale	23	37	57	87	
	KN Morris	13	57	57	60	
	EJ-7281	0	43	47	60	
	EJ-7282	0	30	57	67	
		Aug 20	31-Aug	23-Sep	8-Oct	29-Oct
13-Jun	Umbrella	10	33	70	90	93
	Keller	0	0	20	30	53
	M-81E	0	10	23	60	67
	Dale	7	7	40	57	63
	KN Morris	0	13	70	73	80
	EJ-7281	0	7	42	60	70
	EJ-7282	0	0	47	72	80
		20-Aug	31-Aug	23-Sep	12-Oct	7-Nov
2-Jul	Umbrella	0	23	90	90	93
	Keller	0	0	28	28	60
	M-81E	0	3	52	52	67
	Dale	0	7	45	45	78
	KN Morris	0	10	67	67	77
	EJ-7281	0	7	50	50	67
	EJ-7282	0	7	60	60	73

1.9.3 Yield Determinations – Fresh and Dry Weights – Planting Dates and Varieties

For fresh weight and dry weight yield determinations, approximately 10 ft^2 of plot area were cleared in each of three separate rows in each of four field replications per treatment. The samples were cut, removed from the field for fresh weight measurement, then subsamples of 5 plants were selected from each replication, run through a chipper, and placed in a hot greenhouse for about 10+ days, then in a drying oven overnight (at 122˚F/50˚C) for determination of dry weights, moisture content at harvest and to allow yields to also be expressed on a dry weight basis.

2009-2010: In 2010 only three varieties were planted across all three planting dates (Umbrella, M-81E and Dale), with the other three entries (TX-09020, TX-09025, and TX-09026) only planted on 7/07 since seed supplies were limited and they were received too late for earlier plantings. The highest fresh weight yields in planting date 1 were observed in the variety M-81E, with fresh weight yield of 37.1 t/acre on the first harvest date. M-81E and Dale variety fresh weight yields were similar (35.4 t/acre and 36.2 t/acre, respectively) on the second planting date. The highest four fresh weight yields for the third planting were TX-09026 (28.0 t/ac), TX-09020 (27.9 t/ac), M-81E (26.3 t/ac) and TX-09025 (26.2 t/ac).

Table 34: 2010 fresh weigh yields as a function of planting date treatment and harvest date in sweet sorghum at WSREC, 2010.

Variety	Fresh Weight Yield (T/acre)	
	Average	Std Dev
FIRST Planting Date (5/19)		
Umbrella	28.4	0.8
M-81E	37.1	1.9
Dale	32.7	3.1
SECOND Planting Date (6/16)		
Umbrella	31.3	2.5
M-81E	35.4	2
Dale	36.2	3.4
THIRD Planting Date (7/07)		
Umbrella	21.4	1.6
M-81E	26.3	2.4
Dale	23.9	2.1
TX-09020	27.9	1.4
TX-09025	26.2	2.3
TX-09026	28	1.7

Fresh weight yields at harvest (which was about soft dough stage for the M-81E variety, with some differences across other entries) ranged from about 28 to 37 t/acre across varieties for the first planting date, 31 to 36 t/acre for the second planting date, and 21 to 28 t/acre for the third planting date. Whole plant moisture content at harvest timing in the different treatments, varieties are not shown in Table 33, but the data was collected and will be presented in later evaluations of this data set. Fresh weight average yields were not significantly different between planting dates 5/19 and 6/16 on average, but planting date 6/16 yields were significantly higher for the variety Dale. Yields of all varieties planted on the third planting date (7/07) were significantly lower than earlier planting dates in each variety comparison.

2010-2011: In 2011, the highest fresh weight and dry weight yields in planting date 1 were observed in the varieties M-81E and TX-09025, with fresh weight yields between 35 and 39 t/acre on the first harvest date (9/19) and between 41 and 44 t/ac on the second harvest date (10/05-06). These fresh weight yields corresponded with dry weight yields of 8.95 t/ac (TX-09025) and 9.63 t/ac (M-81E) on the first harvest date and 10.66 (TX-09025) and 11.27 t/acre (M-81E) on the second harvest date (Table 21).

Table 35: 2011 fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of planting date treatment and harvest date (for planting date 5/20) in sweet sorghum at WSREC.

Variety	Fresh Weight (T/acre)		Dry weight : fresh weight Ratio		Dry Weight (T/acre)		Plant Height (ft)
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average
FIRST HARVEST date (9/19)							
Umbrella	29.3	2.1	0.243	0.01	7.11	0.47	10.1
M-81E	39.1	0.7	0.246	0.01	9.63	0.2	10.5
Dale	31.8	1.2	0.249	0.01	7.9	0.13	10.3
TX-09020	35.6	1	0.249	0.02	8.87	0.8	10.6
TX-09025	35.4	2.7	0.253	0.01	8.95	0.93	9.8
TX-09026	32.7	2.2	0.241	0.01	7.85	0.24	9.9
SECOND HARVEST date (10/05)							
Umbrella	30.2	2.2	0.265	0.017	7.99	0.53	10.3
M-81E	43.7	2.4	0.258	0.01	11.27	0.3	11.1
Dale	34.3	2.1	0.263	0.008	9.04	0.77	10.4
TX-09020	38.7	3.1	0.263	0.003	10.18	0.81	11.5
TX-09025	41.3	3.6	0.258	0.005	10.66	0.78	10.2
TX-09026	36.8	2.6	0.262	0.01	9.68	1.08	10.5

For planting date 5/20, plant height averages within a week of the first harvest date (prior to widespread lodging) averaged close to 10 feet, with few large differences between varieties, as shown in Table 34. Although not shown in the figures or tables, partitioning evaluations were done on 5 plant samples for variety M-81E and TX-09025 in all plot replications, separating the plants into stems, heads/panicles, and leaves (with leaves separated from leaf sheaths at the edge of the stem). Percent of total fresh weight as stems was 78.1 percent (M-81E) and 76.6 percent (TX-09025). Percent of total fresh weight in leaves averaged 19.4 percent in M-81E and 20.3 percent in TX-09025. The percent of total fresh weight in the head/panicle averaged 2.5 percent in M-81E and 3.1 percent in TX-09025.

Table 36: 2011 fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of planting date treatment and harvest date (for planting date 6/09) in sweet sorghum at WSREC.

Variety	Fresh Weight (T/acre)		Dry weight: fresh weight Ratio		Dry Weight (T/acre)		Plant Height (ft)
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average
FIRST HARVEST date (9/19)							
Umbrella	26.8	1.2	0.243	0.005	6.5	0.21	9
M-81E	32.6	1	0.253	0.007	8.25	0.46	8.9
Dale	32.8	2.8	0.242	0.003	7.93	0.59	9.3
TX-09020	32.7	2.3	0.243	0.01	7.94	0.32	8.8
TX-09025	37.1	3.4	0.252	0.009	9.36	1	8.9
TX-09026	29.3	2.2	0.245	0.006	7.18	0.56	8.8
SECOND HARVEST date (10/05)							
Umbrella	27.3	0.9	0.309	0.003	8.42	0.22	9.5
M-81E	35	2.4	0.313	0.015	10.93	0.43	9.6
Dale	33.4	1.3	0.302	0.012	10.08	0.19	10.2
TX-09020	34.1	3.4	0.303	0.008	10.35	1.28	9.2
TX-09025	36.5	2.9	0.31	0.007	11.3	0.8	9.4
TX-09026	29.1	2	0.317	0.009	9.24	0.9	9.7

Table 37: 2011 fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of planting date treatment and harvest date (for planting date 7/01) in sweet sorghum at WSREC.

Variety	Fresh Weight (T/acre)		Dry weight: fresh weight Ratio		Dry Weight (T/acre)		Plant Height (ft)
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average
FIRST HARVEST date (9/19)							
Umbrella	21.3	3.36	0.283	0.01	6.06	1.17	8.5
M-81E	24.2	0.44	0.296	0.005	7.16	0.22	8.7
Dale	23.6	1.56	0.29	0.013	6.83	0.16	8.6
TX-09020	23.1	2.87	0.299	0.006	6.93	0.99	8.3
TX-09025	21.9	1.38	0.284	0.01	6.23	0.57	8.5
TX-09026	24.4	1.28	0.299	0.01	7.3	0.33	9.2
SECOND HARVEST date (10/05)							
Umbrella	19.8	2.04	0.317	0.012	6.33	0.87	8.7
M-81E	24.9	1.67	0.329	0.013	8.17	0.49	9.7
Dale	22.1	0.97	0.312	0.015	6.89	0.41	9
TX-09020	22.8	1.73	0.318	0.006	7.24	0.47	8.8
TX-09025	23.5	1.48	0.32	0.007	7.53	0.63	9.5
TX-09026	25.5	3.11	0.313	0.009	7.95	0.91	9.9

2011-2012: The highest fresh weight and dry weight yields from planting date 5/23 were observed in the varieties M-81E and EJ-7281, with fresh weight yields between 37 and 41 t/ac on the first harvest date (9/20) and second harvest date (10/09). These fresh weight yields corresponded with dry weight yields of 10.55 t/ac (EJ-7281) and 11.18 t/ac (M-81E) on the first harvest date and 11.3 t/ac (EJ-7281) and 11.9 t/ac (M-81E) on the second harvest date (Table 21). For planting date 6/13, plant height averages within a week of the first harvest date (prior to widespread lodging) averaged close to 10 feet, with few large differences between varieties. Although not shown in the tables, partitioning evaluations were done on 5 plant samples for variety M-81E and EJ-7281 in all plot replications, separating the plants into stems, heads/panicles, and leaves (with leaves separated from leaf sheaths at the edge of the stem). Percent of total fresh weight as stems averaged 73 percent. Percent of total fresh weight in leaves averaged 24 percent. The percent of total fresh weight in the head/panicle averaged less than 3 percent.

Table 38: 2012 fresh weights, dry weight : fresh weight ratios, and dry weight yields as a function of planting date treatment and harvest date (for planting date 5/23) in sweet sorghum at WSREC.

Variety	Fresh Weight (T/acre)		Dry weight: fresh weight Ratio		Dry Weight (T/acre)		Plant Height (ft)
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average
FIRST HARVEST date (9/20)							
Umbrella	30.42	1.84	0.271	0.004	8.24	0.61	9.13
Keller	34.41	3.51	0.272	0.01	9.36	0.98	10.4
M-81E	41.42	0.99	0.27	0.01	11.18	0.29	10.6
Dale	34.3	2.34	0.276	0.01	9.49	1.03	9.67
KN Morris	33.5	2.6	0.29	0.01	9.7	0.64	10.4
EJ-7281	38.88	2.41	0.271	0.004	10.55	0.8	11.03
EJ-7282	37.64	2.87	0.268	0.003	10.07	0.7	10.8
SECOND HARVEST date (10/09)							
Umbrella	30.71	1.32	0.296	0.005	9.09	0.54	9.3
Keller	32.78	3.25	0.298	0.01	9.73	0.61	11.33
M-81E	40.76	2.91	0.292	0.002	11.92	0.91	12.03
Dale	33.69	2.94	0.303	0.004	10.22	0.9	10.13
KN Morris	33.21	0.76	0.313	0.006	10.41	0.29	11.23
EJ-7281	37.39	0.38	0.303	0.006	11.32	0.09	12.2
EJ-7282	36.99	0.38	0.29	0.004	10.73	0.09	10.97

Table 39: 2012 fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of planting date treatment and harvest date (for planting date 6/13) in sweet sorghum at WSREC.

Variety	Fresh Weight (T/acre)		Dry weight : fresh weight Ratio		Dry Weight (T/acre)		Plant Height (ft)
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average
FIRST HARVEST date (10/12)							
Umbrella	31.54	0.5	0.273	0.003	8.61	0.22	8.73
Keller	33.11	2.34	0.269	0.004	8.92	0.74	9.5
M-81E	37.28	1.19	0.268	0.004	9.99	0.44	10.17
Dale	38.37	1.33	0.268	0.002	10.27	0.29	9.13
KN Morris	33.18	0.7	0.289	0.003	9.6	0.15	9.13
EJ-7281	36.59	2.68	0.278	0.004	10.18	0.85	10.43
EJ-7282	33.83	1.04	0.28	0.001	9.47	0.32	9.8
SECOND HARVEST date (11/01)							
Umbrella	29.15	1.15	0.309	0.003	9.01	0.31	9.23
Keller	30.38	1.54	0.313	0.015	9.52	0.69	9.8
M-81E	34.09	0.33	0.302	0.012	10.3	0.31	10.87
Dale	32.42	0.33	0.303	0.008	9.83	0.17	9.97
KN Morris	32.56	1.18	0.31	0.007	10.09	0.13	9.77
EJ-7281	34.85	1.14	0.317	0.009	11.06	0.53	10.93
EJ-7282	30.71	1.04	0.317	0.009	9.75	0.61	9.8

Table 40: 2012 fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of planting date treatment and harvest date (for planting date 7/02) in sweet sorghum at WSREC.

Variety	Fresh Weight (T/acre)		Dry weight : fresh weight (Ratio)		Dry Weight (T/acre)		Plant Height (ft)
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average
FIRST HARVEST date (10/31)							
Umbrella	23.89	2.4	0.25	0.003	5.98	0.67	8.77
Keller	28.6	2.88	0.247	0.003	7.05	0.68	9.07
M-81E	29.73	1.74	0.255	0.006	7.6	0.56	9.77
Dale	26.64	0.44	0.258	0.008	6.88	0.09	10.13
KN Morris	29.87	2.14	0.261	0.003	7.8	0.5	9.63
EJ-7281	29.15	1.32	0.252	0.007	7.36	0.52	10.5
EJ-7282	26.93	2.41	0.242	0.001	6.53	0.56	9.63
SECOND HARVEST date (11/21)							
Umbrella	22.91	1.09	0.293	0.004	6.71	0.38	9.03
Keller	25.99	1.32	0.297	0.003	7.73	0.46	9.87
M-81E	26.54	1.04	0.289	0.003	7.67	0.27	10.63
Dale	22.76	0.93	0.297	0.005	6.76	0.31	9.43
KN Morris	27.15	2.33	0.309	0.006	8.37	0.58	9.47
EJ-7281	27.7	0.55	0.302	0.004	8.36	0.17	10.47
EJ-7282	23.7	0.13	0.287	0.002	6.8	0.07	9.83

Refractometer (degree Brix) measurements for expressed stem sap

Since this crop is being grown for bioenergy, simple sugar analyses were done as percent Brix using hand-held, temperature-compensated refractometers. These measurements were made on the stem sections collected fresh in the field at harvest stage, with samples collected at about ¼, ½, and ¾ of plant height. As for the variety M-81E in the irrigation study part of this field trial, percent sugar tended to increase significantly at sampling locations higher on the plant stems (mid and top compared with lower stem section). Varietal differences in Brix readings were evident at both harvest date samplings, and relative ranking of varieties in Brix readings tended to also be consistent with lower, mid and top stem readings (following tables).

Table 41: 2010 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest timing from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") on both the harvest dates (dates shown) in the planting date trial of sweet sorghum at WSREC in 2010.

Planting Date	Variety	Harvest Date	Degree Brix Lower stem section	Degree Brix Mid stem section	Degree Brix Top stem section	Degree Brix across all readings
			Average	Average	Average	Average
PD-1: 19-May	Umbrella	30-Sep	10.77	11.6	12.8	11.72
	M-81E	30-Sep	9.7	10.8	12.1	10.87
	Dale	30-Sep	11.9	12.9	13.7	12.83
PD-2: 16-Jun	Umbrella	19-Oct	11.6	11.8	13.1	12.17
	M-81E	19-Oct	10.3	10.9	12.9	11.37
	Dale	19-Oct	12	12.6	13.8	12.8
PD-3: 7-Jul	Umbrella	7-Nov	11.9	10.6	11.8	11.43
	M-81E	7-Nov	9.4	10.1	10.6	10.03
	Dale	7-Nov	10.8	11.5	12.8	11.77

Table 42: 2011 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest time from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") on both the harvest dates (dates shown) in the planting date trial of sweet sorghum at WSREC.

Planting	Variety	Harvest Date	Degree Brix Lower stem section		Degree Brix Mid stem section		Degree Brix Top stem section		Degree Brix across all readings
			Average	Std dev	Average	Std dev	Average	Std dev	Average
PD-1: 20-May	Umbrella	19-Sep	12.45	0.34	13.8	0.63	16.5	0.41	14.25
		10/ 5/ 06	13.45	0.4	14.1	0.42	16.18	0.39	14.58
	M-81E	19-Sep	11.78	0.36	12.98	0.41	15.75	0.51	13.5
		10/ 5/ 06	12.65	0.37	13.5	0.45	15.68	0.87	13.94
	Dale	19-Sep	13.12	0.22	14.35	0.24	16.65	0.47	14.71
		10/ 5/ 06	13.73	0.64	14.6	1	17.65	0.74	15.33
	TX-09025	19-Sep	12.93	0.21	14.13	0.41	16.6	0.55	14.55
		10/ 5/ 06	13.68	0.53	14.63	0.64	17.05	0.34	15.12
PD-2: 9-Jun	Umbrella	10/ 5/ 06	12.68	0.51	13	0.56	14.78	0.44	13.48
		10/ 27/ 08	13.1	0.77	13.6	0.76	14.95	0.38	13.88
	M-81E	10/ 5/ 06	11.6	0.8	12.8	0.38	14.55	0.4	12.98
		10/ 27/ 08	12.9	0.71	13.35	1.03	14.53	0.22	13.59
	Dale	10/ 5/ 06	13	0.37	13.73	0.57	15.45	0.48	14.06
		10/ 27/ 08	13.43	0.4	14.08	0.8	15.23	0.54	14.24
	TX-09025	10/ 5/ 06	13.4	0.5	13.63	0.7	15.78	0.71	14.27
		10/ 27/ 08	13.6	0.48	13.85	0.34	15.13	0.52	14.19
PD-3: 1-Jul	Umbrella	10/ 27/ 08	10	0.94	12.18	0.31	13.03	1.27	11.73
		11/ 17/ 18	11.9	0.39	12.55	0.4	13.78	1.04	12.74
	M-81E	10/ 27/ 08	10.08	0.34	11.48	0.68	13.38	0.85	11.64
		11/ 17/ 18	11.03	0.68	11.83	0.29	13.35	0.61	12.07
	Dale	10/ 27/ 08	11.28	0.22	12.53	0.35	12.93	0.99	12.24
		11/ 17/ 18	12.1	0.37	12.93	0.73	14.1	0.37	13.04
	TX-09025	10/ 27/ 08	11.08	0.55	12.7	0.18	13.35	0.66	12.38
		11/ 17/ 18	12.33	0.59	12.68	0.73	14.33	0.51	13.11

Table 43: 2012 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest time from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") on both the harvest dates (date shown) in the planting date trial of sweet sorghum at WSREC.

Planting Date	Variety	Harvest Date	Degree Brix Lower stem section		Degree Brix Mid stem sectio		Degree Brix Top stem sectio	
			Average	Std dev	Average	Std dev	Average	Std dev
PD-1: 23-May	Umbrella	20-Sep	13.33	0.81	14.13	1.01	14.78	1.04
		9-Oct	13.28	0.76	14.68	0.75	15.5	1.15
	M-81E	20-Sep	12.48	0.63	14.2	1.13	14	0.91
		9-Oct	12.93	0.9	14.18	0.46	14.9	0.89
	Dale	20-Sep	14.28	0.76	15.03	0.9	15.18	1.24
		9-Oct	13.78	0.72	15.25	0.84	15.58	0.59
	EJ-7282	20-Sep	12.55	0.29	14.05	0.39	14.6	1.24
		9-Oct	12.48	0.61	14.4	0.18	14.55	0.78
PD-2: 13-Jun	Umbrella	12-Oct	12.03	0.57	13.93	0.86	14.3	0.86
		1-Nov	13.85	0.91	14.13	1.13	14.45	1.08
	M-81E	12-Oct	12.23	0.62	13.63	0.67	13.68	0.29
		1-Nov	13.03	0.53	14	0.77	13.85	0.75
	Dale	12-Oct	13.25	0.91	14.13	0.99	14.85	0.96
		1-Nov	14.03	0.97	13.5	0.66	14.05	0.69
	EJ-7282	12-Oct	12.65	0.57	13.4	0.51	14.18	0.82
		1-Nov	13.78	0.87	14.33	0.46	14.3	0.56
PD-3: 2-Jul	Umbrella	31-Oct	11.43	0.93	12.5	0.65	12.63	1.4
		21-Nov	13.1	1.17	12.95	1.18	12.73	0.26
	M-81E	31-Oct	11.78	0.95	12.55	0.81	13.78	0.78
		21-Nov	11.93	1.04	13.4	0.67	13.55	0.62
	Dale	31-Oct	12.6	0.72	13.28	0.64	13.88	1
		21-Nov	12.9	0.91	14.78	1.23	14.23	1.01
	EJ-7282	31-Oct	12.33	1.21	13.3	0.27	13.45	0.79
		21-Nov	12.83	0.95	13.68	0.36	13.75	0.86

Nitrogen Trials

All three years, a nitrogen fertilizer rate response study with two varieties was done.

Specifically in the locations where the nitrogen fertilizer rate trials were done each year, residual estimated soil NO_3-N averaged about 53 (2010), 26 (2011) and 57 (2012) lb total nitrate-nitrogen in the upper 5 feet of the soil profile. We determined initial soil nitrate levels in the upper 5 feet of the soil profile based on prior year estimates that forage sorghum in this soil had very active rooting and soil water uptake in the upper 5 to 6 feet of the soil profile. Wheat grown for silage was grown the previous year in the sites for the trial and received relatively light nitrogen fertilizer applications.

Nitrogen fertilizer treatments were made using applications of granular urea made at rates of 0, 40, 80, 120, and 160 lb N/ac all years (2010, 2011, 2012), plus one additional treatment level of 200 lb N/ac made in 2011 and 2012 trials. Timing of nitrogen fertilizer applications were one-time applications made about 2 ½ to 3 1/2 weeks after planting and just prior to the first furrow irrigation in the study. Application dates were July 1 (2010), June 28 (2011 and 2012).

Varieties Grown, Planting Dates

Varieties utilized in the evaluations were M-81E and Dale, provided by commercial seed suppliers. Seeding rates were to achieve plant populations of approximately 55,000 to 65,000 plants per acre. Planting and harvest dates used each year are shown in Table 44. Soil samples were collected near planting and again post-harvest in order to allow calculation of changes in stored soil water for use in water balance and total crop water use calculations, and also to evaluate harvest timing changes in soil nitrate-N.

Table 44: Planting and harvest dates as a function of treatment.

Trial and treatment	Planting Date- 2010	Harvest Date- 2010	Planting Date-2011	Harvest Date- 2011	Planting Date- 2012	Harvest Date- 2012
Nitrogen Rate Trial	6/16/2010	10/24/2010	6/9/2011	10/9/2011	6/13/2012	10/14/2012

1.9.4 Results and Discussion

Applied Water and Evapotranspiration

Total applied water across all nitrogen treatments each year, including early post-planting sprinkler irrigation, are shown in Table 45. Estimated soil water use was determined as the difference in gravimetric soil water at planting time and harvest timing, determined in soil samples collected to a depth of 8 feet. The estimates of average soil water use were determined in three randomly selected locations within the nitrogen treatment trial area, and are not specific to any level of nitrogen treatment. Total rainfall during the growing season (period between planting and harvest) each year was less than 1 inch.

Table 45: Total applied water and estimated soil water use between planting and harvest timing in irrigation and planting date treatments.

Period of Time	2010	2011	2012
		Acre inches	
Total all sprinkler plus furrow irrigations	17.2	19.8	20
Est. Soil Water Use	-2.7	-1.5	-2.8
Total Estimated Plant Water Use	19.9	21.3	22.8

Nitrogen treatment differences and estimated soil water use overall during the period from planting through the harvest for each year was only evaluated in three nitrogen treatment levels (0, 80 and 160 lb N/ac). Net soil water use was not significantly different between 80 and 160 lb N/acre treatments, and was in the range of about 1 to 3 inches of net soil water depletion during the season (from planting time soil water levels to post-harvest levels). The ending soil water levels were higher in the 2011 and 2012 lb N/ac treatments when compared to the other two treatments, with about 3 inches higher levels of stored soil moisture in the 0 lb/ac treatment when compared with the 80 and 160 lb N/ac treatments. This was likely associated with the reduced growth rates, lower vigor and reduced leaf area (data not shown) in the 0 N treatment.

Lodging Issues – Nitrogen management trial

Lodging was a significant issue in all nitrogen treatments with both varieties, with worse lodging issues in 2011 and 2012 than in 2010. In 2010 the lodging mostly occurred after early September, intensifying across treatments later in September and October (Table 46). In 2011 there was little lodging in the field until relatively late in the season, with the majority of the lodging starting to occur soon after the September 8 field evaluations, at which time all treatments averaged less than 10 percent lodging (Table 3, 4, 5). Lodging intensified in the weeks after that, culminating in over 80 percent lodging in all treatments on the last measured date (October 12). Specialized harvesters, commonly used for sugarcane, will be needed for sweet sorghum.

Lodging can be a significant problem with sweet sorghum, and it is important to note several observations and findings associated with the lodging across years of the trial:

(1) there were no severe weather situations (rainfall events in excess of 0.25 inches, high wind periods with winds greater than 20 mph) that were associated with the extent of the lodging, the timing of the lodging, or any treatment differences in lodging percentage on measured dates, and:

(2) we evaluated stalks each year for indications of disease occurrences (such as Fusarium presence) and did not identify stalk rot, root damage or related disease incidence of any significance in any of the treatments each year.

Table 46: Lodging percentage in sampled areas as a function of date and nitrogen treatment in sweet sorghum at WSREC, 2010. First value shown is variety "Dale", second value is variety "M81E".

Nitrogen Treatment	Lodging (as a percent of the full plant population) - considered as "lodged" if plant at a 45 degree angle to ground or less				
	20-Aug	5-Sep	22-Sep	3-Oct	10-Oct
0	0 / 0	10/1	15 / 0	25 / 32	40 / 45
40	5/1	8/1	22 / 15	25 / 37	30 / 40
80	0 / 0	0 / 0	31 / 27	45 / 65	55 / 65
120	5/1	16 / 22	35 / 31	60 / 70	65 / 77
160	10/1	10/15	22 / 51	55 / 88	61 / 90

Table 47: Lodging percentage in sampled areas as a function of date and nitrogen treatment in sweet sorghum at WSREC, 2011. First value shown in variety "Dale", second value is variety "M81E".

Irrigation Treatment	Lodging (as a percent of the full plant population) - considered as "lodged" if plant at a 45 degree angle to the ground or less				
	23-Aug	8-Sep	19-Sep	30-Sep	12-Oct
0	0	8/5	23 / 29	31 / 40	45 / 58
40	0	0 / 5	18 / 30	20 / 30	47 / 55
80	0	5/10	15 / 35	15 / 45	38 / 71
120	0	6	31 / 35	60 / 75	64 / 88
160	0	7	25 / 35	60 / 74	65 / 90
200	0	10	35 / 30	55 / 78	72 / 90

Table 48: Lodging percentage in sampled areas as a function of date and irrigation treatment in sweet sorghum at WSREC, 2012. First value shown is variety "Dale", second value is variety "M81E".

Irrigation Treatment	Lodging (as a percent of the full plant population) -considered as "lodged" if plant at a 45 degree angle to the ground or less				
	August 20	27-Aug	9-Sep	23-Sep	8-Oct
0	0	5/1	12/15	37 / 50	60 / 73
40	0	10/10	10/20	35 / 45	60 / 70
80	0	12/17	25 / 35	50 / 58	70 / 85
120	10/1	10/22	30 / 40	42 / 65	65 / 85
160	10/1	15 / 15	31 / 35	67 / 70	72 / 80
200	6	15 / 35	45 / 40	75 / 80	80 / 90

Yield Determinations – Fresh and Dry Weights

For fresh weight and dry weight yield determinations, approximately 10 ft^2 of plot areas were cleared in each of two separate rows in each of four field replications per treatment. The samples were cut, removed from the field for fresh weight measurement, then subsamples of 5 plants were selected from each replication, run through a chipper, and placed in a hot greenhouse for about 5 to 7 days, then in a drying oven overnight (at 50 degrees C) for determination of dry weights, moisture content at harvest and to allow yields to also be expressed on a dry weight basis. Yield information in is shown in Tables 49 through 54.

Table 49: 2010 trial fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of nitrogen rate treatment for the cultivar "DALE" on October harvest date in sweet sorghum at WSREC.

Nitrogen treatment	Fresh Weight (t/ac)		Dry weight: fresh weight ratio		Dry Weight (t/ac)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
0	10.3	2.1	0.311	0.007	3.2	0.39
40	16.7	1.7	0.314	0.01	5.24	0.43
80	29.7	2.3	0.274	0.009	8.14	0.67
120	36.6	3.5	0.26	0.007	9.52	0.58
160	35.1	2.2	0.253	0.006	8.88	0.41

Table 50: 2011 trial fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of nitrogen rate treament for the cultivar "DALE" on October harvest date in sweet sorghum at WSREC.

Nitrogen treatment	Fresh Weight (t/ac)		Dry weight: fresh weight ratio		Dry Weight (t/ac)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
0	7.8	2.2	0.298	0.003	2.32	0.91
40	12.9	3	0.291	0.008	3.75	0.55
80	24.4	1.9	0.28	0.006	6.83	0.61
120	31.2	2.1	0.276	0.004	8.61	0.75
160	29.7	1.8	0.269	0.008	7.98	0.58
200	31.5	1.7	0.27	0.005	8.51	0.44

In 2011 plant height averages within a week of the harvest date averaged 7.0 feet, 8.2 feet, 9.2 feet, 9.8 feet and 10.3 feet for nitrogen treatments 0, 40, 80, 120 and 160 lb N/ac, respectively (data not shown). Although not shown in the figures or tables, partitioning evaluations were done on 7 plant samples in all plot replications, separating the plants into stems, heads/panicles, and leaves (with leaves separated from leaf sheaths at the edge of the stem). Percent of total fresh weight as stems ranged from about 71 percent in the low nitrogen treatments (0 and 40 lb/ac) to a high of about 81 percent in the higher nitrogen application treatments (120, 160 lb

N/ac) treatments. Percent of total fresh weight in leaves ranged from a low of about 16 percent in higher nitrogen application treatments to about 23 percent in the lowest two nitrogen application treatments. Percent of total fresh weight in the head/panicle averaging from a low of 3 percent in the lowest nitrogen treatment to a high of about 4.2 percent in the highest two nitrogen treatments.

In 2012 plant height averages about three weeks prior to the start of harvests averaged 6.9 feet, 8.6 feet, 10.1 feet. 10.4 feet and 11.2 feet for nitrogen treatments receiving 0, 40, 80, 120, and 160 lb N/ac, respectively (data not shown). Partitioning evaluations were done on 7 plant samples, separating the plants into stems, heads/panicles, and leaves (with leaves separated from leaf sheaths at the edge of the stem). Percent of total fresh weight as stems ranged from about 74 percent in the low nitrogen treatments (0 and 40 lb/ac) to a high of about 77 percent in higher nitrogen treatments. Percent of total fresh weight in leaves ranged from a low of about 20 percent in higher nitrogen application treatments to about 23 percent in the lowest nitrogen treatments (0, 40 lb/acre), with percent of total fresh weight in the head/panicle showing little treatment differences, ranging from about 2 percent in lowest nitrogen treatments to only about 3.5 percent in the highest nitrogen treatments (160, 200 lb N/ac).

Table 51: 2012 trial fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of nitrogen rate treatments for the cultivar "DALE" on October harvest date in sweet sorghum at WSREC.

Nitrogen treatment	Fresh Weight (t/ac)		Dry weight: fresh weight ratio		Dry Weight (t/ac)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
0	11.4	1.6	0.279	0.01	3.18	0.79
40	19.7	1.79	0.278	0.011	5.48	0.83
80	31.6	2.13	0.273	0.009	8.63	0.51
120	34.5	1.59	0.261	0.008	9	0.37
160	33.8	2.55	0.263	0.007	8.89	0.56
200	35.7	2.78	0.261	0.012	9.32	0.42

Table 52: 2010 trial fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of nitrogen rate treatment for the cultivar "M*!E" on October harvest date in sweet sorghum at WSREC.

Nitrogen treatment (lb N / acre)	Fresh Weight (t/ac)		Dry weight: fresh weight ratio		Dry Weight (t/ac)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
0	8.9	2.34	0.331	0.006	2.95	0.9
40	15.5	1.7	0.328	0.015	5.08	0.85
80	26.9	2.2	0.289	0.012	7.77	1.12
120	34	2.45	0.253	0.011	8.6	0.56
160	31.7	2.31	0.264	0.007	8.37	0.69

Table 53: 2011 trial fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of nitrogen rate treatment for the cultivar "M81E" on October harvest date in sweet sorghum at WSREC.

Nitrogen treatment (lb N / acre)	Fresh Weight (t/ac)		Dry weight: fresh weight ratio		Dry Weight (t/ac)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
0	6.8	1.46	0.31	0.013	2.11	1.05
40	14.1	1.6	0.307	0.009	4.33	1.39
80	22.3	1.55	0.296	0.006	6.6	0.89
120	29.5	2.06	0.288	0.007	8.5	0.65
160	29.8	1.88	0.289	0.005	8.61	0.68
200	27	1.51	0.276	0.006	7.45	0.93

Table 54: 2012 trial fresh weights, dry weight:fresh weight ratios, and dry weight yields as a function of nitrogen rate treatment for the cultivar "M81E" on October harvest date in sweet sorghum at WSREC.

Nitrogen treatment (lb N / acre)	Fresh Weight (t/ac)		Dry weight: fresh weight ratio		Dry Weight (t/ac)	
	Average	Std Dev	Average	Std Dev	Average	Std Dev
0	12.7	1.79	0.299	0.004	3.8	1.1
40	20.2	1.63	0.302	0.008	6.1	0.6
80	29.7	2.08	0.286	0.009	8.49	0.76
120	28.2	2.01	0.279	0.015	7.87	0.88
160	31.5	1.43	0.274	0.004	8.63	0.51
200	30.6	1.1	0.28	0.009	8.57	0.94

Refractometer (degree Brix) measurements for expressed stem sap

Sap solution samples were taken from stem samples cut from sampled plants at specific locations described below, with sap expressed using a stem press to exert pressure until a minimum of 3 ml of liquid was expressed per sample. These measurements were made with a hand-held refractometer on the stem sections collected fresh in the field at harvest stage, with samples collected at about 1/4, 1/2 and 3/4 of plant height (following tables for different years and harvest dates shown.

Some averages for percent stem sugar will be presented, averaging the data summaries across multiple measurement locations on the plants (bottom, mid and upper zones as described above). A relatively consistent finding in this data is that Brix readings tended to increase significantly at sampling locations higher on the plant stems, as shown in the following tables. Some standardization of this type of measurement will be needed in future evaluations, or alternatively it may be useful to consider some other ways to express sap to measure sugars from solutions expressed from the full length of sampled stem tissues rather than these sub-sections. Evaluations were only done on the variety “M81-E” due to the large number of samples required.

Table 55: 2010 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest time from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid"), and ¼ height ("lower") near harvest time on October 17-19 in 2010 sweet sorghum field trial at WSREC, variety M81E.

N treatment	Degree Brix Lower stem section		Degree Brix Mid stem section		Degree Brix Top stem section	
	Average	Std dev	Average	Std dev	Average	Std dev
0	9.55	0.47	10.6	0.53	11.2	0.52
40	10.12	0.51	11.3	0.6	12.9	0.31
80	13.4	0.37	13.6	0.55	14.7	0.16
120	12.9	0.4	13.9	0.39	15.1	0.37
160	13.1	0.45	12.7	0.44	14	0.51

Table 56: 2011 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest time from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid") and ¼ height ("lower") near harvest time on October 4-7 in 2011 sweet sorghum field trial at WSREC, variety M81E.

N Treatmen	Degree Brix Lower stem section		Degree Brix Mid stem section		Degree Brix Top stem section	
	Average	Std dev	Average	Std dev	Average	Std dev
0	10	0.22	10.6	0.3	11.8	0.4
40	12.2	0.38	13.9	0.22	14	0.36
80	13.5	0.43	15.4	0.25	15.9	0.39
120	14	0.55	15.3	0.47	16.4	0.44
160	13.6	0.31	14.8	0.62	16.1	0.45
200	13.3	0.18	14	0.33	15.2	0.51

Refractometer data from harvest timing indicated that in addition to the consistency with which the percent Brix values tended to go up in the mid to top stem sections, there also were consistent increases in percent Brix values going from the more nitrogen stressed, lower applied nitrogen treatments compared with the higher nitrogen application treatments. While the general trends were apparent, the relative size of the differences varied some between years.

Table 57: 2012 percent sugar (Brix) from hand refractometer readings from expressed juice from stem sections taken at harvest time from plant sections at about ¾ of plant height (shown as "top"), ½ of height level ("mid"), and ¼ height ("lower") near harvest time on October 10-12 in 2012 sweet sorghum field trial at WSREC, variety M81E.

N treatment	Degree Brix Lower stem section		Degree Brix Mid stem section		Degree Brix Top stem section	
	Average	Std dev	Average	Std dev	Average	Std dev
0	10.8	0.57	12.9	0.7	12.6	0.6
40	13.4	0.41	14.5	0.5	14.9	0.56
80	13.1	0.78	14.8	0.84	17.1	0.43
120	14.3	0.56	15.3	0.77	15.9	0.79
160	14.1	0.3	15.5	0.63	16.6	0.81
200	14.8	0.84	15.1	0.5	14.8	0.42

Tissue nitrogen concentrations as affected by nitrogen treatments.

Table 58: Plant tissue nitrogen concentrations at 2 to 3 weeks prior to harvest in the cultivar M81E as averaged across plots in two years of the study (2011-12), nitrogen application tratment, and type of tissue partitioning.

N application rate treatements (lb N/ac)	Nitrogen Concentration (mg N/g tissue dry weight)- values shown are mean and (standard deviation)					
	Panicle, including grain		All leaf tissue, blended sample		All stem tissue, blended sample	
	2011	**2012**	**2011**	**2012**	**2011**	**2012**
0	9.6 (1.3)	12.1 (1.1)	7.4 (0.5)1	9.2 (0.6)	1.7 (0.7)	1.6 (0.9)
40	11.2 (2.5)	11.5 (0.4)	8.9 (0.3)	8.8 (0.5)	3.4 (0.5)	2.7 (0.3)
80	12.5 (0.6)	12.9 (0.9)	11.3 (0.1)	12.6 (0.3)	3.1 (0.3)	3.9 (0.2)
120	13.1 (1.2)	13.7 (1.2)	11.6 (0.8)	12.4 (0.5)	3.7 (0.4)	4.6 (0.6)
160	12.2 (1.8)	13.1 (2.1)	12.2 (0.9)	13.7 (1.4)	4.0 (0.8)	4.1 (1.3)
200	12.0 (1.5)	13.9 (0.7)	14.9 (1.2)	13.9 (1.8)	4.8 (0.7)	5.2 (0.2)

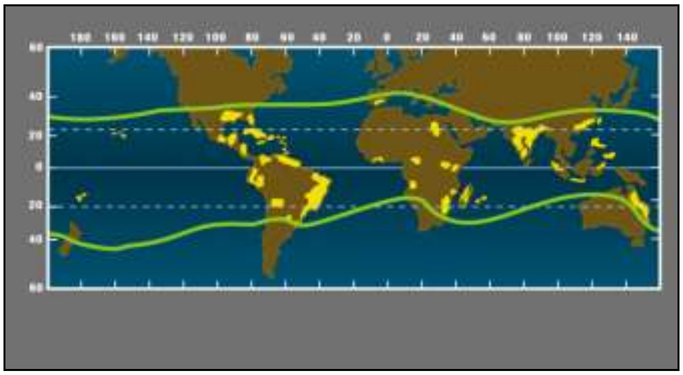
Estimates of nitrogen uptake as a function of nitrogen treatments and years can be calculated using the tissue average concentrations in combination with dry weight yield data and partitioning information, but are incomplete at this time.

1.9.5 Future Plans

Future studies and additional analyses are justified based on results observed to date. Any varieties tested for San Joaquin Valley conditions should be evaluated under fully irrigated and at least moderate deficit irrigation in California production areas to assess whether or not they could have a place in central valley production areas. Varieties that are tolerant to cold weather would potentially allow for earlier planting and harvest and a longer total harvest period, which is essential if sweet sorghum is to be the primary basis for a dedicated biorefinery. Identification of such varieties would be an important element of future research.

1.10 Sugarcane and Energy Cane

Figure 61: Global map of the palm line that delineates the conventional sugarcane production regions.



Sugarcane is a member of the *Saccharum* complex (Mukherjee, 1957). These tall perennial grasses include sugarcane and closely related high fiber energy canes, congeneric relatives and wild ancestors (*S. robustum, S. barberi, S. senensis,* and *S. spontaneum* and various interspecific hybrids), as well as related genera such as *Erianthus* and *Miscanthus*. The complicated genetics that characterize the *Saccharum* complex (Hogarth, 1987; D'Hont et al., 1996) have yielded wide adaptation to a range of environmental conditions. Many genotypes exhibit high productivity and large biomass potential, while the perennial life cycle allows economically efficient production, with replanting from vegetative stalk segments only required after several generations of ratton crops (from regrowth of severed shoots). Current sugarcane and Type I energy cane clones contain about 90% *S. oficinarum* and 10% *S. spontaneum* germplasm (Ming et al., 2006). Sucrose accumulation and robust growth of thick stalks derive mostly from *S. oficinarum*, while genes for vigor, stress tolerance, high fiber and abundant tillering derive mostly from *S. spontaneum*. Current energy cane breeding programs are increasing the percentage of wild relatives in an effort to enhance stress tolerance and vigor.

Sugarcane is an important feedstock for ethanol in many parts of the world. It may represent a bridge crop for biofuels between sugar crops and cellulosic ones (Houghton et al., 2006). Current commercial clones provide sugar in high yields for direct fermentation, along with lignocellulose in bagasse and field trash (leaves) for future exploitation as biofuel or current exploitation as combustion fuel for processing juice. Type I energy canes are clones with somewhat greater fiber content in the stalk than is optimal for sugar processing, and often correspondingly lower sugar content. Type II energy canes have much lower sugar than commercial clones but other potentially advantageous qualities, including high biomass potential.

It is likely that rigorous selection for high sugar and optimal fiber among current sugarcane clones has inadvertently reduced the intrinsic biomass productivity potential. A goal of the present study was to evaluate some of the wider crosses available, including some Type II energy canes containing a high percentage of the wild species, *S. spontaneum*. If total biomass potential can be enhanced, this will lead to high yields of EtOH and improved sustainability, once commercial processing technologies for lignocellulosic feedstocks are developed.

Production in temperate desert environments.

Saccharum is a tropical genus. One of its promising features as a candidate bio-energy crop for California is its C_4 photosynthetic pathway. The theoretical maximum conversion efficiency of solar energy by a NADP-ME type C_4 species, such as sugarcane, is about 6% (Zhu et al., 2008; Beadle and long, 1985; Loomis and Williams, 1963). The most efficient conversion of solar energy reported for a C_4 crop over a production season is about 3.7%, and over shorter periods up to 4.3% (Beadle and Long, 1985; Beale and Long, 1995). Based on these calculations, the maximum theoretical potential productivity of *Saccharum* is 125.4 t/ac/yr.

Well-adapted sugarcane clones are closer than most other crop species, including other C_4 species, to achieving theoretical yield potentials based on the energy content of sunlight (Heinz, 1987). Record yields of sugarcane under commercial conditions (leeward Kauai, Hawaii U.S.A.; annualized production of a 24 month crop) are approximately 31.3 t/ac/yr of biomass and 10.7 t/ac/yr of sugar (Osgood, 2003; Ming et al., 2006), though recently somewhat higher commercial yields in irrigated, arid production regions of Brazil have been reported (Waclawovsky et al., 2010), up to 107.1 t/ac/yr of fresh cane, equivalent to 35.7 t/ac/yr stalk biomass, and about 58 t/ac/yr of total above ground biomass. Experimental yields in irrigated, hence high irradiance, environments in Brazil approached 133.9 t/ac in a 13-month crop, equivalent to 44.6 t/ac stalk biomass and 73.7 t/ac above ground biomass (Waclawovsky et al., 2010). Closing the gap between record and typical yields (Boyer, 1982) is an important goal for sugarcane production for bioenergy.

The most promising regions for high yield sugarcane production are in high irradiance, irrigated production systems with low cost water from river or irrigation canals. The C_4 syndrome is expected to allow sugarcane and energy cane clones to fully utilize the very high temperatures and high radiation fluxes of potential production environments in the Imperial and San Joaquin Valleys. The C_4 syndrome is associated with anatomical features and with high water use efficiency, acclimation to warm environments, and generally high productivity (Sage, 2004; Ehleringer and Bjorkmann, 1977; Heaton et al., 2004). However, in previous trials in the low desert of California, substantial mid-summer bleaching of leaves was observed in some cultivars, suggesting that the region's high daytime temperatures may remain problematic (P. Sebesta personal communication to D.A. Grantz).

Low temperatures early and late in the season also remain a concern (Moore, 1987). Cold tolerance defines the absolute limits of sugarcane distribution, though physiological acclimation to progressively cooling temperatures may extend this range (Thomashow, 1999), and further crossing and selection is very likely to do so, as ancestral species to commercial sugarcane, particularly *S. spontaneum*, have developed considerable tolerance to abiotic stresses (Moore, 1987). The occurrence of freezing night temperatures generally limits global commercial production to within about 30° north and south of the equator (Ming et al., 2006), generally restricted to the areas where native *Palmaceae* (palm trees) are found (Fig. 61). In Louisiana and Florida, where risk of freezing nights dictates short growing seasons of about 9 months compared with 12 months in tropical and subtropical environments such as Hawaii. However, over 80 countries produce sugarcane, for sugar, rum, and increasingly biofuel, and nearly a third of these experience freezing temperatures during the off-season (Eggleston and Legendre, 2003).

There has been considerable introgression of *S. spontaneum* germplasm into both sugarcane and energy clones (Ming et al., 2006). There appears to be considerable potential for enhanced productivity for bioenergy clones specifically selected for California's arid inland valleys. Lignin and cellulose are co-regulated at the level of gene expression (Ragauskas et al., 2006) so that repressing lignin increases both cellulose synthesis (Li et al., 2003) and its enzymic digestibility (Boudet et al., 2003). In conventional breeding stress tolerance is often linked to high fiber content (Ming et al., 2006; Irvine, 1977), which will be more readily exploited for energy cane than it has been for sugarcane.

Production environments in California

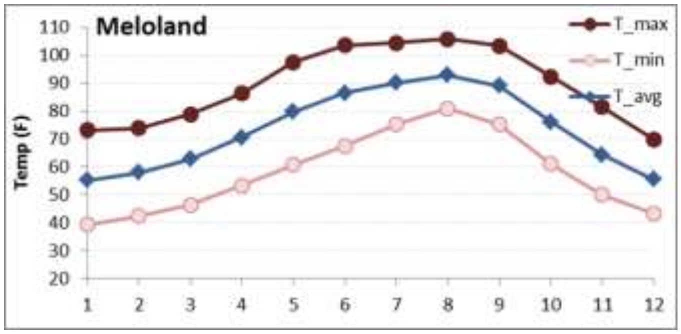
We have tested a range of germplasm in two promising production environments, both low elevation, arid and irrigated. Both the Imperial Valley and the San Joaquin Valley represent apparently favorable environments for cultivation of sugarcane and energy cane, based on the criteria listed above. In both environments day temperatures in mid-summer may be too high, and in winter the level of chilling stress may be inhibitory. Both environments provide high levels of solar irradiance and abundant irrigation resources.

Imperial Valley

Experimental sugarcane production has taken place in the Imperial Valley for decades, with peak activities in the 1930's, 1960's, and again in the 2000's, with yields up to 26.8 t/ac/yr above ground biomass, using clones selected elsewhere (Bazdarich and Sebesta, 2001).

The Imperial Valley lies in the Sonoran Desert, representing a nearly ideal environment for production of sugarcane and energy canes, with the exception of temperature extremes noted above. The growing season is over 9 months, including a warm to very hot summer (Fig. 62). There is abundant water by irrigation from the Colorado River, and there is a dry, sunny, cool, and generally frost-free ripening season. Additionally there is almost complete freedom from typhoons and hurricanes. These have been considered the hallmarks of a classic sugarcane production area.

Figure 62: Climate data for UC Desert Research and Extension Center, Holtville, CA, in the Imperial Valley.



The Imperial Valley lies around 33° N, at an elevation near or below sea level. The experimental fields used in the present experiments lie at an altitude around 18 m below sea level, at a latitude of 32.7º N, with average annual maximum/minimum temperatures of 89.6/55.4º F. The region is quite arid, with annual rainfall of approximately 3 inches (7 cm). The wettest month is January with less than 0.5 inch. Summer midday temperatures exceed 113 º F, and are occasionally even hotter. Winter temperatures are moderate and with only occasional light frosts (California Climate Data Archive, 2010). These temperatures in the Imperial Valley exceed the typical production criteria for sugarcane in both winter and summer. Weather data experienced during the research seasons discussed here are summarized in Appendix A, Figure A.5.

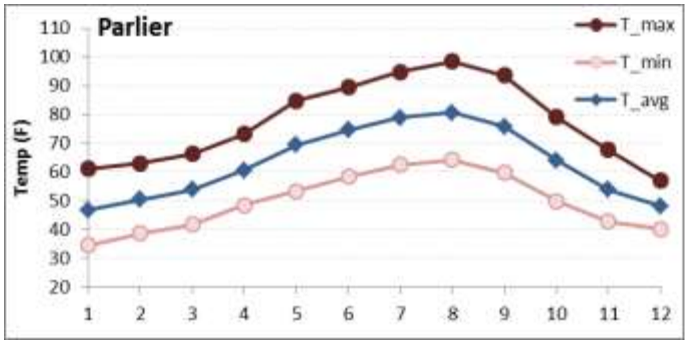
Saccharum clones were grown in the deep alluvial soil (42% clay, 41% silt, 16% sand) of the University of California, Desert Research and Extension Center in Holtville, southern Imperial County. The soils are not optimal for sugarcane, being somewhat alkaline (pH = 7.8), with a cation exchange capacity of about 32 µeq/g. The fields that were available had a high electrical conductivity (EC = 8.19), indicating salinity at levels would be expected to suppress yields of sugarcane, a salt-sensitive species. Ammonium acetate extraction indicated that sodium (39.5 milliequivalents per 100 g soil) and calcium (34.0 milliequivalents per 100 g soil) each contributed about equally.

San Joaquin Valley

Sugarcane is currently grown in the San Joaquin Valley, produced and sold at local farmers' markets for chewing cane and for juice, while a commercial sugarcane molasses industry was once viable in the area (Colon, 2008).

The San Joaquin Valley is nearly as promising as the Imperial Valley by the environmental criteria suggested above. The San Joaquin Valley lies about 35° N- 38° N, at an elevation of about 100 m above mean sea level. Temperatures in the San Joaquin Valley also exceed the typical bounds for sugarcane production in both winter and summer (Fig. 63).

Figure 63: Climate data for UC Desert Research and Extension Center, Parlier, CA, in the San Joaquin Valley.



Saccharum clones were grown in the deep, fine sandy loam, soils at the University of California, Kearney Research and Extension Center in Parlier, southern Fresno County. These soils were also somewhat alkaline (pH = 8.2) but with lower salinity than in the Imperial Valley (EC = 0.81) with more calcium (6.0 milliequivalents per 100 g soil) than sodium (0.3 milliequivalents per 100 g soil). Rainfall averages 11.6 in/yr, mostly Dec-March. The wettest month is January with about 2.2 inches.

Experimental Methods and Germplasm

Germplasm Evaluated

The sugarcane crop was planted from clonal *Saccharum* material. Limited quantities of vegetative seed pieces were obtained from a variety of sources (Table 59). Material from out of state was obtained from the collection of the USDA/ARS Sugarcane Laboratory in Houma Louisiana. These materials were harvested according to phytosanitary protocols, inspected and certified at the source, and then passed through greenhouse quarantine and re-inspection as required by California Department of Food and Agriculture, prior to planting in the field. Other clones were obtained from growers in the San Joaquin and Imperial Valleys. Initial plantings were at wide spacing to increase the amount of vegetative planting (stalk) material. All plots were originated as directly planted stalk pieces (billets), with subsequent years based on rattooned (grown from the stubble left after harvest of the stalks).

The clones that were evaluated were intended to represent a range of high sucrose to high biomass materials. Some of these materials remain proprietary and are only generally described here (Table 59). Further information can be obtained from the USDA/ARS in Houma LA.

Planting Procedures and Crop Calendars

Figure 64: Planting configuration of sugarcane billets, common in the Imperial Valley and used in our experimental plots.

All experimental plots were furrow irrigated, with 8 inch (20 cm) deep furrows established at 60 inch (5 foot, 1.5 m) spacing. In some fields, to accommodate available machinery, this was accomplished by planting alternate beds at 30 inch spacing. Initial plantings at wide spacing were planted at approximately 60 inch spacing within the rows. In subsequent plantings, seed pieces of vegetative stalk material (billets) were planted in beds, with billets overlapping 2- to 3-fold to assure adequate stand establishment.

The experimental plantings were generally planted in late fall or early winter (Tables 60, 61, 62). The initial wide planting was established in mid- to late- March 2008, to accommodate the quarantine requirements (Tables 60, 62).

Table 59: Clonal genotypes of Saccharum spp. hybrids evaluated.

Clone	Description[1]	Source
Ho95-988	Commercial sugarcane clone in Louisiana. Hybrid of *S. oficinarum* with *S. spontaneum* and *S. robustum*.	USDA/ ARS / SRRC in Houma LA.
Ho00-961	Type I Energy Cane[2]. hybrid of *S. officinarum, S. spontaneum, S. barberi,* and *S.*	USDA/ ARS / SRRC in Houma LA.
LCP85-384	A highly successful commercial clone in Louisiana. Nominally 90% *S. oficinarum*, 10% *S. spontaneum*	Local grower in Imperial Valley.
L99-233	Commercial sugarcane release in Louisiana. Nominally 90% *S. oficinarum*, 10% *S. spontaneum*	USDA/ ARS / SRRC in Houma LA.
US02-147	Type II Energy Cane[3]. F1 wild cane x sugarcane. Nominally 50% *S. oficinarum*, 50% *S. spontaneum*.	USDA/ ARS / SRRC in Houma LA.
US02-144	Type II Energy Cane[3]. F1 wild cane x sugarcane. Nominally 50% *S. oficinarum*, 50% *S. spontaneum*.	USDA/ ARS / SRRC in Houma LA.
US72-114	Type II Energy Cane[3]. BC1 with sugarcane.	USDA/ ARS / SRRC in Houma LA.
TCP87-3388	A successful commercial clone in Texas. Nominally 90% *S. oficinarum*, 10% *S. spontaneum*	Local grower in the Imperial Valley.
US06-9001	Type II Energy Cane[3]. BC1 with wild cane	USDA/ ARS / SRRC in Houma LA.
US06-9002	Type II Energy Cane[3]. BC1 with wild cane	USDA/ ARS / SRRC in Houma LA.
Elephant	Apparently a southeast Asian chewing cane. Nominally 90% *S. oficinarum*, 10% *S. spontaneum*	Local grower in San Joaquin Valley.
Mexican	Apparently a Mexican commercial sugar clone (pedigree unknown). Nominally 90% *S. oficinarum*, 10% *S. spontaneum*	Local grower in San Joaquin Valley.

[1]In some cases derived as educated guesses, (after Grantz et al., 2012).

[2]Clone with higher fiber than sugar clones, but only slightly lower sucrose.

[3]Clone with much higher fiber and lower sugar than typical sucrose clones.

Once sufficient planting material had been generated in California, plots were established in rows 20 feet (6.2 m) long, with 6 rows per plot. This provided credible yield measurements without excessive interference from edge effects.

In 2010 a very large plot was established in rows 70 feet (22 m) long, also at 1.5 m between rows, and with 7 rows per plot. This field suffered from management difficulties and was only harvested for yield at the second rattoon stage (Table 60).

Table 60: Crop schedule at the Desert Research and Extension Center, Holtville, CA, in the Imperial Valley (wide spacing and 70 foot x 7 row plots).

Year	2008	2009	2012
Configuration	Wide planting		70 foot x 7 row plots
Crop	Plant	First Rattoon	Second Rattoon
Plant date	3/ 18/ 08	na	2/ 9/ 10
Harvest date	1/ 7/ 08	1/ 13/ 09	1/ 8/ 13

Table 61: Crop schedule at the Desert Research and Extension Center, Holtville, CA, in the Imperial Valley (20 foot x 3 row plots).

Year	2009	2010	2011	2012
Configuration	20 foot x 3 row plots			
Crop	Plant	First Rattoon	Second Rattoon	Third Rattoon
Plant date	1/9/2009	na	na	na
Harvest date	1/12/2010	1/24/2011	2/27/2012	1/9/2013

Table 62: Crop schedule at the Kearney Research and Extension Center, Parlier, CA, in the San Joaquin Valley.

Year	2008	2009	2009	2010
Configuration	Wide planting		20 foot x 3 row plots	
Crop	Plant	First Rattoon	Plant	First Rattoon
Plant date	3/25/2008	na	12/10/2008	na
Harvest date	12/8/2008	12/14/2009	12/14/200	11/8/2010

In all cases the field was divided into 4 blocks to mitigate any variation in the soil or irrigation system. In general blocks did not differ significantly.

Pest management

Saccharum is slow to establish a full canopy, leaving substantial periods of open ground where weeds can flourish. In our experiments, weed control was by cultivation prior to planting, and by topical application of Gramoxone (paraquat) in early morning when winds were calm, prior to substantial canopy establishment. Later, occasional hand hoeing was required in localized areas of the plots.

In general sugarcane is not subject to heavy pest pressure. Pesticide use in sugarcane was very low, relative to other potential biofuel feedstocks (Domiguez-Faus et al., 2009).

Figure 65: Longitudinal section through a sugarcane stalk, showing tunnel damage caused by Mexican rice borer larvae. The red discoloration was common in many clones in our experimental trials. Photo by F. Reay-Jones, obtained on the web from Hummel et al. (2008).

In our experimental plantings in the Imperial Valley, the only pest of note was the Mexican Rice Borer (*Eoreuma loftini*; Dyar)). There was substantial borer infestation in early crops, particularly in the commercial clones. This was not observed in the San Joaquin Valley. The attack by borer weakens the sugarcane plant, and reduces potential productivity. It also damages the sugar containing stalks, resulting in stalk breakage and in consumption of the harvestable sugar. The characteristic red discoloration of the pith (Fig. 65) was evident in many stalks of the susceptible clones at the time of cutting in the Imperial Valley. Often stalks broke during our careful passage through the field, which did not happen as frequently in the San Joaquin Valley plots.

The rice borer is well protected by its invasive life style. We attempted to suppress populations by application of Coragen at 5 oz acre-1. This was done immediately after harvest, when the application had maximum access to cut stalk ends. The treatment was effective in reducing visible pest pressure.

Successful cultivation of *Saccharum* clones in the Imperial Valley will depend on successful management of this already well-established insect.

Harvest

Harvest of cane in the Imperial Valley is typically done with specialized billet chopper harvesters (Fig. 66a), loaded into either small wagons or into larger on-road trucks. Our experimental plots were generally harvested by hand with cane knives and machetes (depending on worker preference). All harvest weights from subplots were obtained by hand harvest.

The large plot (70 foot rows) was harvested as in Fig. 66a in 2010 and 2011, but yields were not obtained for logistical reasons associated with the donated harvester, and because management issues suggested that the yields were suppressed below expected levels.

Yields were expressed on an oven dry basis, per unit ground area. Yields from the wide-spaced plantings were expressed on a ground area basis allotted to each plant (2.25 m^2/plant), rather than per plant. However, these yields are not strictly comparable to yields from the commercially spaced trials.

Figure 66: (a) Billet harvesting of sugarcane at UC Desert Research and Extension Center in the Imperial Valley, using a specialized sugarcane harvester. (b) Sugarcane ready for harvest at UC Kearney Research and Extension Center, Parlier, CA, in the San Joaquin Valley.

At harvest, stalk diameter was determined with calipers, at the third internode. Two measurements at right angles were averaged, since the stalks were not cylindrical, but rather were oval in cross section.

Juice was expressed from the cut stalk by crushing with large pliers, and sugar content was determined (Brix as percent sucrose) using a hand held refractometer.

Harvest data from experimental plots

The complete harvest data is presented in Tables 75-97. In this section we analyze a reduced data set, consisting of averages of two classes of clonal materials. These are commercial clones (including near commercial clones and Type I energy canes), and Type II energy cane clones (Tables 63, 64, 65). The data in Table 63 allow several generalizations regarding biomass production potential.

Here we exclude the Elephant clone, obtained from Southeast Asian growers in the San Joaquin Valley, and the Mexican clone, obtained from Hispanic growers in the Imperial Valley. Both are described in the complete data set. Though their pedigree is unknown, both Elephant and Mexican were productive under at least some conditions and yielded sweet juice that was highly favored for chewing.

Biomass yield

Maximum yields averaged over 4 blocks in the field in the Imperial Valley under wide spacing for the plant crop were 9.8 ± 3 t/ac for commercial clones and 27.2 ± 1.6 t/ac for Type II clones (Table 75). For the first rattoon crop these numbers increased to 26.8 ± 3.4 t/ac for commercial and 39.7 ± 2.7 t/ac for Type II. At the denser commercial spacing yields were lower, 17.4 ± 7 t/ac and 17 ± 2.9 t/ac for the commercial clones and 13.4 ± 2 t/ac and 19.6 ± 2.3 t/ac for Type II clones.

In the San Joaquin Valley at wide spacing, maximum yields were 21.9 ± 0.1 t/ac and 16.5 ± 1.6 t/ac for the plant and rattoon crops for commercial clones and 31.25 ± 0.1 t/ac and 40.6 ± 1.96 t/ac for Type II clones. At commercial spacing maximum yields were 19.6 ± 0.4 t/ac and 16.1 ± 0.4 t/ac for the two crops for commercial clones, and 22.8 ± 0.4 t/ac and 23.2 ± 0.1 t/ac for the Type II clones.

In the plant crop, the Type II energy cane clones performed substantially better than the commercial clones (Table 63). The commercial clones declined slightly in the first rattoon, while the Type II clones increased slightly. In subsequent rattoon crops, conducted without further fertilizer application, the commercial clones declined much more severely than the Type II clones, which declined much more gradually. This indicates a potential to utilize more marginal and less fertile soils.

Table 63: Averages across all experiments of biomass (oven dry) yield of high *S. oficinarum* clones ("commercial sugarcane") and of experimental high *S. spontaneum* clones ("Type II Energy Cane").

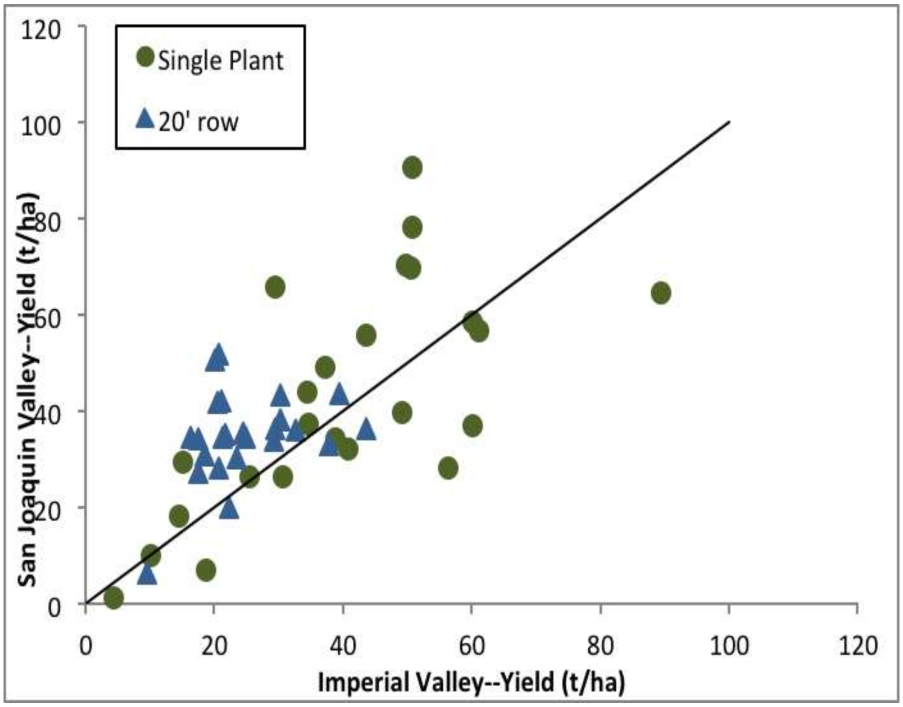
Environment	Planting Configuration		Plant Crop	First Ratton	Second Ratton	Third Ratton
Imperial Valley	Wide Spacing	Commercial Sugarcane	36.6 ton ha^{-1}	35.2	na	na
		Type II Energy Cane	51.1	52.7	na	na
	Commercial Spacing	Commercial Sugarcane	31.2	25.1	19.8	9.8
		Type II Energy Cane	22.4	25.1	22	16.5
San Joaquin Valley	Wide Spacing	Commercial Sugarcane	34.8	28.5	na	na
		Type II Energy Cane	59.8	71	na	na
	Commercial Spacing	Commercial Sugarcane	37.4	34.8	na	na
		Type II Energy Cane	38.8	37.8	na	na

Yields in the San Joaquin Valley were generally higher than in the Imperial Valley (Table 63; Fig. 67, data are clustered above the 1 : 1). These are yields for all clones in 2008 and 2009 (Fig. 67). The two years exhibited very similar relationships (not shown). Maximum yields in the two environments were similar in these years. The slight bias in favor of the San Joaquin Valley may be related to the more moderate summer temperatures, but is more likely a reflection of the salinity of the soils in the assigned fields at each experimental farm.

The Type II clones performed much better at wide spacing than at commercial spacing, while the commercial clones performed similarly at the two spacings. Fig. 67 differentiates the wide spacing from the commercially spaced plantings. The commercial spacing demonstrates a well-defined cluster of yields among the clones, including both the commercial and Type II germplasm. However, the widely spaced data, while responding similarly to the two environments, are spread out along the 1 : 1 line. The clones at the higher end are the Type II clones. The greater tillering ability and overall greater vigor of the high percentage *S. spontaneum* clones (Fig. 68) appear to be more capable of exploiting the wide spacing, and may indeed be most productive under these conditions. This was not explicitly analyzed in these studies, but spacing trials among these novel materials may represent a potential key to improved lignocellulosic biomass productivity.

A potential concern with these thin-stalked clones (Table 65; Fig. 69) is their greater density and woodiness, which has implications for harvesting equipment. The greater tillering capacity shown in Fig. 68, is closely related to the thinner and reedier stalks shown in Fig. 69. In all trials, the stalk diameters were larger in the San Joaquin Valley. This likely reflects the improved water relations, which is related to stalk expansion, associated with either the reduced salinity or the reduced evaporative demand in the San Joaquin Valley relative to that in the Imperial Valley. Over all trials, the commercial clones had a mean diameter of 24.5 mm (1 inch) while the Type II clones had a mean diameter of 17.4 mm (0.7 inch).

Figure 67: Comparison of yields in the San Joaquin and Imperial Valleys, including data from single plant and 20 foot row plots of all varieties. Yields in the two locations were well correlated, by somewhat higher in the lower salinity and lower temperature San Joaquin Valley environment.



Sugar content of expressed juice

Averaged over all members of each class in the Imperial Valley trials (Table 64), Brix was considerably higher in the commercial clones, 19.9 % and 18.6 % in the plant crop at wide and commercial spacing, than in the Type II clones, which were only 14.2 % and 12.6%. These values increased in the successive rattoon crops.

For the Type II energy canes, these values were similar in the San Joaquin Valley. However, the commercial clones were substantially lower, 16.5 % and 15.2 % at the two spacings. This may reflect the greater moisture content of the stalk material at harvest in the San Joaquin Valley.

A rough estimate of sugar yield can be obtained as the product of Brix and total juice content (obtained from percent moisture and total yield). For the commercial clones, these values were considerably higher in the San Joaquin Valley (8.8 t/ac and 8.7 t/ac at commercial and wide spacing) than in the Imperial Valley (only 5.3 t/ac and 6.7 t/ac at the two spacings; averages calculated from data in Tables 76, 81, 90 and 95).

Figure 68: Wild relatives of sugarcane have considerable biomass potential. (a) An unidentified pure *S. spontaneum* clone is shown outside the breeding house at the USDA/ARS Sugarcane breeding Station in Houma, LA; (b) An approximately 50% *S. spontaneum* (F1 with a commercial clone) growing at the UC Kearney Research and Extension Center in the San Joaquin Valley exhibits greater height, tillering, and thinner, woodier stalks relative to the commercial clone in the background.

Table 64: Averages across all experiments of Brix (percent sugar in juice) of high *S. oficinarum* clones ("commercial sugarcane") and of experimental high *S. spontaneum* clones ("Type II Energy Cane").

Environment	Planting		Plant Crop	First Ratton	Second	Third Ratton
Imperial Valley	Wide Spacing	Commercial Sugarcane	19.90%	na	na	na
		Type II Energy Cane	14.2	na	na	na
	Commercial Spacing	Commercial Sugarcane	18.6	22.8	na	21.5
		Type II Energy Cane	12.8	16.2	na	15.4
San Joaquin Valley	Wide Spacing	Commercial Sugarcane	16.5	na	na	na
		Type II Energy Cane	14.2	na	na	na
	Commercial Spacing	Commercial Sugarcane	15.2	16.9	na	na
		Type II Energy Cane	12.6	12.7	na	na

Figure 69: An approximately 50% *S. spontaneum* (F1 with a commercial clone; upper panel), growing at the UC Kearney Research and Extension Center in the San Joaquin Valley exhibits greater height, tillering, and thinner, woodier stalks relative to the commercial clone in the background.

Table 65: Averages across all experiments of stalk diameter of high *S. oficinarum* clones ("commercial sugarcane") and of experimental high *S. spontaneum* clones ("Type II Energy Cane").

Environment	Planting		Plant Crop	First Ratton	Second	Third Ratton
Imperial Valley	Wide Spacing	Commercial Sugarcane	22.8 mm	na	na	na
		Type II Energy Cane	16.5	na	na	na
	Commercial Spacing	Commercial Sugarcane	22.7	18.5	na	na
		Type II Energy Cane	16.3	12.5	na	na
San Joaquin Valley	Wide Spacing	Commercial Sugarcane	25.9	na	na	na
		Type II Energy Cane	18.7	na	na	na
	Commercial Spacing	Commercial Sugarcane	26.6	23.4	na	na
		Type II Energy Cane	17.9	16.8	na	na

Nitrogen Use

Sugarcane production with reference to biofuel production, is estimated under U.S. conditions to average approximately 0.78 ± 0.28 oz. N/L EtOH (Domiguez-Faus et al., 2009). This is similar to projections for sugarbeet but considerably less than for other candidate biofuel feedstocks including maize grain, switchgrass, and sweet sorghum. A review of literature on sugarcane fertilization practices in Australia, South Texas, Louisiana, Florida, and South Africa (Table 66) suggests that in heavier, non-peat soils, substantial fertilization is required for sustained yields. However, sugarcane is understood to be less N efficient than many crop species, suggesting that alternative practices might be considered. There is recent evidence that *Saccharum* may differ from even closely related grain crops, in preferentially utilizing ammonium rather than nitrate from the soil N pool (Robinson et al., 2011). As nitrate fertilizers are labile in the environment, increased use of other, particularly more reduced, forms of N like ammonium may reduce the environmental impact of sugarcane and energy cane cultivation, and reduce the net greenhouse gas balance of associated biofuels.

Table 66: Approximate nitrogen fertilization practices in diverse sugarcane production areas on heavy soils that are not high nitrogen peat.[1]

Crop	Plant	First Rattoon	Second Rattoon	Third Rattoon
N application (lb/ ac)	100	150	150	150
N application (kg/ ha)	112	168	168	168
1These recommendations are synthesized here from many environments, with weighting to those most similar to California conditions. Recommended application rates are therefore approximate and should be confirmed with soil and tissue testing, and will vary with expected yield and soil characteristics (after Johnson et al., 2008; Morgan et al., 2012; Robinson et al., 2011; Rozeff, 1990;Muchovej and Newman, 2004; Wiedenfeld and Enciso, 2004).				

The experiments described here were run with minimal fertilizer inputs (Tables 67, 68, 69, and 70).

Table 67: Fertilization schedule at the Desert Research and Extension Center, Holtville, CA, in the Imperial Valley (wide spacing).

<table>
<tr><td>Year</td><td>2008</td><td>2009</td></tr>
<tr><td>Configuration</td><td colspan="2">Wide planting</td></tr>
<tr><td>Crop</td><td>Plant</td><td>First Rattoon</td></tr>
<tr><td rowspan="3"></td><td>3/15/2008</td><td>12/3/2008</td></tr>
<tr><td>11-52 urea</td><td>100 lb urea</td></tr>
<tr><td>na</td><td>50 lb N/acre</td></tr>
<tr><td rowspan="3"></td><td>4/21/2008</td><td rowspan="3"></td></tr>
<tr><td>10 gal UN32</td></tr>
<tr><td>35 lb N/acre</td></tr>
<tr><td rowspan="3"></td><td>5/2/2008</td><td rowspan="3"></td></tr>
<tr><td>80 lb urea</td></tr>
<tr><td>40 lb N/acre</td></tr>
<tr><td>Total</td><td>About 100 lb</td><td>50 lb N/yr/ha</td></tr>
</table>

Table 68: Fertilization schedule at the Desert Research and Extension Center, Holtville, CA, in the Imperial Valley (70 foot x 7 row plots).

Year	2010	2011	2012
Configuration	70 foot x 7 row plots		
Crop	Plant	First Rattoon	Second Rattoon
	5/ 25/ 10	4/ 11/ 11	6/ 14/ 12
	25 gal UN32	50 lb urea	17 lb N/ acre
	90 lb N/ acre	25 lb N/ acre	7.56 lb P/ acre
			5 lb K/ acre
			3 lb S/ acre
			0.03 lb Fe/ acre
		5/ 24/ 11	
		50 lb urea	
		25 lb N/ acre	
Total N/ acre/ year	90 lb N/ yr/ acre	50 lb N/ yr/ acre	17 lb N/ yr/ acre

Table 69: Fertilization schedule at the Desert Research and Extension Center, Holtville, CA, in the Imperial Valley (20 foot x 3 row plots).

Year	2009	2010	2011	2012
Configuration	20 foot x 3 row plots			
Crop	Plant	First Rattoon	Second Rattoon	Third Rattoon
	12/3/2008	6/4/2010	4/11/2011	6/14/2012
	100 lb urea	15 gal UN32	50 lbs urea	17 lb N/acre
	50 lb N/acre	50 lb N/acre	25 lb N/acre	7.56 lb P/acre
				5 lb K/acre
				3 lb S/acre
				0.03 lb Fe/acre
			5/24/2011	
			50 lb urea	
			25 lb N/acre	
	50 lb	50 lb	50 lb	17 lb

Table 70: Fertilization schedule at the Kearney Research and Extension Center, Parlier, CA, in the San Joaquin Valley.

Year	2008	2009	2009	2010	2012
Configuration	Wide planting		20 foot x 3 row plots		20 foot x 1 row plots
Crop	Plant	First Rattoon	Plant	First Rattoon	Plant
Total N/acre/year	3/13/2008	11/24/2008	11/24/2008	na	na
	150 lb NH_4NO_3	300 lb NH_4NO_3	300 lb NH_4NO_3		
	50 lb N/acre	100 lb N/acre	100 lb N/acre		
	3/20/2008				
	150 lb NH_4NO_3				
	50 lb N/acre				
Total N/acre/year	100 lb N/acre	100 lb N/acre	100 lb N/acre	na	na

Water Use

Figure 70: Gravity fed canal water from the Colorado River is the essential condition of continued agricultural productivity in the Imperial Valley.

U.S. average water use to produce EtOH was about 1280 L/L, greater than sugarbeet, similar to maize grain and switchgrass, but lower than sweet sorghum. World average water consumption for EtOH was 105 m^3/GJoule EtOH or 2516 L/L (Dominguez-Faus et al., 2009). This was greater than sugarbeet but similar to maize grain and much less than sweet sorghum. Water cost to recover energy for electricity generation was about half (50 m^3/GJoule), reflecting the efficiency of using the cellulosic plant body as well as the high sucrose sap.

In both production environments in the current experiments, irrigation water was applied on an approximate 10-day cycle, by furrow, based on experienced agronomic judgment.

In 2013 in the Imperial Valley, flexible PVC lateral pipes were gated at each furrow, and monitored with a gauge at the main. While the gauges were subject to several failure modes, including invasion by rodents and canal debris, partial data were obtained. By matching irrigation amounts with weather data over these periods, it is apparent that irrigation was supplied at somewhat below rates of potential evapotranspiration (ETo; Table 71), resulting in apparent crop coefficients less than 1.0. This suggests that our plots were under-irrigated during substantial periods of growth, and that optimal irrigation practices may improve yields over those obtained here.

We previously used the Crop Coefficients from the UN Food and Agriculture Organization Irrigation and Drainage Paper No. 56, with local climate information to calculate anticipated water use for sugarcane production in the Imperial Valley (Table 72) and in the San Joaquin Valley (Table 73).

Table 71: Experimental water application to 70-foot plot.

Water Use Applied to Sugarcane, Imperial Valley			
	ETo	Effective Irrigation[1]	Percent ETo (Apparent Average Crop Coefficient, Kc)
2010	68.39	63.28	0.92
2011	59.02	57.17	0.97
2013	54.15	45.71	0.84

[1]Applied water plus rain multiplied by 0.85 to account for leaching and runoff. Based on partial records indicative of entire production year.

Table 72: Calculated water use by sugarcane in the Imperial Valley.

Predicted Sugarcane Water Consumption in Imperial Valley from UN FAO1					
Plant Date	Crop Coefficients (Kc 1,2,3)2	Average Kc	Water Use (inch/ year) 3	Water Use (Acre Feet/ year)	Water Use (mm/ year)
15-Apr	0.4, 1.25, 0.75	1.06	71.6	6	1819
1-Oct	0.4, 1.25, 0.75	1.06	78.4	6.5	1991
15-Apr	0.4, 1.10, 0.75	0.95	64.4	5.4	1636
1-Oct	0.4, 1.10, 0.75	0.95	70.1	5.8	1780

[1]Taken from Bali, Grantz and Snyder, 2009.

[2]After FAO #56; Allen et al.); low altitude crop, 13 month cycle, plant cane crop.

[3]Calculated using CIMIS data from Melolands Station.

Table 73: Calculated water use by sugarcane in the San Joaquin Valley.

Predicted Sugarcane Water Consumption in San Joaquin Valley from UN FAO[1]					
Plant Date	Crop Coefficients (Kc 1,2,3)[2]	Average Kc	Water Use (inch/ year)[3]	Water Use (Acre Feet/ year)	Water Use (mm/ year)
15-Apr	0.4, 1.25, 0.75	1.06	51.6	4.3	1311
1-Oct	0.4, 1.25, 0.75	1.06	57.5	4.8	1460
15-Apr	0.4, 1.10, 0.75	0.95	46.4	3.9	1178
1-Oct	0.4, 1.10, 0.75	0.95	51.4	4.3	1305
[1]Taken from Bali, Grantz and Snyder, 2009.					
[2]After FAO # 56; low altitude crop, 13 month cycle, plant cane crop.					
[2]Calculated using CIMIS data from Parlier Station.					

These calculations suggested that irrigation requirements in the Imperial Valley might be similar to that currently applied to the widespread crop, alfalfa. The range of soil textures in the Imperial Valley will require that site-specific irrigation requirements be determined. Further, the water use efficiency of the crop, and of the resulting biofuel product, may not be maximized at the highest yield and water application rates. These tradeoffs will require evaluation as the potential biofuel industry matures in these environments.

Complete Harvest Data in the Imperial Valley

Widely spaced individual plants

Table 74: Biomass yield of widely spaced plants in the Imperial Valley.

	dry yield (t/ha)					
	Plant			First Rattoon		
	2008			2009		
	mean		s.e	mean		s.e
Ho95-988	30.5	cd	6.8	10.1	fg	3.3
Ho00-961	37.2	bcd	2	15	feg	4.2
LCP85-384	40.8	bc	4.2	60	b	7.6
L99-233	25.3	ed	1.6	34.6	ced	2.6
US02-147	34.3	cd	1.3	29.5	fed	4.3
US02-144	61	a	3.6	89.3	a	6.1
US72-114	60	a	3.2	43.6	cbd	3.8
TCP87-3388	49	ba	6.6	56.4	b	8.2
US06-9001	49.7	ba	3.8	50.6	cb	8.6
US06-9002	50.5	ba	7.1	50.7	cb	9.4
Elephant	14.4	e	1.4	4.2	g	1.8
Mexican	38.8	bcd	6	18.6	feg	3.4

Table 75: Percent moisture of the shoot (stalk plus leafy trash) at harvest for wisely spaced plants in the Imperial Valley.

	Moisture (%)					
	Plant			First Rattoon		
	2008			2009		
	mean		s.e	mean		s.e
Ho95-988	67.08	f	0	70.14	g	0
Ho00-961	68.91	e	0	70.65	f	0
LCP85-384	68.58	e	0.13	60.31	l	0
L99-233	76.19	b	0	71.97	d	0
US02-147	70.83	d	0	73.53	c	0
US02-144	61.44	g	0	63.12	j	0
US72-114	66.77	f	0	69.3	h	0
TCP87-3388	67.07	f	0	62.52	k	0
US06-9001	68.18	e	0	71.83	e	0
US06-9002	70.87	d	0	67	i	0
Elephant	83.03	a	0.67	75.33	b	0
Mexican	73.79	c	0	76.53	a	0

Table 76: Stalk diameter at harvest for widely spaced plants in the Imperial Valley.

	Stalk Diameter (mm)					
	Plant			First Rattoon		
	2008			2009		
	Mean		s.e	Mean		s.e
Ho95-988	21.97	c	0.61	na	na	na
Ho00-961	20.56	dce	0.51	na	na	na
LCP85-384	21.43	dc	0.84	na	na	na
L99-233	20.95	dce	0.12	na	na	na
US02-147	16	de	0.3	na	na	na
US02-144	14.99	e	0.48	na	na	na
US72-114	19.02	dce	1.38	na	na	na
TCP87-3388	29.15	b	1.58	na	na	na
US06-9001	15.94	de	1.74	na	na	na
US06-9002	16.57	dce	0.99	na	na	na
Elephant	37.03	a	2.52	na	na	na
Mexican	31.31	b	1.72	na	na	na

Table 77: Measured sugar content of expressed juice (sap) for widely spaced plants in the Imperial Valley.

	Brix (%)					
	Plant			First Rattoon		
	2008			2009		
	mean		s.e	mean		s.e
Ho95-988	21.4	a	0.1	na	na	na
Ho00-961	18.7	bac	0.8	na	na	na
LCP85-384	19.9	ba	0.5	na	na	na
L99-233	16.7	bdc	1.4	na	na	na
US02-147	14.9	edc	0.8	na	na	na
US02-144	19.2	ba	0.1	na	na	na
US72-114	12.8	efd	0.5	na	na	na
TCP87-3388	22.6	a	0.4	na	na	na
US06-9001	12.8	efd	1.1	na	na	na
US06-9002	11.5	ef	1.1	na	na	na
Elephant	10.6	f	1.8	na	na	na
Mexican	14.7	efdc	0	na	na	na

Table 78: Calculated yield of sucrose for widely spaced plants in the Imperial Valley.

	projected sugar yield (t/ha)					
	Plant			First Rattoon		
	2008			2009		
	mean		s.e	mean		s.e.
Ho95-988	10.8	dc	1.8	na	na	na
Ho00-961	16.7	ba	0.2	na	na	na
LCP85-384	14.5	bc	1.8	na	na	na
L99-233	12.4	bdc	1.9	na	na	na
US02-147	13.2	bdc	1.1	na	na	na
US02-144	17.2	ba	0.4	na	na	na
US72-114	16	bac	0.8	na	na	na
TCP87-3388	20.9	a	3.8	na	na	na
US06-9001	15.1	bc	0.8	na	na	na
US06-9002	12.3	bdc	0.1	na	na	na
Elephant	7.6	d	0.9	na	na	na
Mexican	12.3	bdc	1.1	na	na	na

Commercially spaced plantings, 20 Foot (7 m) x 3 row plots

Table 79: Biomass yield of 20 foot x 3 row plots in the Imperial Valley.

dry yield (t/ ha)								
	Plant 2009		1st Rattoon 2010		2nd Rattoon 2011		3rd Rattoon 2012	
	mean	s.e	mean	s..e	mean	s.e.	mean	s.e
Ho95-988	29.2 a	3.2	24.5 bdc	2.7	14.6 bac	1.2	8.7 c	0.9
Ho00-961	30.2 a	4.1	16.3dc	3.9	16.4 bac	4.5	7.3 c	1.8
LCP85-384	39.4 a	15.6	29.4bac	8.9	25.9 a	2.5	12.6 bc	1.8
L99-233	24.7 a	7.4	17.4dc	5.2	10.8 bdc	1.6	11.8 bc	1.7
US02-147	20.0 a	5.1	20.6bdc	6	21.7 ba	6.1	11.4 bc	4.3
US02-144	30.1 a	4.5	43.6a	5.2	25.8 a	2.2	21.6 a	4.9
US72-114	21.0 a	3	21.3bdc	4	15.8 bac	3.9	14.5 bac	1.3
TCP87-3388	32.5b a	5.7	37.8ba	6.5	24.8 a	3.4	8.8 c	1.7
US06-9001	17.5 a	3.9	21.7bdc	3.6	14.5 bac	3.1	19.2 ba	3.5
US06-9002	23.5 a	7.4	18.4dc	5.4	14.7 bac	4.1	15.8 bac	0.4
Elephant	22.1 a	4.6	9.4d	4.2	2.3 d	1.4	0.0 d	0
Mexican	20.4 a	6.8	20.7bdc	5.3	9.4 dc	2.9	8.5 c	3.4

Table 80: Stalk diameter at harvest for 20 foot x 3 row plots in the Imperial Valley.

Diameter (mm)								
	Plant 2009		1st Rattoon 2010		2nd Rattoon 2011		3rd Rattoon 2012	
	mean	s.e	mean	s.e	mean	s.e	mean	s.e
Ho95-988	23.01 c	0.21	20.45 ba	0.84	na	na	na	na
Ho00-961	21.39 dc	1.26	17.73 bac	0.65	na	na	na	na
LCP85-384	21.37 dc	0.66	20.73 ba	1.02	na	na	na	na
L99-233	20.86 dce	0.51	11.90 dec	2.41	na	na	na	na
US02-147	16.94 f	0.39	14.47 bdec	3.06	na	na	na	na
US02-144	13.17 g	0.62	17.30 bdac	0.97	na	na	na	na
US72-114	18.40 dfe	0.52	11.37 dec	1.47	na	na	na	na
TCP87-3388	26.84 b	1.58	21.77 a	1.27	na	na	na	na
US06-9001	15.73 gf	1.55	11.02 de	2.43	na	na	na	na
US06-9002	17.48 fe	1.2	8.55 e	1.68	na	na	na	na
Elephant	38.74 a	2.34	10.60 e	na	na	na	na	na
Mexican	28.40 b	1.24	13.72 dec	2.26	na	na	na	na

Table 81: Percent moisture of the shoot (stalk plus leafy trash) at harvest for 20 foot x 3 row plots in the Imperial Valley.

	Moisture (%)							
	Plant 2009		1st Rattoon 2010		2nd Rattoon 2011		3rd Rattoon 2012	
	mean	s.e	mean	s.e	mean	s.e	mean	s.e
Ho95-988	70.14 ba	1.4	69.47 cb	0.47	63.33 cbd	1.52	61.21 bac	2.38
Ho00-961	70.65 ba	0.89	67.84 cb	2.74	62.46 cebd	1.37	66.26 a	2.53
LCP85-384	60.31 b	9.81	68.48 cb	0.27	60.41 ced	0.4	64.08 ba	0.33
L99-233	71.97 ba	0.86	70.06 cb	1.12	66.46 b	1.38	66.54 a	1.03
US02-147	73.53 ba	4.87	62.19 ed	0.67	56.91 ef	1.37	56.34 dc	1.06
US02-144	63.12 ba	1.39	60.08 e	0.78	53.55 f	0.17	52.04 d	4.03
US72-114	69.30 ba	1.22	67.25 cb	0.98	61.92 cebd	1.74	60.20 bc	1.62
TCP87-3388	62.52 ba	8.43	69.30 cb	0.65	58.25 efd	1.91	63.18 ba	0.66
US06-9001	71.83 ba	0.42	66.59 cb	1.12	60.27 ced	2.47	56.57 dc	1.04
US06-9002	67.00 ba	3.13	65.64 cd	1.3	59.94 ced	1.45	57.27 dc	0.55
Elephant	75.33 a	1.32	70.84 b	3.15	75.14 a	7.34	na	na
Mexican	76.53 a	2.16	76.31 a	0.13	65.67 cb	1.64	66.68 a	0.66

Table 82: Measured sugar content of expressed juice (sap) for 20 foot x 3 row plots in the Imperial Valley.

Brix (%)								
	Plant 2009		1st Rattoon 2010		2nd Rattoon 2011		3rd Rattoon 2012	
	mean	s.e	mean	s.e	mean	s.e	mean	s.e
Ho95-988	20.7 a	0.6	23.7 c	0.5	na	na	22.0 a	0.5
Ho00-961	15.6 c	1.7	20.1 dc	1	na	na	20.4 ba	1.6
LCP85-384	20.5 a	0.5	22.9 c	1.7	na	na	22.5 a	0.1
L99-233	17.4 bc	1	19.9 dce	1.5	na	na	20.7 ba	0.8
US02-147	16.0 bc	1	16.5 de	0.4	na	na	16.8 dc	1.3
US02-144	15.8 bc	1.2	15.9 e	0.6	na	na	17.5 dc	0.4
US72-114	11.7 de	0.8	16.9 de	0.5	na	na	15.3 de	0.9
TCP87-3388	18.9 ba	0.4	27.6 b	1.1	na	na	22.1 a	0.3
US06-9001	10.6 e	0.7	15.8 e	0.5	na	na	13.7 e	1.2
US06-9002	10.1 e	0.5	16.0 de	0.3	na	na	13.7 e	0.5
Elephant	14.6 dc	1.2	37.6 a	2.9	na	na	na	na
Mexican	14.5 dc	1.3	28.7 b	1.5	na	na	18.1b c	0.3

Table 83: Calculated yield of sucrose for 20 foot x 3 row plots in the Imperial Valley.

	Projected Sugar (t/ ha)							
	Plant 2009		1st Rattoon 2010		2nd Rattoon 2011		3rd Rattoon 2012	
	mean	s.e	mean	s.e	mean	s.e	mean	s.e
Ho95-988	14.1 a	1.2	12.8 bc	2.2	na	na	3.1 a	0.3
Ho00-961	11.2 bac	1.8	8.3 c	3.4	na	na	2.9 a	0.7
LCP85-384	10.6 bdac	1.4	10.3c	1.8	na	na	5.1 a	0.8
L99-233	11.6 ba	4.1	6.0 c	1.4	na	na	4.9 a	0.8
US02-147	8.0 bdac	0.5	4.7 c	1.9	na	na	2.8 a	1.2
US02-144	8.0 bdac	0.7	10.3c	1.1	na	na	3.8 a	0.4
US72-114	5.6 bdc	1	6.2 c	1	na	na	3.4 a	0.4
TCP87-3388	11.4 bac	3.1	20.1ba	2.8	na	na	3.3 a	0.6
US06-9001	4.9 dc	1.3	7.2 c	1.6	na	na	3.3 a	0.5
US06-9002	4.4 d	0.7	4.5 c	1.6	na	na	2.9 a	0.1
Elephant	9.6 bdac	1.8	13.2bc	6.3	na	na	0.0 b	0
Mexican	9.6 bdac	2.6	23.6 a	4.3	na	na	3.0 a	1.2

Commercially spaced plantings, 70 Foot (7 m) x 7 row plots

Table 84: Biomass yield of 70 foot x 7 row plots in the Imperial Valley.

dry yield (t/ha)		
	2nd Rattoon 2012	
	mean	s.e
LCP85-384	21.09 a	1.9
US02-144	24.20 a	2.01
US06-9002	26.56 a	1.98

Table 85: Percent moisture of the shoot (stalk plus leafy trash) at harvest for 70 foot x 7 row plots in the Imperial Valley.

Moisture (%)		
	2nd Rattoon 2012	
	mean	s.e
LCP85-384	70.06 a	0.64
US02-144	65.51 b	0.73
US06-9002	68.63 a	0.9

Table 86: Measured sugar content of expressed juice (sap) for 70 foot x 7 row plots in the Imperial Valley.

Brix (%)		
	2nd Rattoon 2012	
	mean	s.e
LCP85-384	17.53 a	1.39
US02-144	15.72 a	0.19
US06-9002	12.59 b	1.27

Table 87: Calculated yield of sucrose for 70 foot x 7 row plots in the Imperial Valley.

projected sugar yield (t/ha)		
	2nd Rattoon 2012	
	mean	s.e
LCP85-384	8.07 a	0.65
US02-144	7.73 a	0.41
US06-9002	6.86 a	0.52

Complete Harvest Data in the San Joaquin Valley

Widely spaced individual plants

Table 88: Biomass yield of widely spaced plants in the San Joaquin Valley.

	dry yield (t/ ha)								
	Plant			First Rattoon			Plant		
	2008			2009			2012		
	mean		s.e	mean		s.e	mean		s.e.
Ho95-988	26.34	fg	1.89	10.14	e	1.09	83.87	na	na
Ho00-961	49.31	cb	3.09	29.41	d	4.69	76.69	na	na
LCP85-384	32.29	fe	2.3	37.12	d	2.28	68.94	na	na
L99-233	26.51	fg	3.75	37.47	d	3.62	63.52	na	na
US02-147	43.88	cd	2.74	65.71	c	2.56	79.19	na	na
US02-144	56.62	b	2.9	64.47	c	4.58	84.79	na	na
US72-114	58.47	b	4.36	55.9	c	6.57	107.29	na	na
TCP87-3388	39.67	cde	3.5	28.31	d	3.41	64.71	na	na
US06-9001	70.47	a	4.18	78.18	b	3.58	62.68	na	na
US06-9002	69.76	a	7.5	90.84	a	4.39	95.45	na	na
Elephant	18.1	g	2.04	1.29	e	0.15	40.41	na	na
Mexican	34.16	fde	0.87	6.96	e	1.75	57.43	na	na

Table 89: Percent moisture of shoot (stalk plus leafy trash) at harvest for widely spaced plants in the San Joaquin Valley.

	Moisture (%)								
	Plant			First Rattoon			Plant		
	2008			2009			2012		
	mean		s.e	mean		s.e	mean		s.e
Ho95-988	76.28	f	0	78.92	c	0	70.42	na	na
Ho00-961	74.54	h	0	75.57	h	0	69.87	na	na
LCP85-384	77.54	d	0.03	77.05	f	0	70.69	na	na
L99-233	79.8	c	0	77.52	e	0	70.79	na	na
US02-147	75.91	g	0	73.57	j	0	76.13	na	na
US02-144	70.85	j	0	69.89	l	0	63.95	na	na
US72-114	74.49	h	0	73.88	i	0	68.17	na	na
TCP87-3388	76.82	e	0	78.92	d	0	69.45	na	na
US06-9001	72.46	i	0	76.57	g	0	70.96	na	na
US06-9002	71.18	j	0	73.13	k	0	60.89	na	na
Elephant	85.98	a	0.24	85.4	a	0	73.77	na	na
Mexican	83.54	b	0	80.35	b	0	70.37	na	na

Table 90: Stalk diameter at harvest for widely spaced plants in the San Joaquin Valley.

	Stalk Diameter (mm)								
	Plant			First Rattoon			Plant		
	2008			2009			2012		
	mean		s..e	mean		s.e	mean		s.e
Ho95-988	25.86	d	0.53	na	na	na	26.78	na	na
Ho00-961	25.68	d	0.28	na	na	na	20.95	na	na
LCP85-384	25.97	d	0.49	na	na	na	22.22	na	na
L99-233	22.2	e	0.61	na	na	na	23.56	na	na
US02-147	19.21	f	0.71	na	na	na	16.59	na	na
US02-144	16.72	g	0.51	na	na	na	13.98	na	na
US72-114	20.72	fe	0.72	na	na	na	16.04	na	na
TCP87-3388	29.94	c	0.53	na	na	na	27.86	na	na
US06-9001	18.29	fg	0.78	na	na	na	19.54	na	na
US06-9002	18.41	fg	0.53	na	na	na	14.14	na	na
Elephant	44.79	a	1.05	na	na	na	23.78	na	na
Mexican	36	b	1.24	na	na	na	20.85	na	na

Table 91: Measured sugar content of expressed juice (sap) for widely spaced plants in the San Joaquin Valley.

	Brix (%)								
	Plant			First Rattoon			Plant		
	2008			2009			2012		
	mean		s.e	Mean		s.e	mean		s.e
Ho95-988	16.83	a	0.6	na	na	na	18.85	na	na
Ho00-961	17.16	a	0.59	na	na	na	19.9	na	na
LCP85-384	16.81	a	0.47	na	na	na	18.5	na	na
L99-233	15.23	a	1.01	na	na	na	18.65	na	na
US02-147	15.97	a	0.5	na	na	na	15.65	na	na
US02-144	14.06	b	0.35	na	na	na	15.4	na	na
US72-114	13.49	b	0.35	na	na	na	17.1	na	na
TCP87-3388	16.53	a	0.58	na	na	na	18.55	na	na
US06-9001	14.04	b	0.51	na	na	na	14.15	na	na
US06-9002	13.59	b	0.67	na	na	na	11.5	na	na
Elephant	11.12	c	0.6	na	na	na	15	na	na
Mexican	13.56	b	0.36	na	na	na	20.15	na	na

Table 92: Calculated yield of sucrose for widely spaced plants in the San Joaquin Valley.

	projected sugar yield (t/ ha)								
	Plant			First Rattoon			Plant		
	2008			2009			2012		
	mean		s.e	mean		s.e	mean		s.e
Ho95-988	14.46	ed	1.46	na	na	na	37.64	na	na
Ho00-961	24.88	ba	1.95	na	na	na	35.39	na	na
LCP85-384	18.93	bdc	1.68	na	na	na	30.76	na	na
L99-233	16.8	edc	3.03	na	na	na	28.72	na	na
US02-147	22.18	bac	1.76	na	na	na	39.52	na	na
US02-144	19.42	bdc	1.25	na	na	na	23.17	na	na
US72-114	23.21	ba	2.12	na	na	na	39.29	na	na
TCP87-3388	21.92	bac	2.47	na	na	na	27.29	na	na
US06-9001	25.98	a	1.75	na	na	na	21.67	na	na
US06-9002	22.87	bac	2.11	na	na	na	17.09	na	na
Elephant	12.68	e	1.5	na	na	na	17.05	na	na
Mexican	23.55	ba	1.01	na	na	na	27.49	na	na

Commercially spaced plantings, 20 Foot (7 m) x 3 row plots

Table 93: Biomass yield for 20 foot x 3 row plots in the San Joaquin Valley.

	dry yield (t/ha)								
	Plant 2009			1st Rattoon 2010			2nd Rattoon 2011		
	mean		s.e	mean		s.e	mean		s.e
Ho95-988	33.93	ac	1.69	35.53	ba	7.21	na	na	na
Ho00-961	38.23	a	5.86	34.57	ba	4.71	na	na	na
LCP85-384	43.83	a	5.76	36.47	ba	2.77	na	na	na
L99-233	34.67	ac	2.95	34.41	ba	6.39	na	na	na
US02-147	50.79	a	4.78	51.84	a	4.23	na	na	na
US02-144	43.45	a	1.41	36.56	ba	9.7	na	na	na
US72-114	42.06	a	3.03	34.59	ba	7.05	na	na	na
TCP87-3388	36.19	ac	5.87	33.03	ba	5.01	na	na	na
US06-9001	27.31	c	8.71	35.33	ba	11.43	na	na	na
US06-9002	30.43	c	6.07	30.89	ba	1.23	na	na	na
Elephant	20.03	c	2.98	6.48	c	3.92	na	na	na
Mexican	42.02	a	9.69	28.33	b	5.39	na	na	na

Table 94: Percent moisture of the shoot (stalk plus leafy trash) at harvest for 20 foot x 3 row plots in the San Joaquin Valley.

	Moisture (%)								
	Plant 2009			1st Rattoon 2010			2nd Rattoon 2011		
	mean		s.e	mean		s.e	mean		s.e
Ho95-988	78.92	bc	1.15	76.37	ba	0.91	na	na	na
Ho00-961	75.57	cd	1.25	73.73	ba	0.82	na	na	na
LCP85-384	77.05	c	1.92	75.12	ba	0.64	na	na	na
L99-233	77.52	c	1.41	76.71	ba	1.5	na	na	na
US02-147	73.57	d	1.29	73.35	ba	1.3	na	na	na
US02-144	69.89	d	1.58	75.9	ba	5.74	na	na	na
US72-114	73.88	cd	1.01	76.76	ba	5.12	na	na	na
TCP87-3388	78.92	c	0.85	76.88	ba	0.73	na	na	na
US06-9001	76.57	c	2.78	71.06	b	7.83	na	na	na
US06-9002	73.13	d	3.76	71.3	b	1.02	na	na	na
Elephant	85.4	a	0.53	82.84	a	1.92	na	na	na
Mexican	80.35	ba	3.25	82.16	ba	0.2	na	na	na

Table 95: Stalk diameter at harvest for 20 foot x 3 row plots in the San Joaquin Valley.

	Diameter (mm)								
	Plant 2009			1st Rattoon 2010			2nd Rattoon 2011		
	mean		s.e	mean		s.e	mean		s.e
Ho95-988	27.44	d	0.93	25.16	c	1.31	na	na	na
Ho00-961	25.16	ed	0.68	21.55	dce	0.69	na	na	na
LCP85-384	26.82	d	0.78	22.87	c	1.36	na	na	na
L99-233	23.19	ef	0.92	22.55	dc	1.32	na	na	na
US02-147	18.04	gh	0.74	18.44	dfe	1.39	na	na	na
US02-144	17.31	h	0.37	15.03	F0	0.87	na	na	na
US72-114	20.48	gf	0.36	17.92	fe	0.48	na	na	na
TCP87-3388	30.46	c	1.5	24.82	c	0.78	na	na	na
US06-9001	16.75	h	0.47	16.75	f	0.68	na	na	na
US06-9002	16.97	h	0.45	16.02	f	0.7	na	na	na
Elephant	48.64	a	2.33	34.93	a	4.34	na	na	na
Mexican	33.58	b	0.76	29.11	b	1.29	na	na	na

Table 96: Measured sugar content of expressed juice (sap) for 20 foot x 3 row plots in the San Joaquin Valley.

	Brix (%)								
	Plant 2009			1st Rattoon 2010			2nd Rattoon 2011		
	mean		s.e	mean		s.e	mean		s.e
Ho95-988	15.41	ba	1.21	17.78	a	0.96	na	na	na
Ho00-961	16.16	a	1	17.56	a	1.53	na	na	na
LCP85-384	14.18	bdac	1.34	17.25	a	0.72	na	na	na
L99-233	15.33	ba	0.49	16.11	ba	0.85	na	na	na
US02-147	14.63	bac	0.8	16.13	ba	0.93	na	na	na
US02-144	14.7	bac	0.87	14.34	bac	0.48	na	na	na
US72-114	12.14	bdac	1.5	12.18	dc	0.83	na	na	na
TCP87-3388	15.06	ba	0.98	15.89	ba	1.26	na	na	na
US06-9001	9.85	d	2.84	10.85	d	1.44	na	na	na
US06-9002	11.74	bdac	1.93	10.15	d	1.38	na	na	na
Elephant	10.44	dc	0.53	13.58	bdc	1.28	na	na	na
Mexican	11.49	bdc	0.57	13.18	dc	0.82	na	na	na

Table 97: Calculated yield of sucrose for 20 foot x 3 row plots in the San Joaquin Valley.

	Projected Sugar (t/ha)								
	Plant 2009			1st Rattoon 2010			2nd Rattoon 2011		
	mean		s.e	mean		s.e	mean		s.e
Ho95-988	19.48	d	1.02	19.81	ba	2.77	na	na	na
Ho00-961	19.14	ed	3	17.26	ba	2.98	na	na	na
LCP85-384	20.61	d	2.19	19.15	ba	2.12	na	na	na
L99-233	18.46	ef	1.8	18.31	ba	3.3	na	na	na
US02-147	20.66	gh	1.91	22.91	a	1.7	na	na	na
US02-144	14.81	h	0.63	17.59	ba	3.2	na	na	na
US72-114	14.39	gf	1.9	14.41	bc	2.11	na	na	na
TCP87-3388	20.27	c	3.25	16.93	ba	1.58	na	na	na
US06-9001	9.04	h	3.47	8.76	dc	0.68	na	na	na
US06-9002	9.92	h	2.49	7.73	dc	0.86	na	na	na
Elephant	12.21	a	1.95	5.41	d	2.6	na	na	na
Mexican	19.25	b	2.32	17.18	ba	3.27	na	na	na

Summary

We grew a range of commercial sugarcane and Type II (low sugar) energy cane clones. Maximum yields of dry biomass (after removal of approximately 70% moisture at harvest) in the Imperial Valley under wide spacing were 21.9-26.8 t/ac for commercial clones and 27.2-39.7 t/ac for Type II clones in the plant and first rattoon crops. At denser commercial spacing, yields were 16.9-17.4 t/ac for the commercial clones and -19.6 t/ac for Type II clones.

In the San Joaquin Valley, maximum yields at wide spacing were 21.9-16.5 t/ac for commercial clones and 21.3-40.5 t/ac for Type II clones, and at commercial spacing 19.6-16.1 t/ac for commercial and 22.8-23.2 t/ac for Type II clones. Type II energy cane clones produced substantially more total biomass than the commercial clones, and performed much better at wide spacing than at commercial spacing, while the commercial clones performed similarly at both spacings. This reflects aggressive tillering.

Yields in the San Joaquin Valley were generally higher than in the Imperial Valley, with thicker stalks and more moisture at harvest, though biomass yields exhibited similar maxima in the two environments. However, despite lower Brix in the commercial clones, calculated sugar yields were higher in the San Joaquin Valley (8.75 t/ac and 8.66 t/ac at commercial and wide spacing) than in the Imperial Valley (5.27 t/ac and 6.74 t/ac).

Minimal N fertilizer was applied to our trials. Yields were adequate initially and decreased by the second rattoon in the commercial clones more severely than the Type II clones, suggesting their greater potential to exploit marginal environments with low inputs. N requirements appear consistent with literature values of 100 lb N for the plant crop, incorporated in the spring after substantial growth, and somewhat more (150 lb N/ac) for the rattoon crops. Further work with amount, timing, and composition of N fertilizer may be able to reduce the greenhouse footprint of energy cane production.

Water was applied at less than expected crop requirements, potentially reducing yields in these studies. Based on calculations, high yielding sugarcane will require about as much water as the current crop, alfalfa (about 606.5 ac ft/year).

The yield potential of better sugarcane varieties, and particularly of very high yielding Type II energy canes in the Imperial Valley, appears to be excellent. Yields were also excellent in the San Joaquin Valley, but the trials were performed on the east side of the Valley, where energy crops may not be economically viable.

CHAPTER 2:
Crop Commercialization: Cost Analysis, Adoption, and Economic Analysis of the Role of Crops as Biofuel Feedstocks

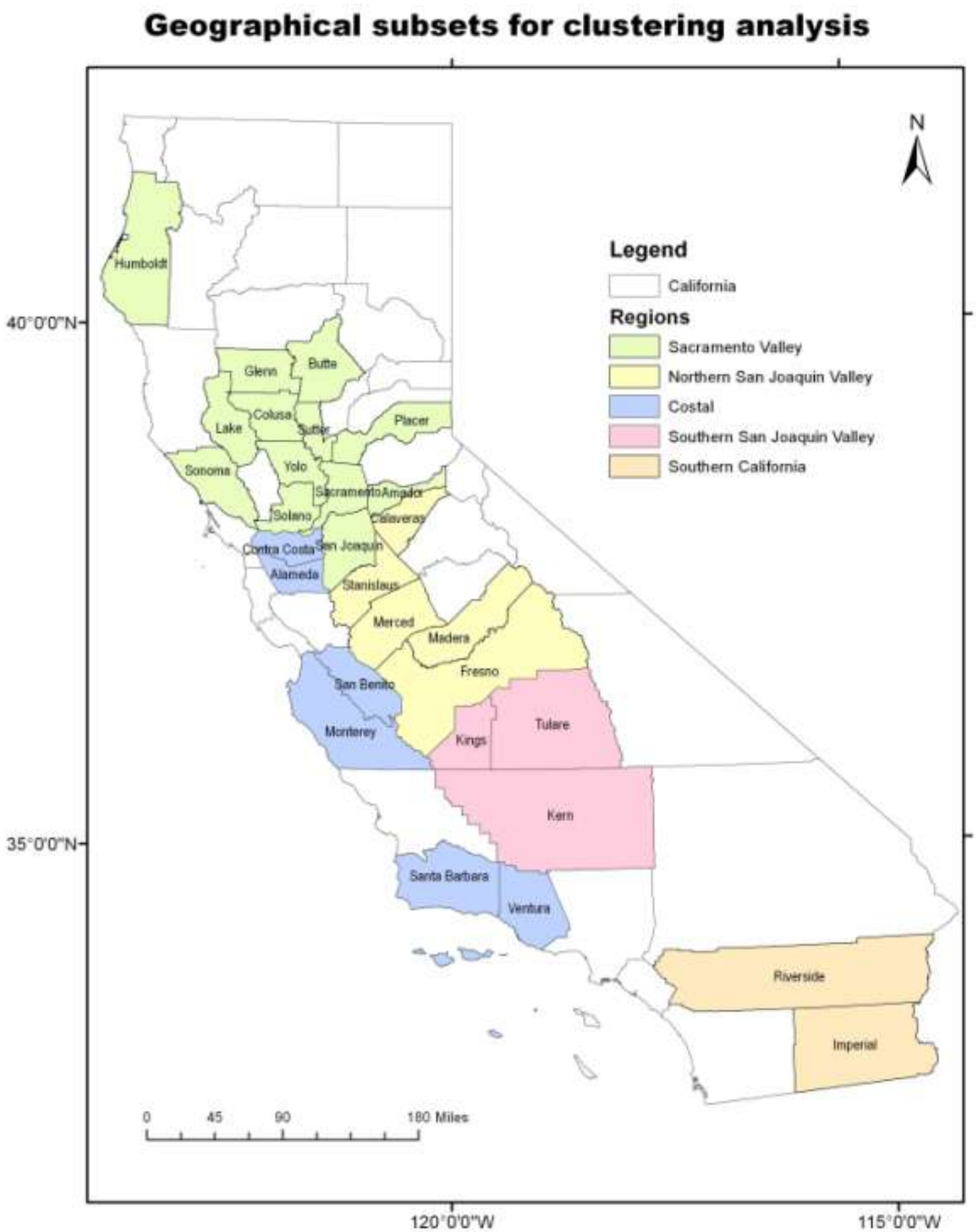
2.1 Introduction

We examined the economic conditions under which four new bio-energy crops, specifically sweet sorghum (SSGM), canola (CANO), sugarcane (CANE) and camelina (CAME), could be adopted in California. The crops and land area displaced locally by the adoption of these four crops are also identified. For this purpose we applied a multi-region, multi-input and multi-output model that was developed for California, the Bioenergy Crop Adoption Model (BCAM), which uses principles of positive mathematical programming (PMP) to capture local marginal cost information to calibrate the model to previously observed cropping patterns in the region. The cropping pattern is based upon farmers' choices and behavior in the near recent past throughout California. By using farmers' actual crop choice data over time, this analysis reflects the diverse patterns of land use that have emerged in California as a consequence of the many and varying factors influencing farm management decisions at a local scale throughout the state. After the model is calibrated, we evaluated scenarios related to our study's objective, the assessment of the conditions for the introduction of three energy crops (i.e. SSGM, CANO, CANE and CAME) in the California agricultural systems and its effect on land use in the state. Data used in this assessment on crop performance and response to management factors is based on research supported in this grant and reported here in Chapter 2.

2.2 Geographic Division and Crop Clustering

For the purposes of analysis, we have divided California into five production regions (Figure 71) as a way to capture and summarize the great variability of farming conditions and systems in the state. These five regions are: Sacramento Valley (SAC), Northern San Joaquin Valley (NSJ), Southern San Joaquin Valley (SSJ), Southern California (SCA) including Imperial, Riverside, and San Diego Counties; and Coastal California (COA) primarily the Ventura-Oxnard region, Santa Maria Valley, and Salinas-Pajaro River Valley.

Figure 71: The geographical subsets of California for cloistering analysis.



In addition, using cluster analysis[7], we determined nine production clusters for each of the five regions. The major crops within each crop cluster were determined by identifying the fewest number of crops that accounted for 95 percent of the crop frequency. Those crops that fit this criterion established the cropping pattern for each of the nine clusters in each of the five California regions. Once the number of crops was determined, the prominent crops were rescaled by 95 percent so that the primary crops summed to 100 percent. The representative cropping patterns in each the nine clusters for each region are given in Tables 98 to 101.

Table 98: Observed Cropping Pattern in Sacramento Valley measured in acres (1997-2007 data)

Crops	Sacramento Valley								
	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9
Alfalfa	16,260	11,303	110,473	9,245	13,456		36,245	64,580	349,180
Barley	2,463	4,155			7,625		18,001	3,573	
Beans	6,661	27,260	4,698		7,946	9,764	59,719	7,827	46,641
Corn	11,754	23,188	16,918	5,761	121,619	5,029	76,260	53,235	110,281
Oat Hay	17,491	10,804	15,413	3,289	47,289	2,966	16,906	19,909	37,932
Onion	1,987	13,796			3,588	5,933	49,867		27,465
Rice	12,426	8,062	16,304	214,136	8,266	46,303	12,649		
Safflower	3,246	17,037	11,115		6,984	6,660	33,812	9,654	64,142
Sudangrass	1,987		5,373		9,291			3,000	
Tomato	3,666	78,123	10,992		7,817	18,368	252,255	10,472	293,663
Wheat	19,338	88,512	34,634	6,929	30,437	22,906	191,806	23,590	236,136

Table 99: Observed Cropping Pattern in Northern San Joaquin Valley measured in acres (1997-2007 data)

Crops	Northern San Joaquin Valley								
	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9
Alfalfa	8,988	18,623	330,359	15,265		96,538	67,033	47,747	94,004
Barley		6,361						3,719	
Beans	7,793	4,436	90,824	2,435	8,042				15,209
Broccoli	2,103	4,018	13,349	2,740					
Corn	8,628	14,480	155,074	101,158	4,961	31,088	61,171	15,468	103,021
Cotton	4,653	113,497	29,318		83,160	91,072	21,486	51,827	
Garlic		8,077			24,680				
Lettuce	2,866	6,236			26,683				
Oat Hay	13,396		69,241	59,408		7,067	14,422	3,693	71,751
Onion	3,039	9,081			21,291			3,564	
Potato	7,677			14,352				8,669	
Rice	2,132			2,957		3,899			
Tomato	9,507	25,989	117,272		108,579	13,194	3,949	40,361	8,708
Wheat	9,219	47,123	36,804	18,005	19,565	24,021	30,340	11,543	16,719

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[7] A matrix of crop frequencies by section was created. The matrix of annual frequencies for each crop within each section over the 10-year period for each region was used to perform a non-metric multidimensional analysis using Manhattan distance. Kruskal and Wish (1978) describe the procedure as minimizing the distance of function stress as:

$$Min\sqrt{\frac{\sum_i\sum_j\left[f(\delta_{ij})-d_{ij}\right]^2}{\sum_i\sum_j d_{ij}^2}}$$

where $f(\delta_{ij})$ is the density function of the system and d_{ij} is each element of matrix with rows i, and columns j. The resulting minimized distances, based on three coordinates, were further grouped with a cluster analysis within each region from which we found the nine clusters for each California region.

Table 100: Observed Cropping Pattern in Southern San Joaquin Valley measured in acres (1997-2007 data)

Crops	Southern San Joaquin Valley								
	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9
Alfalfa	22,450	11,176	10,917	69,238		45,420	73,420	102,940	66,071
Barley	3,836								
Beans	4,316		3,107	3,478	4,818	2,594	9,248		3,866
Broccoli					6,653				
Carrots	22,189	3,637	11,968	5,142	70,348	5,188	7,669		
Corn	5,841	52,134	3,621	27,082		9,658	138,495	119,713	64,143
Cotton	23,409	18,256	96,958	10,635	6,228	44,574	221,050	18,335	54,177
Garlic			5,741		7,856	1,472			
Lettuce					10,545				
Oathay	23,409	13,633		6,930			11,504	14,424	6,114
Onion	4,359		8,060		21,939	2,870			
Potato	5,013	2,685	8,383	2,075	60,864				
Safflower		11,176	4,979	3,616			16,353		
Tomato	6,713		22,616		15,782	3,642	13,083		
Wheat	23,104	93,384	22,049	18,364	6,167	12,583	170,299	101,707	48,189

Table 101: Observed Cropping Pattern in Southern California measured in acres (1997-2007 data)

Crops	Southern California								
	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9
Alfalfa	10,175	66,691	13,801	2,290	18,833	22,488	21,337	32,917	92,896
Barley	1,631								
Beans	1,825			6,049					
Bermudagrass	3,767	5,282	18,142		1,151	8,799	522	1,891	18,177
Broccoli	3,301	4,226	1,218	10,974	1,267	1,422	10,377	11,259	19,226
Carrots	2,330	2,052		14,819		668	4,095	25,569	29,188
Corn	4,350	2,633	906	13,609	1,282	1,325	3,994	8,852	10,137
Cotton	2,253	3,169	874		13,458	1,605	2,890		9,176
Lettuce	5,010	5,741	437	24,886	1,748	808	18,085	28,319	49,463
Oat hay	5,670	1,638	1,468			528			
Onion	2,019	3,527	1,155	4,104	379	5,008	4,978	18,951	55,231
Potato	7,146		406	6,783				2,578	2,796
Safflower	2,719	1,439			408	129			
Sudangrass	1,087	3,077	1,124		524	1,120	1,947	3,352	4,806
Tomato	1,087								2,534
Wheat	23,069	16,994	12,949	2,247	3,831	10,501	9,855	16,072	52,609

It is important to emphasize that in this project we conducted a partial equilibrium analysis. What was needed for this purpose are those crops that accurately represent the consistent, recurring crop choice decisions of farmers in California. The 5 percent that is not included represent those marginal or occasional crops that change constantly, which do not reflect the long-term equilibrium of the system. It is important to note, however, that a still significant amount of land is not included here, making outcomes conservative. Additionally, it is noteworthy that this same amount of land is highly subject to change as a characteristic of farming strategies in California and is not unique to an economic environment where bioenergy crop adoption is possible.

2.3 Data Sources

Crop choice decisions and production areas were defined by two datasets: the mandatory pesticide use reporting data collected by the California Department of Pesticide Regulation[8] (DPR) and the historical crop land use recorded by the respective County Agricultural Commissioners (CAC). This analysis excludes land planted to woody perennial crops, like orchards and vineyards, under the assumption that such areas are not frequently rotated to new crops in response to small marginal changes in crop prices.

DPR data includes land area for each crop within a designated 259 ha (640 ac) section. There are gaps in the DPR land area/crop choice data because: 1) DPR did not query data from some areas, and 2) some crops were grown without pesticide application. For these reasons, we also used data from the CAC to create the foundation datasets for delineating production areas. Thus we collected CAC historical data for all the available crops at the county-level during five years (2004-08) and we used their average to help provide missing data in the DPR records.

For economic information about crop production of the incumbent crops, we used a set of enterprise crop budgets obtained from the UC-Davis Cost and Return Studies[9]. These budgets are derived from a combination of sources, including growers' reports, observations by UCCE extension advisors in each county, and literature sources. They have been developed over a multi-year period and vary in what is reported. To be used for simultaneous comparisons, they must be adjusted to reflect a consistent format and timeframe. Then, these diverse budgets were adjusted for price levels using 2007 as a base year.

In the case of the data for the new energy crops that are being sought (i.e. SSGM, CANO, CANE and CAME) we used different sources of information. Thus for the cost of production of SSGM we used a silage sorghum enterprise budget from the UC-Davis C&SR as a proxy. We updated this silage sorghum budget first using 2012 prices; and then in order to standardize it with respect to the base year of the budgets of the incumbent crops used in the BCAM model, we adjusted the SSGM budget again using 2007 prices (Table 102). In addition, for SSGM yields, professional judgments were made based on field trials conducted by Hutmacher, Kaffka and Wright from 2010 to 2012 in the western San Joaquin Valley, as reported here.

[8] http://www.cdpr.ca.gov/
[9] coststudies.ucdavis.edu/

Table 102: Estimated cost per acre to produce sweet sorghum in California (base year: 2012)

INPUT	Quantity	Unit	Price	Total
WATER				**$249.90**
Irrigation	30	Ac-in	$8.33	$249.90
HERBICIDE				**$57.21**
Yukon	6	onz	$5.72	$34.32
Prowl H2O	3	pint	$7.63	$22.89
SEED				**$16.00**
Sorghum Seed	10	lb	$1.60	$16.00
FERTILIZER				**$89.60**
80-0-0	140	LbN	$0.64	$89.60
INSECTICIDE				**$3.79**
Lorsban 15G	2	oz	$0.20	$0.40
Lorsban 4E	1	pint	$3.39	$3.39
CUSTOM				**$36.00**
Plant	1	acre	$21.00	$21.00
Injection-Fertilizer	1	acre	$15.00	$15.00
LABOR				**$33.55**
Labor (Machine)	1.67	hrs	$16.08	$26.85
Labor (Non-machine)	0.5	hrs	$13.40	$6.70
FUEL				**$29.42**
Gas	0.95	gal	$3.82	$3.63
Diesel	7.52	gal	$3.43	$25.79
MACHINE COSTS				**$15.00**
Lube				$7.00
Repair				$8.00
WORKING CAPITAL				**$7.63**
Interest				$7.63
Total Operating Cost per Acre				$538.10
Total Overhead per Acre				$370.00
Total Cost per Acre (2012)				$908.10
Total Cost per Acre (2007)				$830.00
Yield per Acre				40 Tons

In the case of CANO the estimated cost of production and yield for this crop were obtained from field trials and simulations conducted by Kaffka, Zhang, Hutmacher, and George (2013) under the assumption of appropriate input use and soil water depletion derived from rainfall or irrigation 450 mm (1.5 ac ft) or greater. This could be considered a conservative estimate of the cost of production and for yields of this crop. In addition, as in the case of SSGM, the CANO production budgets were adjusted using 2007 prices to standardize it with respect to the base year of the incumbent crops budgets (Table 103).

Table 103: Estimated cost per hectare to produce canola in California (base year: 2012).

INPUT	Quantity (per ac)	UNIT	Cost/Unit	Total
FERTILIZER				**$227.90**
Nitrogen (dry)	175	lb	$0.74	$129.50
Phosphorous (dry)	20	lb	$0.74	$14.80
Potassium (dry)	120	lb	$0.54	$64.80
Sulfur (dry)	20	lb	$0.94	$18.80
PESTICIDES				**$56.40**
Assure II	2	pint	$20.00	$40.00
Ammonium Sulfate	4	pint	$0.35	$1.40
M90	50	ml	$0.05	$2.50
Capture	1	Ac	$12.50	$12.50
SEED				**$48.00**
Canola	6	lb	$8.00	$48.00
LABOR				**$47.17**
Labor (Machine)	2.1	hrs	16.08	$33.77
Labor (non-machine)	1	hrs	13.4	$13.40
FUEL				**$30.87**
Diesel	9	gal	$3.43	$30.87
REPAIR & MAINTENANCE				**$12.80**
Lubricants	1	Ac	$2.20	$2.20
Repair	1	Ac	$10.60	$10.60
CUSTOM & CONSULTANT				**$31.37**
Rental Sprayer	1	Ac	$2.16	$2.16
Custom Aerial Spray	1	Ac	$8.03	$8.03
Rental Ripper Shooter	1	Ac	$6.18	$6.18
Soil Test	1	Ac	$15.00	$15.00
OTHERS				**$266.53**
Overhead				$250.00
Crop Insurance				$10.00
Interest on Operative Capital				$6.53
Total Cost per Acre 2012				$721.04
Total Cost per Acre 2007				$659.09
Yield per Acre				2,500 lb

For CANE we used as a proxy for some of the costs of production (field preparation and planting) for cotton and Bermuda grass provided by Bali et al (2012) as well as the 2011 projected cost and returns for the production of sugarcane in Louisiana (Salassi and Deliberto, 2011). The latter information helps us to build a 2012 cost of production of CANE, which, similar to the other two energy crops, was later adjusted using 2007 prices (Table 104). Data on crop rotations and management strategy were also derived from interviews with California Ethanol and Power[10], and Imperial Bioresources, two companies that have pursued diverse strategies for establishing sugarcane ethanol businesses in the Imperial Valley. Based on their experience and reports, a typical sugarcane crop would be harvested four times during a five-year period, including establishment. For well-adapted cultivars, an average of 45 t/ac/y harvest could be expected and 12% Brix. These yield figures are close to the higher yields reported above and average Brix measurements.

Table 104: Estimated cost per acre to produce canola in California (base year: 2012) (4-year production cycle).

Input	Total Cost per Acre
Seed	$1,016.10
Planting	$872.57
First Rattoon	$512.24
Second Rattoon	$512.24
Third Rattoon	$512.24
Fourth Rattoon	$512.24
Fertilization	$1,432.00
Irrigation	$1,157.32
Others	$2,000.00
Total per Acre 2012 (4 year period)	$8,526.95
Total per Acre per year 2012	$2,131.74
Total per Acre per year 2007	$1,948.85
Yield per Acre per harvest	45 Tons

Finally for CAME we use the same cost structure as CANO with two small differences. First we assumed that the use of fertilizer is half for CAME compared to the use for CANO. Second, we assume a lower yield equal to 1,600 lb/Ac.

[10] www.californiaethanolpower.com

Table 105: Estimated cost per acre to produce camelina in California (base year: 2012) (4-year production cycle).

INPUT	Quantity (per ac)	UNIT	Cost/Unit	Total
FERTILIZER				**$157.60**
Nitrogen (dry)	80	lb	$0.74	$59.20
Phosphorous (dry)	20	lb	$0.74	$14.80
Potassium (dry)	120	lb	$0.54	$64.80
Sulfur (dry)	20	lb	$0.94	$18.80
PESTICIDES				**$56.40**
Assure II	2	pint	$20.00	$40.00
Ammonium Sulfate	4	pint	$0.35	$1.40
M90	50	ml	$0.05	$2.50
Capture	1	Ac	$12.50	$12.50
SEED				**$48.00**
Canola	6	lb	$8.00	$48.00
LABOR				**$47.17**
Labor (Machine)	2.1	hrs	16.08	$33.77
Labor (non-machine)	1	hrs	13.4	$13.40
FUEL				**$30.87**
Diesel	9	gal	$3.43	$30.87
REPAIR & MAINTENANCE				**$12.80**
Lubricants	1	Ac	$2.20	$2.20
Repair	1	Ac	$10.60	$10.60
CUSTOM & CONSULTANT				**$16.37**
Rental Sprayer	1	Ac	$2.16	$2.16
Custom Aerial Spray	1	Ac	$8.03	$8.03
Rental Ripper Shooter	1	Ac	$6.18	$6.18
Soil Test	1	Ac	$15.00	$15.00
OTHERS				**$266.53**
Overhead				$250.00
Crop Insurance				$10.00
Interest on Operative Capital				$6.53
Total Cost per Acre 2012				$635.74
Total Cost per Acre 2007				$581.12
Yield per Acre				1,600 lb

2.4 Theoretical Foundation of the BCAM Model

The BCAM model is a multi-region, multi-input and multi-output model, which uses PMP optimization principles. PMP methods estimate the parameters of the production functions of each incumbent crop (**i.e. β_i and ω_i**) using the shadow prices of inputs in the base system, which can be defined as the maximum price that farmers are willing to pay for an extra unit of inputs (i.e. land or water) for producing a crop *i*. The PMP model then transforms these opportunity costs into parameters of a quadratic production function (i.e. ◎$_i$ and ◎$_i$) that preserves the core relationship information within the system as new crops are introduced. This allows the land area values for each crop to vary with a change in price, while holding the marginal values of the base system constant. In addition the additional PMP curvature adds flexibility to the traditional linear objective function avoiding overspecialization (i.e. to allocate all the resources to produce only one crop –the most profitable one) (Howitt 1995). In other words, the BCAM model used a PMP optimization approach to calibrate against the existing cropping system in order to obtain some parameters that would help to recover the marginal input costs from the observed average costs of those inputs. The model structure allows the output price and the input costs to be varied. Once the PMP coefficients were established, incremental changes in profit of the new (exogenous) energy crop was optimized by adjusting the energy crop output price over a range of price increases at specified, regular increments.

The yields of the incumbent crops are substituted with the PMP derived quadratic production function. New crop alternatives are tested by holding the non-linear coefficients of the existing cropping system constant while incrementally increasing the profit for the exogenous energy crops, which enter in the model as a linear equation. Exogenous energy crops are not part of the initial system and have no opportunity cost constraint.

A quadratic system of equations, which embody the previous information, is maximized (Eq. 1 and 2) for each cluster in each region. Then results are aggregated to determine the final outcome at a regional level.

$$MAX_{X_{i,land}} \begin{pmatrix} \sum_{i \neq Energy} \left[\left\{ P_i \left(\beta_i - \omega_i X_{i,land} \right) - C_i \right\} X_{i,land} \right] + \\ \left[\left\{ P_{Energy} Y_{Energy} - C_i \right\} X_{Energy,land} \right] \end{pmatrix} \quad \text{(Eq. 1)}$$

subject to: $\sum_i X_{i,j} \leq \bar{R}_j \quad \forall j = land\ and\ water$ (Eq. 2)

where P_i is the historical price of crop *i* and in the case of the energy crops (i.e. *i=Energy*) is the variable used for simulation, β_i is the intercept of the quadratic production function of crop *i*, ω_i is the slope of the quadratic production function of crop *i*, C_i is the cost per acre of crop *i*, $X_{i,j}$ is the amount of input *j* (land or water) that is used to produce crop *i*, Y_{Energy} is the expected yield of the new energy crop (i.e. either SSGM, CANO, CANE and CAME) derived from agronomic research reported here, and $\bar{R}_j$ is the maximum amount of input *j* (land or water) available in the cluster of a region.

It is common in bioenergy supply and demand discussions to focus on changes in biomass yield, output price, and input costs. However, in this analysis profits are maximized instead. Profit is a composite function of those three factors. The solution represents a marginal profit level that acts like a long run incentive, similar to a production contract price. Thus in the BCAM model, the results are generated as profit; however, it is possible to work backward from the profit to infer other variables (price, yield or cost per acre) by keeping constant two of them and solving for the third. Therefore in this case the BCAM model generates a profit and we can identify the underlying price, keeping yield and input costs constant at the cluster level.

In this analysis we did not consider storage, and transportation costs to the processing facility for all the energy crops. Also the model outputs rely on existing technology and production practices as a foundation for examining the adoption of the new crop. Therefore, any cropping pattern that we found from our simulations, if different from the current pattern, will be adopted only if it is more profitable than the observed pattern of crops that was identified using farmers' prior crop adoption and production behavior.

2.5 Results

Simulation Results. Case 1: Canola (Cano)

As discussed, BCAM was calibrated using the observed cropping pattern in the five California regions (Tables 106 to 109) as well as the reported production costs and yield information for each crop in each of those regions. The price of CANO then was increased iteratively to simulate the effect of a continuous increase in price, holding other crop prices constant. This allows a determination of 1) the entry price in each of the five California regions, and 2) which incumbent crops are affected by this introduction.

It is important to emphasize that in our simulation analysis for CANO, we assume only one production cycle that goes from November to June. To simulate the effect of changing prices, we used a set of prices that began at $100/ton, which was increased iteratively by $10/ton until the price variable reached a maximum of $1,000/ton. Yields were assumed (conservatively) to average 1 ton/ac of seed at 45% oil. Actual yields can be much higher at times under favorable conditions (Chapter 2).

Using the BCAM simulation framework, we determined the entry price range for each region, which is defined as the minimum price range in which the crop (in this case CANO) begins to appear in the agriculture system of those five regions. In this study, more specifically, the entry price range was defined as the minimum range price at which it is expected that the region will dedicate between 5,000 and 100,000 acres to the production of CANO. Thus, the entry price ranges for 2013 in dollars per ton were determined as follows: SAC $313.02 - $430.21, NSJ $350.18 - $395.59, SSJ $307.20-$324.01, SCA $358.92-$608.02 and COA $569.08-$572.78 (Table 106). We found that there is a clear advantage of the SSJ region for the adoption of CANO reflected in a lower price range than in the other regions. On the other hand, the SCA region shows the highest price for the adoption of this crop in the upper range (i.e. 50,000 and 100,000 acres) while the COA region shows a range price consistently around $570/ton for each acreage level.

Table 106: Regional entry prices for canola at different adoption levels (i.e. number of acres) measured in dollars per ton.

Number of Acres	Sacramento Valley	Northern San Joaquin Valley	Southern San Joaquin Valley	Southern California	Coastal
5,000	$313.02	$350.18	$307.20	$358.92	$569.08
25,000	$336.44	$355.48	$310.74	$558.96	$569.86
50,000	$360.47	$362.11	$315.16	$593.25	$570.83
100,000	$430.21	$395.59	$324.01	$608.02	$572.78

When we analyzed the crop displacement effect of the introduction of CANO in the five different regions we found a lot of heterogeneity in the displacement effect. This reflects the heterogeneity of the underlying agricultural systems. We determined that because of the introduction of CANO in the system (in a level of 100,000 acres) wheat is displaced in approximately 34,000 acres in SCA while oat hay and corn is displaced in approximately 15,000 and 14,000 acres respectively (Table 107). In the case of the NSJ region the crop that is affected the most is cotton with a reduction of 83,000 acres approximately, equivalent to a contraction of 22% of the total acreage of this crop in NSJ. Cotton is also the most affected in the SSJ region with a contraction of approximately 34,000 acres. In the SSJ area wheat is also importantly affected with a contraction of their acreage in approximately 20,000 acres. In the case of the SCA region alfalfa, cotton and wheat are impacted by a reduction in their acreage by an average of 26,000 acres. Finally we can observe that the region whose crops are most affected by the introduction of CANO is the COA region, primarily in regions with non-irrigated cropping. It is important to specify that in this region we observe not only negative effects or crop displacement because of the introduction of CANO but we also expect another crop to increase its acreage. Thus we found that in the COA region barley acreage is reduced in 145,000 acres while beans and oat hay reduced their acreage in 73,000 and 34,000 acres respectively. As we should remember we were analyzing the effect of introducing 100,000 acres of CANO but the crop displacement effect was higher than this value, this is because wheat is also benefited by the introduction of this crop; that is, wheat increases acreage by approximately 319%, equivalent to 161,000 acres. This indicates some level of economic complementarity between wheat and CANO in the COA region. This requires further analysis and contradicts the idea of linearity in the effect of displacement (simple replacement) of the incumbent crops when introducing feedstock in an agricultural system.

Table 107: Crop displacement in the five California regions because of introduction of 100,000 acres of Canola.

Sacramento Valley		Northern San Joaquin Valley		Southern San Joaquin Valley	
Wheat	34,571	Cotton	83,266	Cotton	34,485
Oat hay	15,426	Wheat	7,327	Wheat	20,462
Corn	14,259	Lettuce	2,985	Oat hay	14,241
Alfalfa	10,127	Corn	2,667	Corn	13,390
Safflower	7,355	Beans	2,294	Beans	13,187
Southern California		**Coastal**			
Alfalfa	29,669	Barley	145,970		
Cotton	26,775	Beans	73,849		
Wheat	24,631	Oat hay	34,653		
Corn	13,442	Corn	5,279		
Oat hay	9,304	Carrot	603		

Simulation Results. Case 2: Sweet Sorghum (SSGM)

As with CANO, we determined the minimum price range in which SSGM is adopted in each of the five California regions. BCAM was used in a manner similar to CANO. It is important to emphasize that for our simulation work we assume only one production cycle that goes from May to October. To simulate the effect of changing prices, we used a set of prices that began at $20/ton, which was increased iteratively by $0.5/ton until the price variable reached a maximum of $70/ton. Hence, based on those assumptions we were able to determine the minimum price range at which the region would dedicate between 5,000 and 100,000 acres to the production of SSGM. Thus, the entry price ranges that we found for 2013 in dollars per ton were: SAC $23.49 - $24.07, NSJ $24.00 - $24.21, SSJ $22.91-$23.44, SCA $23.48-$24.42. (Table 108). We found that there is a clear advantage of the SSJ region for the adoption of SSGM reflected in a lower price range compared to the other three regions. The BCAM model, however, in the case of SSGM adoption in the coastal areas, cannot be taken as a reliable predictor. In this instance, both intensively irrigated and dry-farmed regions (clusters) are included in the coastal area. Dry-farmed systems are found in the coastal foothills where cattle ranching is the primary enterprise. Cropping is included to diversify income sources and provide additional forage resources in the form of crop residues. It is unlikely for agroecological reasons that a summer annual crop like SSGM would be produced on dry farmed land where winter annuals exclusively are produced currently, so no prices are included in the table. Additional modification of the BCAM model to reflect this important distinction remains for future development. This limitation only affects SSGM, a summer annual, not the winter annual crops canola and camelina. In summary, for CANO we found that SSJ is the region that is most likely to support early adoption for both energy crops. On the other hand the NSJ and SCA regions require the highest price range for the adoption of this crop.

Table 108: Regional entry prices for sweet sorghum at different adoption levels (i.e. number of acres) measured in dollars per ton.

Number of Acres	Sacramento Valley	Northern San Joaquin Valley	Southern San Joaquin Valley	Southern California	Coastal
5,000	23.49	24	22.91	23.48	---
25,000	23.72	24.04	23.02	23.67	---
50,000	23.99	24.1	23.16	23.89	---
100,000	24.07	24.21	23.44	24.42	---

In Table 109 we can observe the displacement effect because of the introduction of SSGM in each of the five regions. It is important to note that in the five regions there is a group of crops that are completely displaced by the introduction of SSGM. Thus in SCA oat hay and cotton are completely displaced while in SAC and SSJ the crops that are completely displaced are sudangrass and beans. On the other hand in absolute terms, cotton is the most affected crop in three regions (i.e. NSJ, SSJ and SCA). In SAC the most affected crops are corn and beans with a reduction in acreage of 35,000 and 30,000 acres respectively. As in the case of the introduction of CANO when SSGM is introduced in the COA region some crops are highly affected and others are benefited by it. Thus we found that bean acreage is reduced by approximately 147,000 acres while wheat acreage is reduced by approximately 44,000 acres. Also in this region we found that Barley acreage increased by 52,000 acres. This increase of acreage for some crops not only happened in the COA region but also in the SAC region where oat hay acreage increased by approximately 10,000 acres, while in the SSJ region beans and barley increase by 5,000 and 9,000 acres respectively. This is another example that when a feedstock is introduced agricultural system we should expect not only rivalry but also complementarity effects.

Finally it is important to emphasize that this analysis was done considering one production cycle only; with one planting date (i.e. May 15) and two harvesting dates (i.e. September 15th and October 1st). Also, we should report that during this period is when the crop (i.e. SSGM) with the highest yield potential (i.e. 40 tons/acre) according to the Hutmacher et al (2010-2012) field studies (this report, Chapter 2). If the cycle of production is changed to include other dates, or if multiple production cycles are included in the analysis, it is logical to expect a higher entry price range to compensate for the lower yield of these other cycles; which according to Hutmacher et al (2010-2012) could be as low as 25 tons/acre. For example, we conducted a specific analysis for four counties (Kern, Kings, Tulare and Fresno). Based on field experiments (this report), we found that if SSGM is grown under a scheme of multiple cycles in those counties, it will require a cropping schedule reported in Table 109. On this basis, we were able to determine a set of prices that are required to get a production of SSGM equal to 50,000 ton/year. We found that when the yield is the highest (i.e. 40 ton/acre) the entry price is the lowest, specifically $22.97/ton in Kern, $23.02/ton in Kings, $23.03/ton in Tulare and $24.07/ton in Fresno (Table 110) similar to those obtain in the previous case (i.e. one cycle case). The highest prices for each county occurs when the yield is lowest (i.e. 25 ton/acre for Kern, Kings and Tulare and 20 ton/acre for Fresno county), then those prices are $36.69/ton for Kern, $36.80/ton for Kings, $37.08/ton for Tulare and $49.22/ton for Fresno (Table 111). Therefore, in a more realistic case, with different production cycles, adoption prices will be related to different yields and associated with different and higher prices; at times, twice the price compared with when the yield is the highest and similar to those obtained in our one harvest cycle case. Since sweet sorghum cannot be stored once it is harvested due to sugar deterioration, the crop must be produced continuously month by month to satisfy a demand for the production.

Table 109: Crop displacement in the five California regions because of introduction of 100,000 acres of sweet sorghum.

Sacramento Valley		**Northern San Joaquin Valley**		**Southern San Joaquin Valley**	
Corn	35,066	Cotton	67,942	Cotton	38,547
Beans	30,924	Lettuce	25,263	Beans	31,427
Sudangras	19,561	Wheat	17,493	Corn	16,173
Wheat	8,932	Corn	13,113	Wheat	4,468
Tomatoes	6,350	Rice	4,395	Alfalfa	3,398
Southern California		**Coastal**			
Cotton	33,163	Beans	107,659		
Wheat	18,540	Wheat	44,491		
Alfalfa	9,344	Corn	13,418		
Oat hay	9,304	Carrots	2,197		
Corn	9,072	Alfalfa	897		

Table 110: Cropping Schedule from field experiments of Hutmacher, Kaffka and Wright (2010-12)

Planting Date	Harvesting Date	Yield (t/ac)
23-May	20-Sep	41.42
23-May	9-Oct	40.76
13-Jun	12-Oct	37.28
13-Jun	31-Oct	34.09
2-Jul	1-Nov	29.73
2-Jul	21-Nov	26.54

Table 111: Minimum Price ($/ton) that is required to get a production of sweet sorghum equal to 50,000 tons/month (or 200,000 tons/year) for each production cycle in each county

Planting Date	Harvesting Date	Yield	PRICES 2013			
			Kern	Kings	Tulare	Fresno
1-May	15-Aug	20	[redacted]			$49.22
1-May	1-Sep	30	[redacted]			$32.81
15-May	15-Sep	40	$22.97	$23.02	$23.03	$24.07
15-May	1-Oct	40	$23.38	$23.56	$23.60	$24.48
15-Jun	15-Oct	35	$26.05	$26.08	$26.14	$27.29
15-Jun	1-Nov	35	$26.26	$26.54	$26.71	$27.78
1-Jul	15-Nov	30	$30.49	$30.66	$30.71	$32.14
1-Jul	1-Dec	25	$36.69	$36.80	$37.08	$38.69

Simulation Results. Case 3: Sugarcane (CANE)

In this report we also examined the impact of the introduction of sugarcane (CANE) in California agricultural systems as well as what the minimum economic conditions are for its introduction. For the CANE analysis we narrowed the geographical scope and focused in two small areas of the SCA region, Imperial Valley and Palo Verde (Figure 72). Sugarcane is a tropical grass and cannot tolerate even moderately cold temperatures found in the Central Valley of California, especially winters with significant periods of below freezing temperatures that occur stochastically in the Central Valley. As with the other crop analyses, we determined the crops account for 95 percent of the crop frequency of those areas. Those crops that fit this criterion were established as the cropping pattern of Imperial Valley and Palo Verde (Table 112).

As with the previous analyses, we used a simulation approach to determine the minimum price range that is required for CANE to be adopted in both Imperial Valley and Palo Verde. Sugarcane is moderately long-lived perennial under Imperial Valley conditions, so we assumed a perennial cycle of production; that is, we assumed that the crop would be present in the field year-round. To simulate the effect of changing prices, we used a set of prices that began at $30/ton as harvested, which was increased iteratively by $0.5/ton until the price variable reached a maximum of $100/ton. Hence, we were able to determine that the minimum price range (in 2013 dollars per ton) at which the region would dedicate between 10,000 and 60,000 acres to the production of CANE are: $44.43 - $48.93 for Imperial Valley and $46.99 - $62.46, for Palo Verde Valley (Table 113). Thus we found that CANE is more likely to be adopted in Imperial Valley than in Palo Verde Valley and therefore we determined that there is an ascendant price differential to the detriment of Palo Verde Valley which goes from 5% at the lowest level of adoption (i.e. 10,000 acres) to approximately 28% at the highest level of adoption (i.e. 60,000 acres), an amount similar to what has been reported by California Ethanol and Power as their acreage target.

Table 112: Observed Cropping Pattern in Imperial Valley and Palo Verde Valley measured in acres (1997-2007 data).

Crops	Imperial	Palo Verde
Alfalfa	184,326.33	61,860.91
Bermudagrass	53,026.94	3,143.13
Broccoli	33,765.14	4,041.16
Carrots	38,096.20	
Corn	21,826.24	2,590.49
Cotton	10,457.22	35,196.13
Lettuce	63,056.76	6,735.27
Onion	54,024.23	
Sugarbeet	25,000.00	
Sudangrass	12,907.69	
Wheat	83,344.34	10,154.72

In table 114 we can examine the crop displacement effect in both Imperial Valley and Palo Verde. We found that in both locations the most affected crops are cotton, Bermuda grass, and alfalfa. Therefore, at adoption levels of 50,000 and 60,000 acres, cotton is totally displaced from the agriculture system of these two locations (i.e. reduction of approximately 10,000 acres in Imperial Valley and 35,000 acres in Palo Verde). On the other hand in the case of Bermuda grass, in Imperial Valley the acreage is reduced by 15,000 (19,000) acres approximately when the adoption of CANE is equal to 50,000 (60,000) acres; while in Palo Verde the acreage reduction of Bermuda grass is between 2,000 and 3,000 acres when the adoption of CANE is either 50,000 or 60,000 acres respectively. In the case of alfalfa, the acreage is reduced in 41,000 acres (50,000 acres) approximately in Imperial Valley when the adoption of CANE is equal to 50,000 acres

(60,000 acres) while in Palo Verde the acreage reduction is very close to it; that is, 42,000 acres (56,000 acres) when the adoption of CANE is equal to 50,000 acres (60,000 acres).

Table 113: Entry prices for sugarcane in the Imperial Valley and Palo Verde Valley at different adoption levels (i.e. number of acres) measured in dollars per ton.

Number of Acres	Imperial Valley	Palo Verde
10,000	44.43	46.99
20,000	45.43	49.7
50,000	47.93	58.87
60,000	48.93	62.46

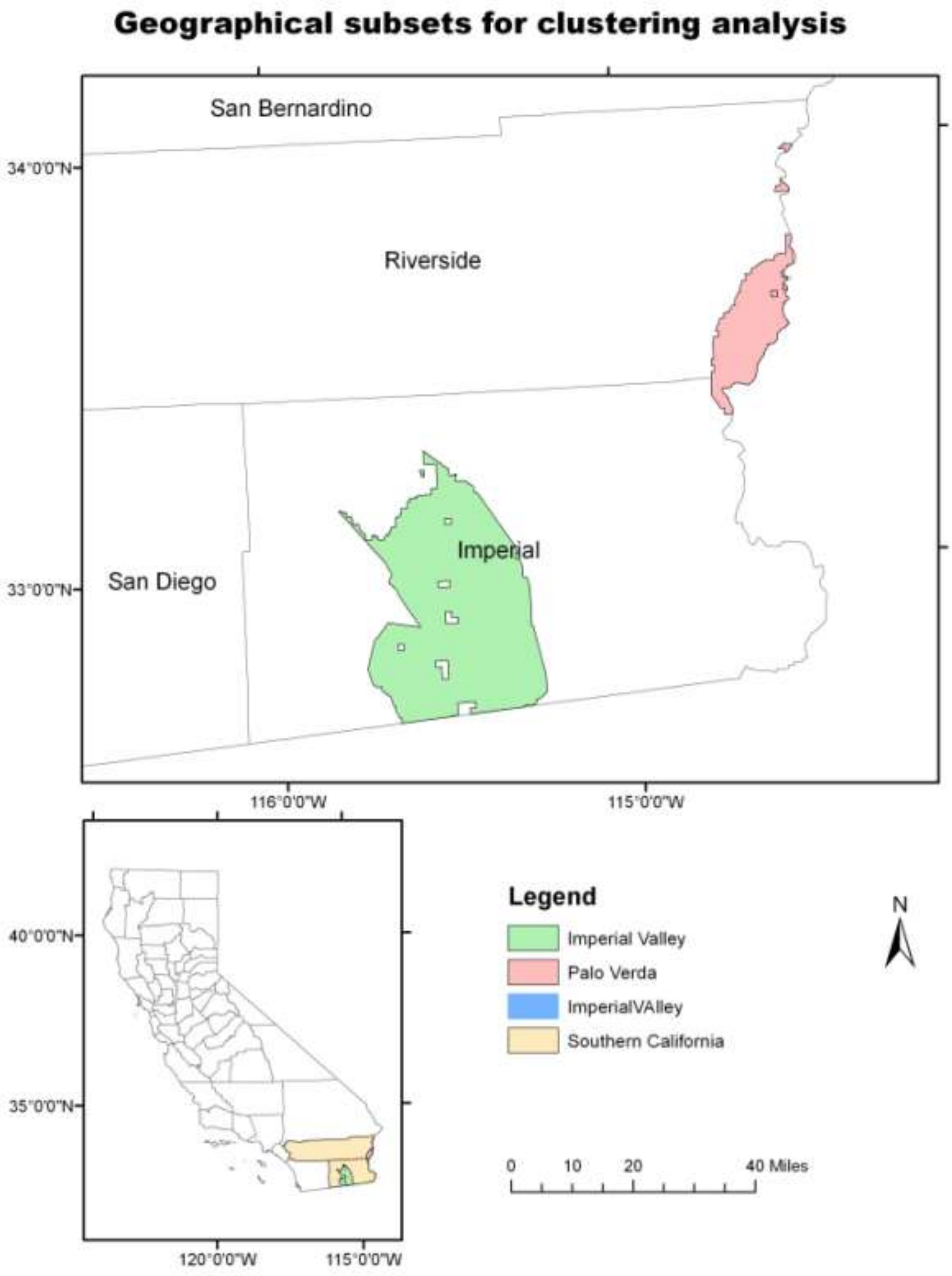
Table 114: Crop displacement in the Imperial Valley and Palo Verde Valley because of introduction of 50,000 and 60,000 acres of sugarcane.

Crops	Imperial Valley		Palo Verde	
	50,000 Ac	60,000 Ac	50,000 Ac	60,000 Ac
Alfalfa	41,682	52,012	42,436	56,606
Bermudagrass	16,209	20,274	2,247	2,951
Cotton	10,457	10,457	35,196	35,196

We also found that some crops would be benefited by the introduction of CANE in the agriculture system of Imperial Valley and Palo Verde. This is more noticeable for the latter where wheat increases in average 25,000 acres for the two level of adoption (i.e. 50,000 and 60,000 acres) while corn increases approximately 6,000 acres for both levels. On the other hand for Imperial Valley wheat is also expected to increase its acreage by approximately 25,000 acres in average for the two highest levels of adoption while sugarbeets are expected to increase in 2,500 acres in average.

Thus, we conclude that the adoption of CANE is more feasible in Imperial Valley than in Palo Verde, because in the latter there is a strong effect of acreage redistribution to some incumbent crops (i.e. wheat and corn) instead of a pure adoption effect of CANE as happens in the former.

Figure 72: Southern California subsets of the Imperial Valley and Palo Verda Valley.



Simulation Results. Case 4: Camelina (CAME)

Finally we also analyzed the effect of the introduction of camelina along all the California agricultural system, specifically as in the previous cases we determined 1) the entry price in each of the five California regions, and 2) which incumbent crops are affected by this introduction.

It is important to emphasize that for our simulation analysis for CAME, we assume only one production cycle that goes from November to May To simulate the effect of changing prices, we used a set of prices that began at $100/ton, which was increased iteratively by $10/ton until the price variable reached a maximum of $1,000/ton. Yields were assumed (conservatively) to average 1 ton/ac of seed at 38% oil.

Using the BCAM simulation framework, we determined the entry price range for each region, which is defined as the minimum price range in which the crop (in this case CAME) begins to appear in the agriculture system of those five regions. In this study, more specifically, the entry price range was defined as the minimum range price at which it is expected that the region will dedicate between 5,000 and 100,000 acres to the production of CAME. Thus, the entry price ranges for 2013 in dollars per ton were determined as follows: SAC $573.12 - $638.42, NSJ $789.74 - $828.90, SSJ $577.91-$809.56, SCA $358.92-$834.04 and COA $614.84-$789.55 (Table 115). We found that there is a clear advantage of the SAC region for the adoption of CAME reflected in a lower price range than in the other regions. On the other hand, the SCA region shows the highest price for the adoption of this crop in the upper range (i.e. 50,000 and 100,000 acres) while the NSJ region shows a range price consistently above $570/ton for each acreage level. The prices showed in Table 115. are high in comparison with those of canola; in addition the fact that the oil content of camelina is lower than that of canola (38% for the former against 45% for the latter), makes the former an even more expensive crop.

Table 115: Regional entry prices for camelina at different adoption levels (i.e. number of acres) measured in dollars per ton.

Number of Acres	Sacramento Valley	Northern San Joaquin Valley	Southern San Joaquin Valley	Southern California	Coastal
5,000	$573.12	$789.74	$577.91	$358.92	$614.84
25,000	$590.10	$797.98	$604.68	$558.96	$591.75
50,000	$603.81	$808.29	$631.70	$808.95	$612.50
100,000	$638.42	$828.90	$809.56	$834.04	$789.55

When we analyzed the crop displacement effect because of the introduction of CAME in the five different regions we found a lot of heterogeneity in the displacement effect as in the case of CANO. Hence we determined that because of the introduction of CAME in the system (in a level of 100,000 acres) corn is displaced in approximately 32,000 acres in SCA while wheat and oat hay are displaced on approximately 23,000 and 19,000 acres respectively (Table 116). On the other hand, cotton is the most displaced crop in NSJ, SSJ and SCA region with an approximate reduction of 129,000; 46,000 and 31,000 acres respectively. It is important to emphasize that barley is completely displaced in the NSJ region as is oat hay in the SCA region. Also, as in the case of CANO, the most affected zone is COA where barley is displaced from 144,000 acres, bean from 62,000 acres and corn from 36,000 acres. In addition, as in the case of CANO, we also found an increase in the acreage of wheat (172,000 acres) in the COA agricultural system because of the introduction of CAME. This positive effect is also observed in the NSJ region where four crops increase their acreage; they are corn with 62,000 acres, rice with 17,000 acres, and alfalfa with 8,000 acres and tomatoes with 3,000 acres approximately. These positive effects provide more evidence that the effects of the introduction of a new feedstock crop are not straightforward and need to be analyzed mathematically by simulation models like the BCAM instead of being assumed to a simple case of food vs fuel.

Table 116: Crop displacement in the five California regions because of introduction of 100,000 acres of camelina.

Sacramento Valley		**Northern San Joaquin Valley**		**Southern San Joaquin**	
Corn	32,548	Cotton	129,566	Cotton	46,946
Wheat	23,525	Oat hay	25,434	Wheat	15,092
Oat hay	19,921	Wheat	22,680	Alfalfa	12,141
Beans	8,015	Barley	10,080	Corn	10,119
Safflower	5,463	Bean	3,510	Oat hay	6,051
Southern California		**Coastal**			
Cotton	31,280	Barley	144,113		
Wheat	19,518	Bean	62,053		
Alfalfa	16,106	Corn	36,567		
Corn	11,503	Oat hay	13,450		
Bermudagrass	9,542	Alfalfa	8,153		

2.6 Potential of Energy Crops for Biofuel Production in California

2.6.1 Conversion Systems (Technology)- Biochemical Pathways

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 green 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 and 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 in Table 117.

Table 117: 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 are valuable livestock feeds and can be further converted into other products, including, in some cases, biopesticides.

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 73, 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. Transesterfication reaction is reversible and carried out with either strong base or acid catalyst at modest (low temperature and pressure) conditions. At an industrial scale, sodium hydroxide or potassium hydroxide is the catalyst most used because of the 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 transesterfication reaction, which results in high yields (~95% of fatty acid methyl esters. However, excessive methanol also affects subsequent separation of methanol from glycerol (Figure 73).

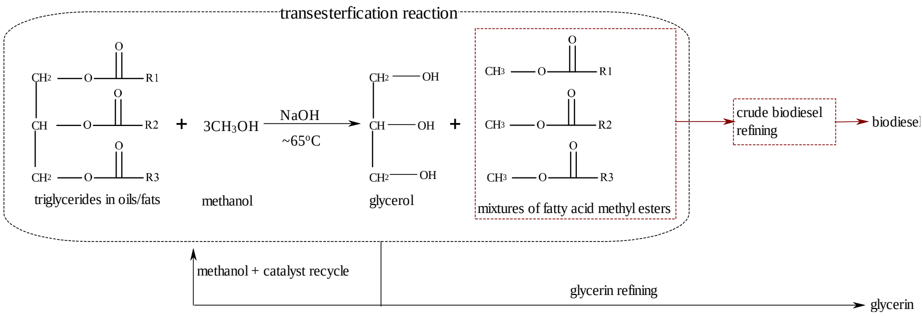
Overall, the FAME process is a relatively simple technique and has modest capital costs, which allows for small production units to be built without excessive extra costs. Smaller units can be located nearer to sources, with potential savings from reduced feedstock transportation and other related logistical 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 properties since the structures of fatty acids including unsaturated carbon-carbon bonds and oxygen content remain unchanged. Therefore, the properties of biodiesel 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. However, the compositional difference between these three oils resulted in the corresponding qualities of biodiesel as the fatty acid profiles in the oils transfer to biodiesels. 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 oxidation stability and higher cold soak filtration (223 s) versus 113 s of canola biodiesel (Sanford, 2009). Overall, camelina biodiesel 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) and greater fatty acids (carbon chain equal to or longer than 20), the meadowfoam biodiesel is featured with 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, as well as reducing the high kinematic viscosity of meadowfoam biodiesel to meet the requirement of ASTM D6751[11] and EN 14214[12] (Moser et al., 2010). Therefore, meadowfoam biodiesel might be more valuable to be blending into soybean biodiesel via FAME.

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

[12] 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.

Figure 73: 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.

Renewable Diesel and Biojet Fuels from Vegetable Oils

Instead of the esters that comprise biodiesel, renewable diesel or jet fuels can be made by hydrogenation and deoxygenation of vegetable oils, resulting in hydrocarbons that can be added to petroleum-based fuels with mostly similar properties. Low-cost H_2 is needed to produce biodiesel esters. H_2 is commonly available at petroleum refineries and Nestle Oil, Inc. and others have created such facilities in Europe and Indonesia. In California, both Crimson Industries and Alt Air, Inc., have investigated or proposed using this pathway.

The process for renewable diesel production includes hydrogenation and deoxygenation of vegetable oils and animal fats, which is similar to those in a petroleum refinery. The catalysts usually include metals, such as nickel or platinum, and the base material, such as carbon, alumina, and zeolite (Snåre, 2007). Generally speaking, the most effective catalyst is comprised of very costly metal, such as platinum. The choice of an effective but less costly catalyst, such as Raney nickel, for hydrogenation and deoxygenation, is very critical for the optimization of the process (Munoz, 2012; Horáček, 2013). The deoxygenation results in an increase of energy content. Because hydrogenation eliminates carbon-carbon double bonds, the fuel cetane number is improved. When the hydrogenation is controlled, as partial or full hydrogenation with deoxygenation, the melting point is modified for good low temperature properties of the resources for hydrogenation; the techno-economic analysis for hydrogenation-derived renewable diesel from canola and camelina showed little economic benefit for larger plants than 5,000 bbl/day (Miller, 2012).

There is interest in making biojet fuels from vegetable oils as well, which require decarboxylation of free fatty acids followed by catalytically isomerization/cracking to make n-alkanes with C chain lengths of C10-C14 in order to achieve the required chemical and physical properties of biojet fuels. Besides biodiesel and biojet fuels produced via this process, low chain length alkanes could be used for the production of biogasoline (primarily hexane and its isomers).

Sugars to Ethanol

Biofuel and biochemical production from agricultural crops are based on the production of the monomeric sugars from biomass. Sweet sorghum and sugarcane store in their stems soluble carbohydrates produced from photosynthesis primarily as six-carbon sugars and, in the case of sweet sorghum, additional five-carbon sugars. These are removed by crushing and expressing plant juices, which are either purified and crystalized as sugar, or fermented using years to ethanol. These crops also accumulate large amounts of lignified cellulosic biomass as stems and leaves. Converting lignified cellulosic compounds to simple sugars requires additional treatments. Both C6 and C5 sugars can be derived from lignified crop residues by decomposing cellulose. Depending on the conversion technology used, different mixes of C5 and C6 sugars of varying purity can be produced.

Traditionally, sugarcane residues (bagasse) have been burned at sugar or ethanol refineries for power. Waste heat has not been captured for other uses. More recently, there have been efforts in Brazil, where most sugarcane is produced, to use residual bagasse for ethanol or biochemical production as well, including capturing some waste heat for biorefinery uses (Alvira et al., 2010). California Ethanol and Power[13] has proposed building a modern biorefinery in the Imperial Valley based on this technology using bagasse to produce steam and electricity along with the fermentation of the extracted juice to ethanol.

Based on the sugar content of the juice alone, energy budget analysis under sub-tropical Hawaiian conditions suggested that an energy input : output ration of 1 : 3 is attainable for ethanol from commercially produced sugarcane sugar (Ming et al., 2006). In Brazil's highly developed sugarcane/ethanol economy, the analogous input : output ratio is 1 : 9 (Macedo, 2000; Ming et al., 2006). In contrast, maize fermentation to ethanol exhibits a ratio below about 1 : 1.5, and is often less (U.S. DOE, 2007), though efficiency has been increasing and the use of maize results in large amounts of high quality animal feed by-products and oil that is made into biodiesel. Inclusion of lignocellulosic materials will increase this energy efficiency substantially.

Energy cane would be used primarily for cellulosic conversions and cellulosic biofuels[14]. Canergy, Inc. has proposed an energy facility in the Imperial Valley based on the Proesa ™

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[13] http://www.californiaethanolpower.com/

[14] Based on Keffer et al., (2009) and Waclawovsky et al, (2010), the potential yields of lignocellulosic fuel ethanol from energy can can be estimated.

Eq. (1) $1 \text{ metric ton hectare}^{-1} = 0.45 \text{ ton acre}^{-1}$

Eq. (2) m^3 EtOH = (ton cane)

× {(0.14 ton raw sugar/ton cane) [(0.96 ton fermentable sugar/t raw sugar)

+ (0.276 t molasses/ton raw sugar) (0.482 t fermentable sugar/ ton molasses)]

× (0.588 m^3 EtOH/ton fermentable sugar) +

[(0.3 ton stalk fiber– 0.14 t sugar) / ton cane

+ (0.65 ton trash fiber/ ton stalk fiber) (0.3 ton stalk fiber/ ton cane)] technology discussed below[15]. Assuming that 14% of stalk biomass is sugar and 70% of fresh cane is water, and that yields in the Imperial Valley of 45 t/ac at 70% moisture and 12-14% Brix may be sustainable with suitable agronomic practices, a yield about 9 m^3 of EtOH/ha, or 962 gallons of EtOH/ac, appears feasible in California.

Lignocellulosic technology is not yet commercial, and the end-product, EtOH, may change to (e.g.) butanol, as the broader liquid transport issues are more fully considered, but several technologies are in development in California and elsewhere (Lynd et al., 2008). Candidate technologies for production of advanced biofuels in California include deconstruction using thermophilic bacteria (maximum growth temperatures of ~70˚C (158˚F)) (Cann, 2010). Alternative technologies include chemical deconstruction by hydrodeoxygenation (dehydration-hydrogenation) processes (Ellman, 2010). Molecular genetic modification of the energy cane itself may facilitate commercialization of these approaches. Combinations of these approaches (Ferreira-Leitão et al., 2010; Yang and Wyman, 2006, 2008; Chu, 2010) will ultimately lead to the utilization of sustainably produced lignocellulosic biomass from energy cane and other regionally appropriate feedstocks.

Celluosic Crops and Residues to Ethanol and Other Fuels

The Proesa™ technology is now being used for second-generation (cellulosic) ethanol at an industrial scale. The first commercial scale facility is operating in Cresentino, Italy, based on wheat straw and some perennial grass hay[16]. Canergy, Inc. LLC, and Imperial Valley-based company, may adopt this technology. It differs from the first generation technology used for Brazilian sugarcane. It relies on cellulosic biomass or agricultural residues as feedstocks. First, the cellulosic biomass is treated by steam and water in order to reduce subsequent chemical costs and minimize sugar degradation products in the raw biomass, which could decrease overall sugar recovery and cause inhibition in the subsequent hydrolysis and fermentation stages. Steam and water pretreatments are optimized for the overall sugar recovery. The core technology of the Proesa™ process is hybrid hydrolysis and fermentation with an engineered microbial strain that converts both C5 and C6 sugars to ethanol with a high final concentration. This technology is an example of consolidated processing, similar to the concept of Consolidated Bioprocessing (CBP) (Lynd, 1996, 2005). Compared to NREL's multi-step cellulosic ethanol production system (Humbird, 2011), a solid-liquid separations step after pretreatment was removed in the CBP system and separate fermentation steps for C5 and C6 sugar were replaced with co-fermentation (hybrid fermentation) of both C5 and C6 sugars. This simplification effectively reduces both capital and operational costs, as shown in Fig. 75.

× (0.292 m3 EtOH/ton fiber)}

The first term in Eq. (2) gives ethanol (EtOH) from sugar, the second term gives EtOH from molasses, and the third term gives cellulosic ethanol from the remaining biomass (bagasse, field trash, attached leaves, etc).

15 http://www.canergyus.com/

16 http://www.biofuelsdigest.com/bdigest/2013/06/11/beta-renewables-begins-shipping-cellulosic-biofuels/

Figure 74: Proesa^{TM} technology (Rubino, 2012).

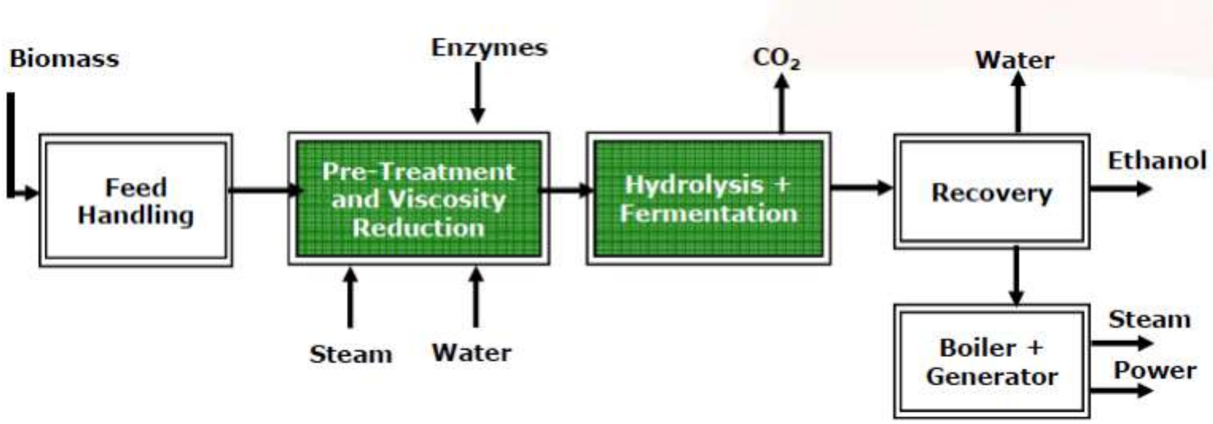
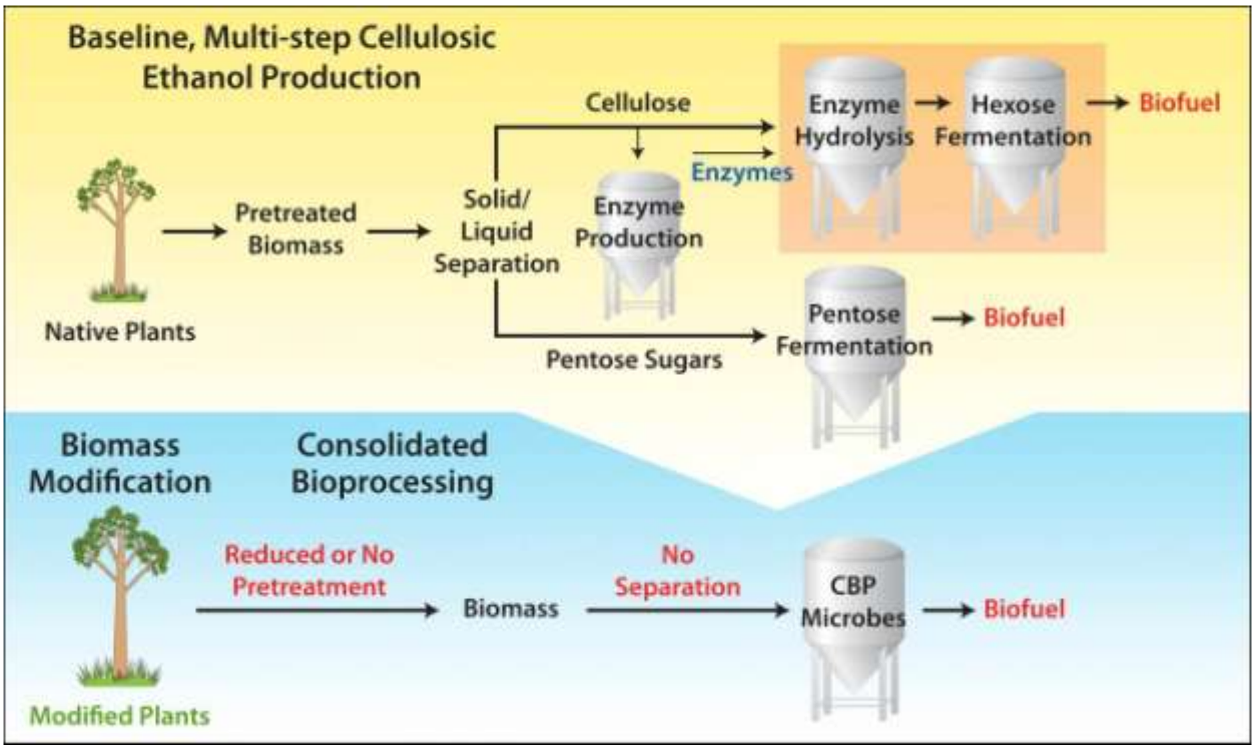


Figure 75: Consolidated bioprocessing next generation biofuel process (BESC).



2.6.2 Winter Annual Oilseeds, Sweet Sorghum and Sugar and Energy Canes

Biofuel and biochemical production from agricultural crops is based on the production of monomeric sugars from biomass. Sweet sorghum and sugarcane store carbohydrates produced from photosynthesis primarily as six-carbon sugars and in the case of sweet sorghum, additional five-carbon sugars. These are primarily soluble and removed from crushing and expressing plant juices. They also accumulate large amounts of lignified cellulosic biomass as stems and leaves. Converting lignified cellulosic compounds to simple sugars requires additional treatments. Both C6 and C5 sugars are derived from crop residues. Depending on the conversion technology used, different mixes of C5 and C6 sugars of varying purity can be produced.

Traditionally, sugarcane residues (bagasse) have been burned at sugar or ethanol refineries for power. Waste heat has not been captured for other uses. More recently, there have been efforts in Brazil, where most sugarcane is produced, to use residual bagasse for ethanol or biochemical production as well (Alvira et al., 2010).

Sugarcane Conversion

Based on sugar content of the juice, alone, energy budget analysis under sub-tropical Hawaiian conditions (Ming et al., 2006) suggested that an energy input : output ratio of 1 : 3 is attainable for ethanol from commercially produced sugarcane sugar. In Brazil's highly developed sugarcane/ethanol economy, the analogous input : output ratio is 1 : 9 (Macedo, 2000; Ming et al., 2006). In contrast, maize fermentation to ethanol exhibits a ratio below about 1 : 1.5, and is often less (U.S. DOE, 2007). Inclusion of lignocellulosic material will increase this substantially.

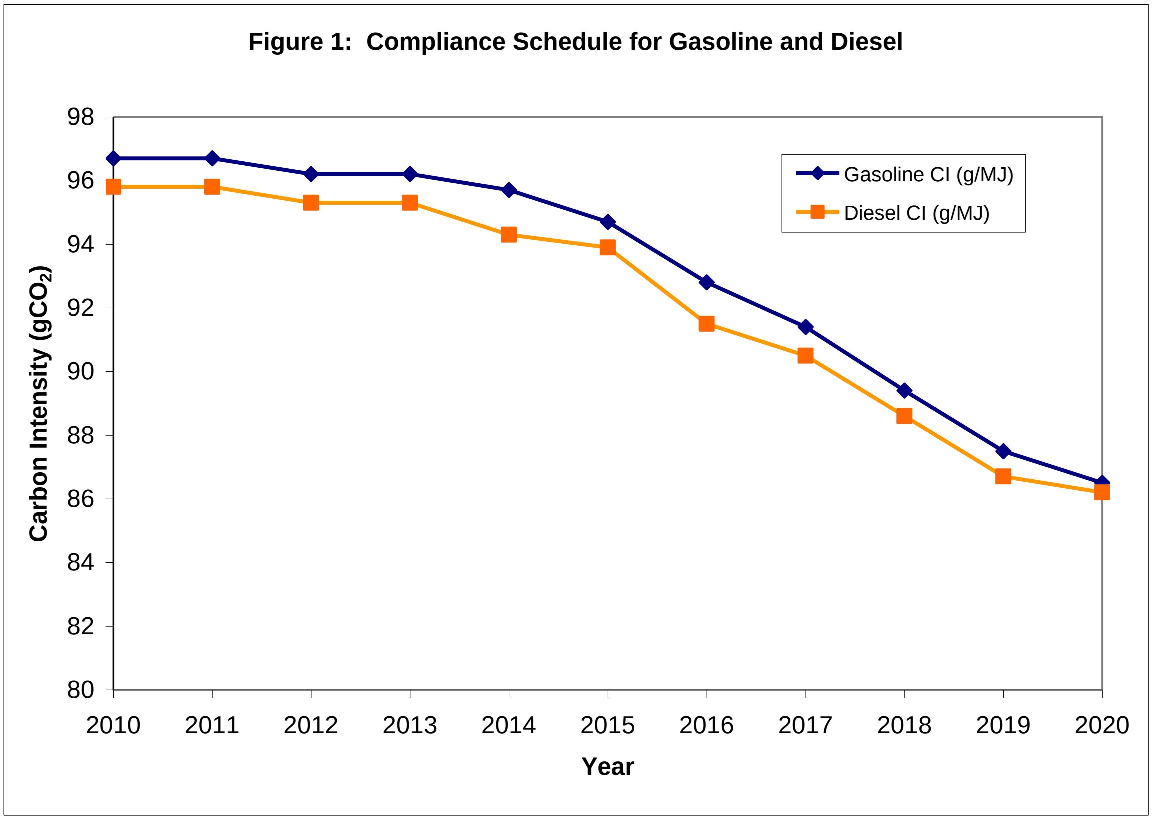
Calculations based on Keffer et al. (2009) and Waclawovsky et al. (2010) suggests the potential yields of lignocellulosic fuel ethanol from energy cane. Assuming that 14% of stalk biomass is sugar and 70% of fresh cane is water, and that yields in the Imperial Valley of 45 ton acre^{-1} at 70 % moisture and 12-14% Brix may be sustainable with suitable agronomic practices, a yield about 9 m^3 of EtOH ha^{-1}, or about 962 gallons of EtOH acre^{-1} appears feasible in California.

Lignocellulosic technology is not yet commercial, and the end-product, EtOH, may change to butanol, as the broader liquid transport issues are more fully considered. Several technologies are in development in California and elsewhere (Lynd et al., 2008). Candidate technologies for production of advanced biofuels in California include deconstruction using thermophilic bacteria (maximum growth temperatures of ~70°C; Cann, 2010). Alternative technologies include chemical deconstruction by hydrodeoxygenation (dehydration-hydrogenation) processes (Ellman, 2010). Molecular genetic modification of the energy cane itself may facilitate commercialization of these approaches. Combinations of these approaches (Ferreira-Leitão et al., 2010; Yang and Wyman, 2006, 2008; Chu, 2010) will ultimately lead to the utilization of sustainably produced lignocellulosic biomass from energy cane and other regionally appropriate feedstocks.

2.6.3 Alternative Fuel Demand and In-State Biofuel Production

California's Global Warming Solutions Act (2006; AB32) is an ambitious attempt to reduce society-wide carbon emissions within California, and also to provide a model for how to achieve such emission reductions elsewhere. As part of the AB32 act, the Low Carbon Fuel Standard (LCFS) provides a mechanism to incentivize the development and use of alternative vehicles and fuels to help reduce the large amount of carbon emissions associated with transportation in the state. This is achieved by gradually lowering the carbon intensity of transportation fuels, and through fuel type and vehicle substitution (vehicle electrification and increased mileage standards) (Fig. 76). Still, projections for fuel demand over the next decade leaves in place the need for significant quantities of alternative transportation fuels, including ones that might be derived from the purpose-grown agricultural feedstocks evaluated here (Table 3.6.2).

Figure 76: Compliance schedule for declining average fuel carbon intensity of gasoline and diesel sold in California.



In addition to the state's Low Carbon Fuel Standard, the federal Renewable Fuel Standard (RFS) requires the use of alternative fuels and mandates the amount and type of the fuels to be used. These mandates include demands for biodiesel fuels and advanced biofuels including sugarcane ethanol. Biodiesel qualifies under both its own mandate and as an advanced biofuel.

Both the LCFS and RFS require that alternative fuels release less C to the atmosphere per unit of energy used than conventional gasoline and diesel fuels. Since all liquid fuels release C, savings from biofuels are derived from the recycling of atmospheric C captured by plants through photosynthesis, compared to the release of fossil or geologically stored C from the use of fossil fuels like petroleum. The C savings from using biofuels in both regulatory programs are estimated through Life Cycle Assessment (LCA). LCA estimates the C costs of using biomass feedstocks and correlated fuel production and use. For the RFS, biodiesel and advanced biofuels must have 50% lower C emissions per unit energy than gasoline. The LCFS does not set a lower limit for C emissions, but instead sets a target for C emissions from gasoline and diesel (Fig. 76), and leaves it up to fuel providers, who are the regulated parties, to find fuels to blend with petroleum that reduce overall fuel CI. The effect is to favor the use of biofuels that have the lowest possible CI.

The US EPA and the California Air Resources board both use life cycle assessment methods to determine a fuel's carbon intensity. This alternative fuel CI is then compared to the CI of average petroleum derived gasoline and diesel. The methods used by each agency have areas of similarity but also differ. They differ chiefly in how they assess market effects on land use. This is referred to as Indirect Land Use Change (ILUC) and embodies the economic idea that diversion of farmland and crops for bioenergy production in the United States provokes increased land use elsewhere to meet national and global demand for those crops no longer served by the diverted crops. Such effects and associated CI values cannot be directly measured but are artifacts (estimates) from models. They are inferred by using complicated economic models of global trade and production. US EPA and the CARB use different models and come to different estimates for these values, but fuel providers in California must meet both sets of estimates to remain compliant with both federal and state regulations.

Because the models used operate at the national and world scale, they lack sufficient detail to accurately reflect the complex, exceedingly diverse character of California's agriculture. The BCAM model (Section 3.6.2) was created to more accurately reflect this complicated land use system and better estimate crop displacement and changes in farmland use. Estimates of total land and the individual crops displaced for the potential bioenergy crops evaluated here are provided in Tables 107 and 109. Crops like dry beans, cotton and Bermuda grass and Sudan grass hay are not included in the models used in California by CARB, and poorly characterized in the models used by US EPA. The fact that new crops are brought into production when crops are added in addition to the crop itself is not accounted, and the effects on fallow land or fallow periods during the multi-year operation of many of the state's complex cropping systems also is not accounted in state and federal modeling efforts. The consequences of common farming and crop rotation practice in California that aggressively supports new crop adoption for any purpose, and opportunities in the agricultural system for more efficient total resource use when new crops are adopted, are that in-state feedstock production is likely to have minimal to no market based effects. This should give in-state producers an opportunity to be lower CI feedstock producers, compared to others who rely on commodities and locations where international trade is the basis for their agricultural economy.

Table 118: Compliance schedule for declining average fuel carbon intensity of gasoline and diesel sold in California.

Year	CI of Gasoline	Vehicles (millions)		Conventional Corn EtOH (billion gal)	Loc CI Corn EtOH (billion gal)	Cellulosic EtOH (billion gal)	Advanced Renewable EtOH (billion gal)	Sugarcane EtOH (billion gal)	% Ethanol in Gasoline
		FFV's	PHEV						
2010	96.7	0	0	1.21	0	0	0	0	10
2011	96.7	0	0	1.21	0	0	0	0	10
2012	96.2	0	0	1.03	0.05	0.05	0.04	0.05	10
2013	96.2	0	0	1.03	0.05	0.05	0.04	0.05	10
2014	95.7	0	0	0.85	0.09	0.1	0.07	0.1	10
2015	94.7	0	0	0.52	0.12	0.22	0.12	0.23	10
2016	92.8	0.1	0.2	0.05	0.17	0.38	0.28	0.39	10.4
2017	91.4	0.3	0.6	0	0.19	0.42	0.31	0.44	11.3
2018	89.4	0.6	1.3	0	0.21	0.45	0.34	0.48	12.2
2019	87.5	0.9	1.9	0	0.23	0.51	0.38	0.53	13.9
2020	86.5	1.3	2.3	0	0.25	0.55	0.41	0.57	15

Direct life cycle assessment was not part of this analysis. The state's Air Resources Board (CARB, 2013) has evaluated both canola biodiesel and sugarcane ethanol from imported sources and provided fuel CIs for these. Camelina has not been assessed because there is little current supply. Canola oil made from North American sources is given a presumptive fuel CI of 62.99 gCO_{2eq} /MJ, compared to 94.71 gCO_{2eq} /MJ for conventional petroleum diesel and 83.25 gCO_{2eq} /MJ for biodiesel from soybean oil. Of this, an estimated 31 gCO_{2eq} /MJ is from ILUC related emissions, leaving 31.99 for farming related carbon costs, transportation of feedstocks, and biodiesel conversion. If canola is produced in largely fallow winter periods in California, with higher yields and with greater resource use efficiency than elsewhere in north America, and if new crops are added to farming systems due to canola's inclusion, then both the CI of farming related costs and ILUC values should be lower for in-state biodiesel production.

Shonnard et al., (2010) have provided an initial assessment of jet fuel and advanced biodiesel from camelina oil feedstocks produced in the prairie regions of the United States. They reported a value of 22.4 gCO_{2eq} /MJ for the farming related costs of camelina production and a FAME conversion pathway. Adding CARB's estimated ILUC value for canola to this estimate for camelina, provides a comparable estimate of 53.5 gCO_{2eq} /MJ. There is no current approved CARB determination, however, for this feedstock and pathway to date. Camelina is qualified for support under the federal Biomass Crop Adoption Program. This program subsidizes production of selected new feedstocks and biofuel pathways. To date, it has had little effect on the production of camelina in California.

CARB also has estimated the fuel CI for ethanol produced from sugarcane in Brazil. For mechanized harvests and efficient use of bagasse-derived electricity at the mill, the value from CARB is 58.6 gCO_{2eq} /MJ compared to 95.66 gCO_{2eq} /MJ for conventional petroleum-based gasoline. Of this value, 46 gCO_{2eq} /MJ is attributed to ILUC and only 12,4 gCO_{2eq} /MJ to feedstock production. If farming sugarcane in California has less ILUC, or even spares land from conversion in Brazil, in-state feedstock production could result in very low fuel CIs.

There are three larger scale ethanol production facilities operating in California, and thirteen smaller-scale biodiesel facilities[17]. The ethanol facilities use corn grain and more recently grain sorghum and each produce approximately 60 mgy. California's current fuel ethanol use is approximately 14.6 billion gal per year[18]. Nearly 10% of that amount is ethanol blended to increase fuel octane levels and to comply with LCFS, so demand for ethanol in the state is approximately 1.46 bgy, far in excess of that produced by the state's three significant facilities. The biodiesel facilities in California are smaller and vary in size considerably. They use waste grease and some vegetable oils and produce about 50 mgy collectively, though actual production is variable. Demand for biodiesel due to the LCFS and RFS is much larger. Diesel fuel use in California in 2012 was 2.65 bgy. Blended with 5% biodiesel, demand could be as large as 130 mgy, greater than in–state supplies. Higher blending rates are possible with current infrastructure and used in some instances and would further increase total demand. Currently,

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[17] http://biomass.ucdavis.edu/tools/

[18] http://www.boe.ca.gov/sptaxprog/reports/MVF_10_Year_Report.pdf

most biofuel used in California is imported, primarily from corn ethanol refineries in the mid-western United States and out-of-state biodiesel producers. Increasing amounts of sugarcane ethanol are being used as well, due to its estimated lower CI than corn ethanol according the California Air Resources Board[19]. There is sufficient demand to support in-state businesses, which would increase direct employment and investment in California, if economically competitive bioenergy businesses can be developed.

2.6.4 Ecological Considerations

All of the proposed bioenergy feedstock crops evaluated here are traditional in California or elsewhere in agricultural regions with sufficiently similar climates. In no case assessed in this analysis would land in California be converted from a more natural condition (less intensive management) to the more highly modified character of farmland. In general, after urbanization, the most significant ecological intervention in landscapes is the conversion from natural or low intensity management landscapes to ones suitable for intensive crop farming (Dale et al., 2013). Such conversion occurred in large areas of California during the late 19th and early 20th centuries, and has largely ceased since that time. There are approximately 10 million irrigated acres in farm use in California, out of a total of approximately 100 million acres of all landscape types.

A number of wildlife species inhabit managed landscapes, and some thrive in such landscapes. Altering annual crops produced in a given area of the state where a large range of crop species already are in production will not alter the character of the landscape with respect to wildlife or other relevant aspects of biodiversity for the most part. The introduction of perennial grasses into largely annual crop dominated landscapes may provide some features favorable to species benefitting from grassland type habitats where these are missing.

Stoms et al., 2011, used an earlier version of the BCAM model to estimate the potential effects on wildlife in California of a diverse set of potential biofuel feedstock crops. This analysis focused on canola, Bermuda grass (a salt-tolerant species used on marginal lands), and sugarbeets. Bermuda grass is somewhat analogous to sugarcane, also a perennial grass. Sugarcane, however, is a much larger crop growing up to several meters high compared to Bermuda grass, and would be grown in a limited part of the state compared to Bermuda grass' larger distribution, mostly the Imperial Valley. They evaluated large-scale landscape cropland conversion based on meeting a significant portion of biofuel demand from within the state. They reported that widespread canola production had the largest effects on wildlife, though these were marginal, and that Bermuda grass pastures or hay fields increased landscape and wildlife diversity. Based on the assumptions used and species considered, most wildlife species of concern were estimated to have modest losses in some locations offset by no-effects or gains in other areas. Stoms et al., 2011, note that precise evaluation for particular species is dependent on local assessment.

[19] http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf
http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/mixed-feedstock-bd-071312.pdf

In general, there are many positive aspects of crops as well as negative ones, and biofuel crops can help with environmental remediation in some instances, as well as making farming systems more economically resilient (Kaffka, 2009). One of the assumptions in the BCAM model is that overall water use on farms is limited to existing, longer-term irrigation district allocations and amounts of groundwater use that resulted in the cropping patterns observed in the state over the last 12 years, as discerned from the data collected by the Department of Pesticide Regulation. The consequence is that the crop shifting predicted by the BCAM model does not in general alter total farm water use, merely its allocation to diverse crops across the complex farming systems found in the state. The use of winter annual oilseed crops also has the potential to reduce modestly or allow for more economically efficient water use on farms due to their use and primary alliance on winter rainfall, rather than irrigation. In this, they substitute for lower-value summer crops that must be irrigated.

C4 grasses, like sugarcane and sweet sorghum, are reported to be efficient users of nutrients, especially fertilizer nitrogen, compared to many other crops. Camelina requires only modest fertilizer nitrogen levels and is an efficient water user. Canola requires more nitrogen but can also recover residual nitrogen left in shallow soil layers by previous summer crops.

Winter annual crops can act like cover crops by increasing infiltrations and slowing runoff. They are protective of soils and fields exposed to winter rainfall, reducing erosion under those conditions to the degree they substitute for bare fallow in winter. Reducing soil erosion also reduces sediment contaminant transport, such as pesticide residues and nutrients. Perennials, like sugarcane, have a similar potential to the degree they substitute for annual crops in crop rotations (Damodhara et al., 2012).

In evaluating economic effects of new crop adoption in this report, overall landscape changes and levels of crop adoption are likely to be tentative and modest. For the most part, either there will be limited or marginal effects due to crop shifting, or potential for positive environmental effects due to improved resource use efficiency. Improving overall farming system resource use efficiency is a significant way to protect nature while still carrying out necessary activities, like producing food, feed, fiver and fuels in a complimentary manner (de Wit, 1992).

CHAPTER 3: Summary and Conclusions

This report documents agronomic research and demonstration, economic analysis of potential bioenergy crop adoption, and transformation technologies for promising bioenergy feedstock crops that were identified by a Technical Advisory Committee as promising crop alternatives for California farmers. Prospects for new bioenergy businesses in California based on these crop feedstocks and potential environmental effects are discussed. Three winter annual oilseed crops: canola (*Brassica napus; B. juncea),* camelina (*Camelina sativa),* and meadowfoam (*Limnanthes alba*) were evaluated in research and demonstration trials over a four year period at several sites throughout California. Canola was always the highest yielding species among the winter annual oilseeds tested across all sites and years. Average yields and oil content across all trials were 2,500 lb of seed per acre and 43.5 % oil content. For the best performing varieties, yields greater than 3,000 lb per acre and oil contents greater than 45% were commonly observed. For camelina, seed yields were lower on average (approximately 1200 lb ac across years and sites), and oil content varied in the 36 to 38% range. Higher yields were observed in some years at all locations, but performance appears to be highly dependent on winter conditions and can be reduced by unusually cold temperatures during critical crop development stages. Because of its longer growing season and larger overall DM accumulation, canola uses more water, responds to larger amounts of nitrogen fertilizer, and has different effects on cropping systems in which it is included. 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, but it is unlikely to be of use in the cropping systems in California due to its very low and variable yields.

Sweet sorghum (*Sorghum bicolor* L. Moench) evaluation focused primarily on the San Joaquin Valley, where climate and soil conditions are most favorable for its production. For sweet sorghum to become the basis for an ethanol or other biofuel production system, it must be harvested over the longest period possible. Sorghums are reported to have an optimum soil temperature for emergence of 70˚F (21˚C) and a minimum soil temperature of 60˚F (15˚C). These temperatures occur in mid-to-late spring in the San Joaquin Valley, but earlier in the Imperial Valley. Alternatively, in locations like the Imperial Valley, it could supplement the use of sugarcane by extending the sugarcane harvest season. Stalk yields were quite high (25 to 44 t/ac FW) depending on irrigation, planting date and fertilization treatments, and stem sugar contents (Brix) occurred within an acceptable range for conversion to ethanol and similar to those commonly reported for sugarcane (11% to 14 %). Sweet sorghum is drought tolerant, but results reported here indicate that it accumulates the most sugar in stems under more complete irrigations treatments, compared to drought stressed ones. Lodging was observed every year in all varieties tested and will require specialized harvesting equipment similar to sugarcane to be available.

Evaluation of sugarcane (*Saccharum oficianarum*) and energy cane (*S. oficianarum x spontaneum*) focused on the Imperial Valley, and to a lesser degree, the eastern San Joaquin Valley. These areas have a year-round climate with sufficiently warm winter temperatures to sustain production of these tropical perennial grasses. A range of commercial sugarcane clones and Type II (low sugar) energy cane clones were evaluated at both locations, in part due to existing sugarcane and energy cane plant resources at the Kearney Agricultural Research Center in Parlier. Minimal nitrogen fertilizer was applied in our trials. Yields were adequate initially and decreased by the second rattoon in the commercial clones more severely than the Type II clones, suggesting their greater potential to exploit marginal environments with low inputs. Nitrogen requirements appear consistent with literature values of 100 lb nitrogen for the plant crop, incorporated in the spring after substantial growth, and somewhat more (150 lb N/acre) for the rattoon or subsequent crops. Further work with amount, timing and composition of nitrogen fertilizer may be able to reduce the greenhouse footprint of energy cane production. Water was applied at less than expected crop requirements, potentially reducing yields in these studies. Based on calculations, high yielding sugarcane will require about as much water as the current crop, alfalfa (about 6 – 6.5 acre feet/year). The yield potential of better sugarcane varieties, and particularly of very high yielding Type II energy canes in the Imperial Valley, appears to be excellent. Yields were also excellent in the San Joaquin Valley, but the trials were performed on the east side of the Valley where energy crops may not be economically viable.

In the case of all crops, either existing unmet demand exists (biodiesel producers for oilseeds), or early stage companies exist that have expressed interest in the feedstock crops analyzed here (sweet sorghum and sugarcane/energy cane). All three types of feedstocks are of interest to diverse groups or established companies currently seeking to expand their current in-state production of biofuels, or establish new biofuel/bioenergy businesses in California. For oilseeds, these include current biodiesel producers able to process virgin vegetable oils using either the FAME process or hydro-cracking to upgrade to green diesel of jet fuels. For sweet sorghum and sugarcane, new biorefineries would be required. In all cases, crop yields for the species evaluated are high enough and costs of production are competitive enough to suggest that farmers would produce these crops if new bioenergy businesses create sufficient in-state demand. The exception is meadowfoam, which produces high quality oils but which is too low yielding and variable to be of interest to growers.

All of the proposed bioenergy feedstock crops evaluated here are traditional in California or elsewhere in agricultural regions with sufficiently similar climates. In no case assessed in this analysis would land in California be converted from a more natural condition (less intensive management) to the more highly modified character of farmland. The adoption of these crops would not require new water resources, but instead cause farmers to adjust their complex cropping systems and existing water supplies to accommodate new crop enterprises. The effects of new crop adoption vary by crop and region and are discussed in the report. These include differences in crop substitution and locations where crops might be adopted. In general, oilseed crops have the largest potential for adoption in many areas of the state, while production of sweet sorghum is likely to be limited to the San Joaquin Valley and possibly the Imperial Valley in support of sugarcane production, while sugarcane is likely limited to the Imperial Valley due to climate requirements. The outcome of economic analyses based on the agronomic data gathered during this project suggests that overall landscape changes and levels of crop adoption are likely to be tentative and modest. For the most part, either there will be limited or marginal effects due to crop shifting, or potential for positive environmental effects due to improved resource use efficiency, or to the soil conserving effects of winter and perennial crops. Environmental effects from crop shifting associated with new crop adoption, therefore, are expected to be minimal if not marginally positive.

The technology needed to use these crops for energy purposes is well-known and already established within the state for oilseeds, or in other locations (sweet sorghum and sugarcane), and could be established here based on models for successful systems. The state's Low Carbon Fuel Standard and the federal Renewable Fuel Standard create demand for compliant alternative fuels. Formal life cycle analysis was not conducted as part of this analysis, but based on current reported standards it appears likely that alternative fuels produced from the feedstock crops analyzed here would meet the standards required by both regulations. The stability of both policies in their present form is essential to secure confidence that investments in expanding existing facilities, and especially in new types of biorefineries, are prudent. California's well-known high costs for regulatory compliance, and financial conditions affecting the cost and availability of capital all remain obstacles to the successful development of new bioenergy enterprises in the state. In general, however, there is potential for gradual, limited adoption of the energy feedstock crops evaluated in this analysis provided in-state demand is created by bioenergy production business located in California.

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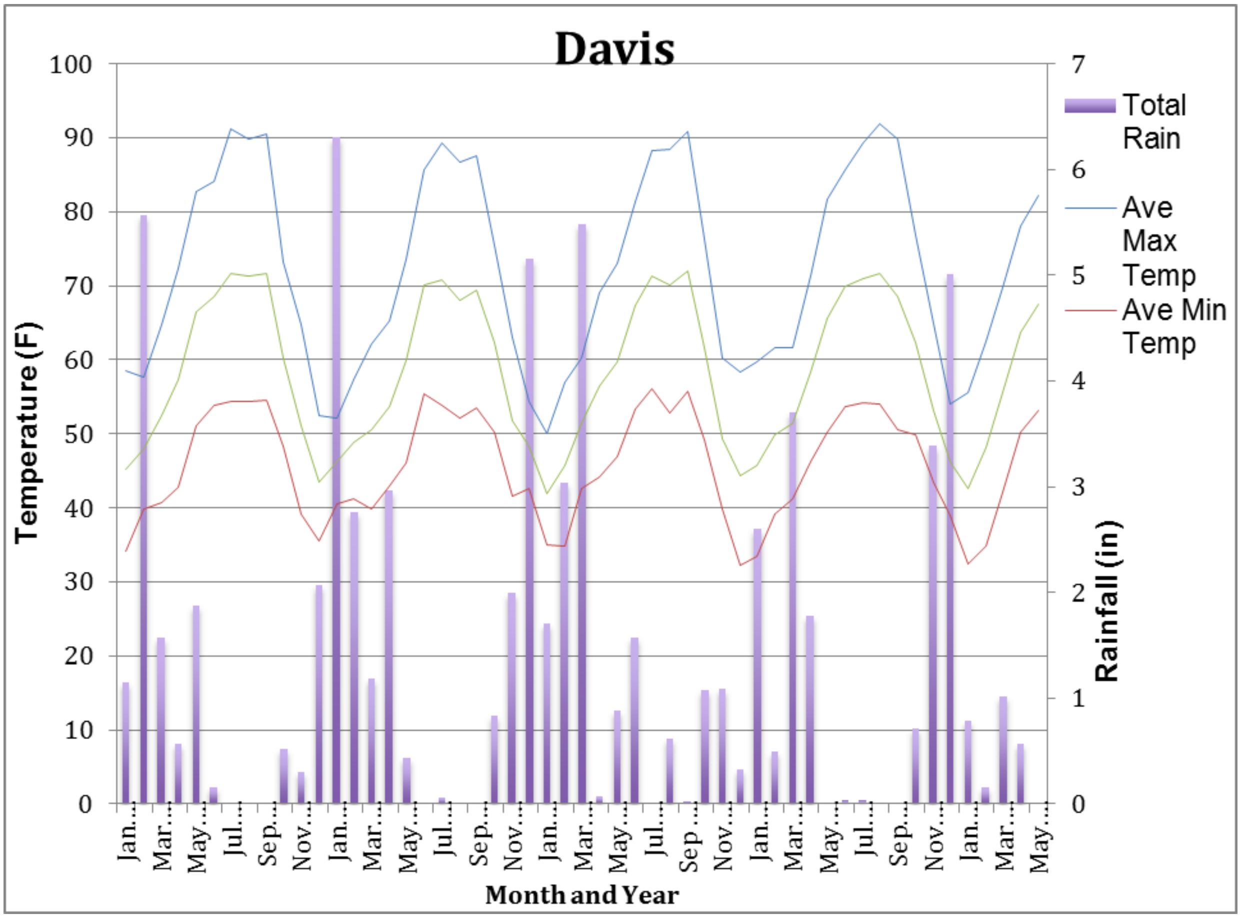
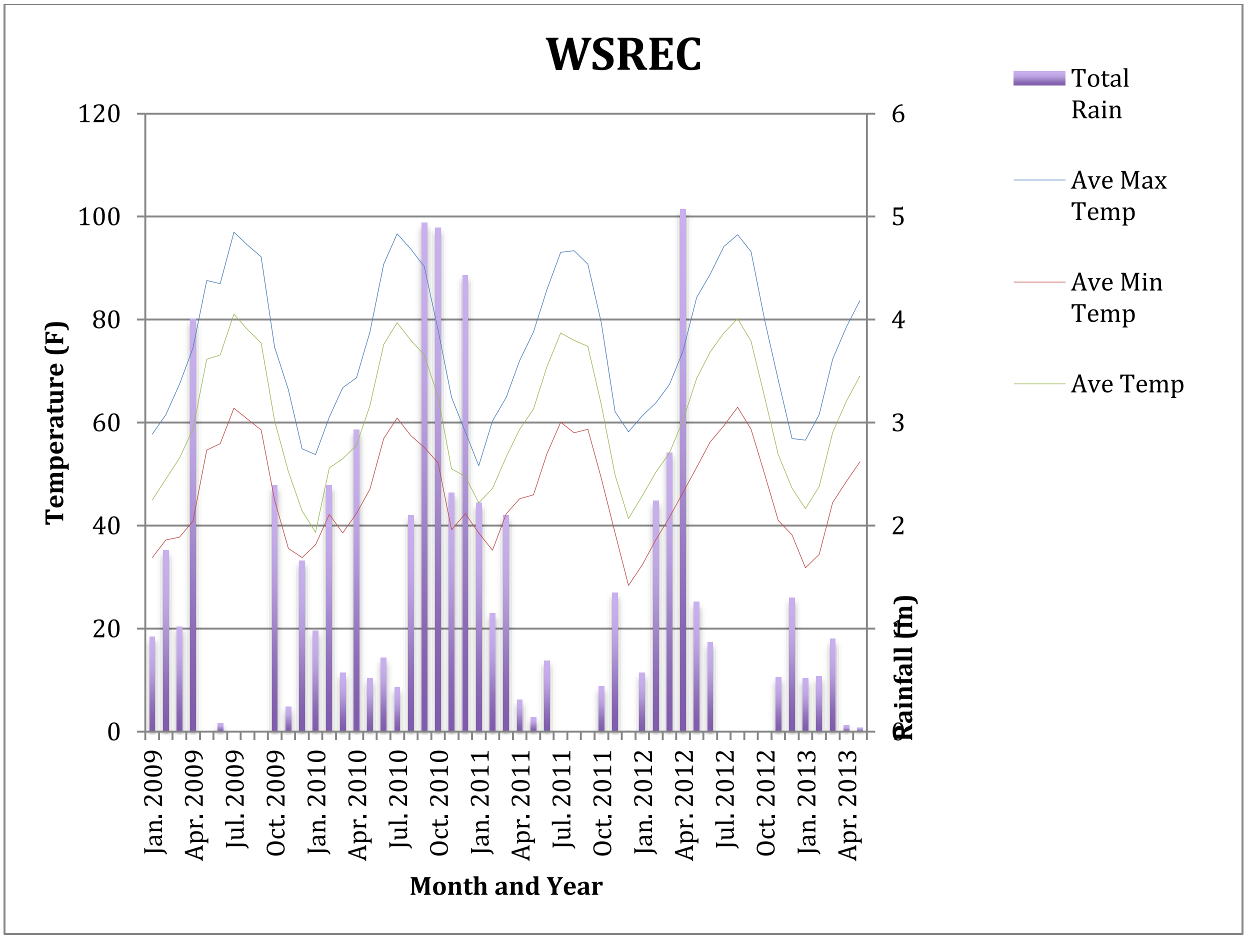
A. Appendix A: Weather Data

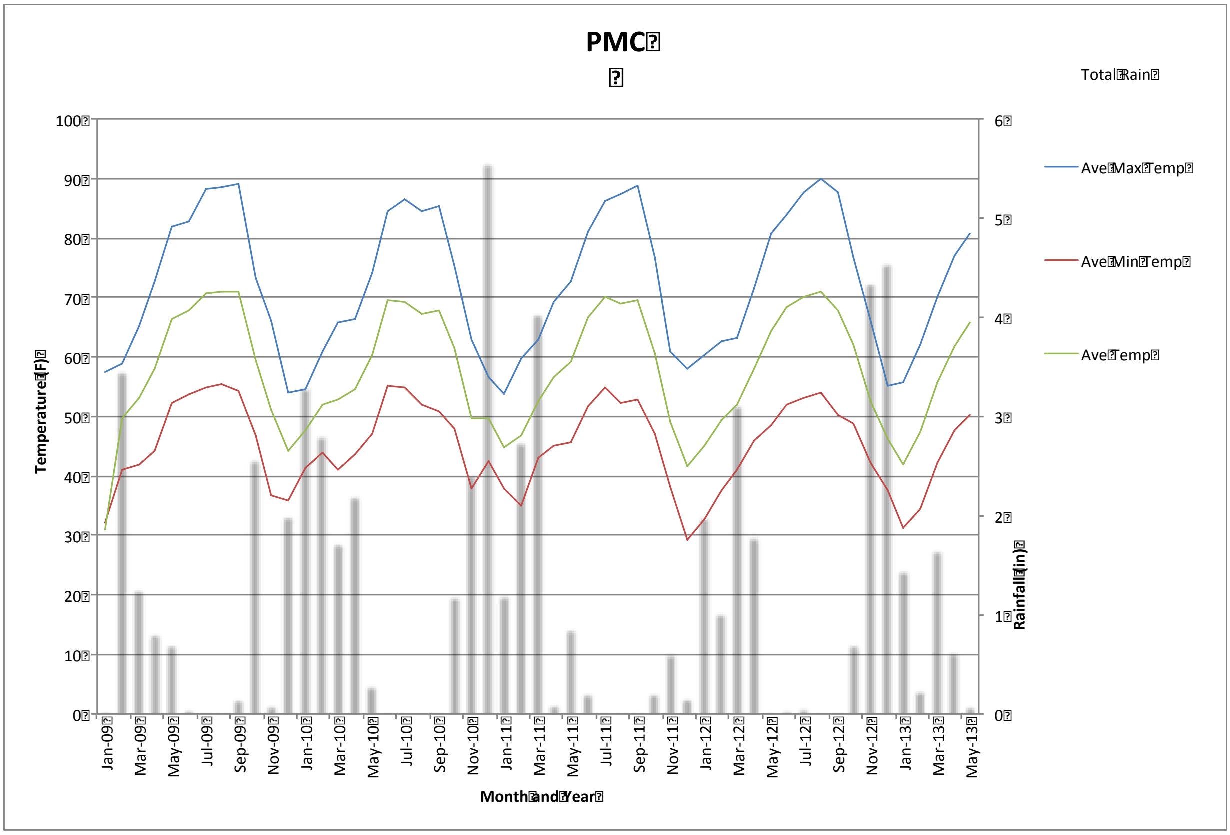
Weather data at the primary research sites during trial years.



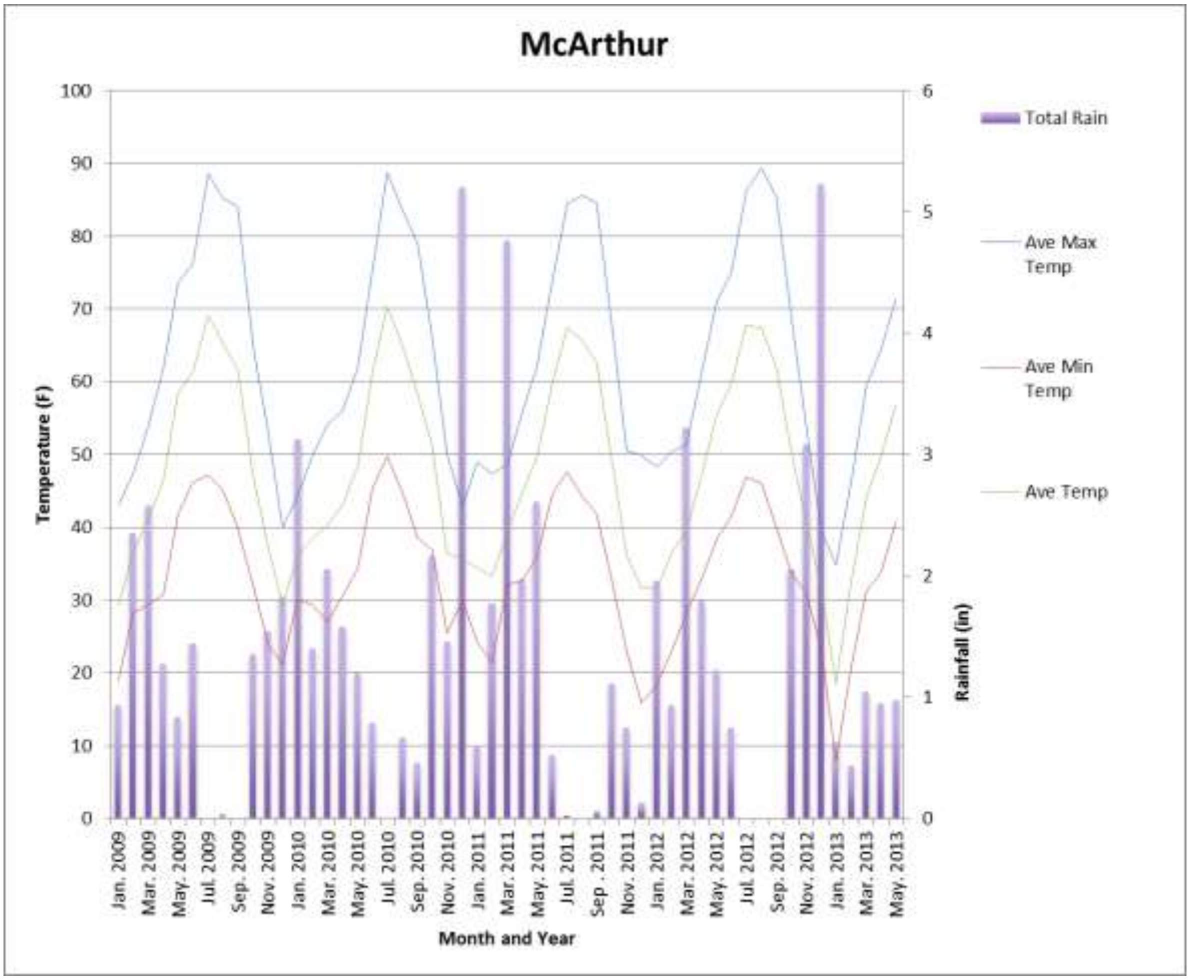
Average temperatures and rainfall in Davis from January 2009 through May 2013.



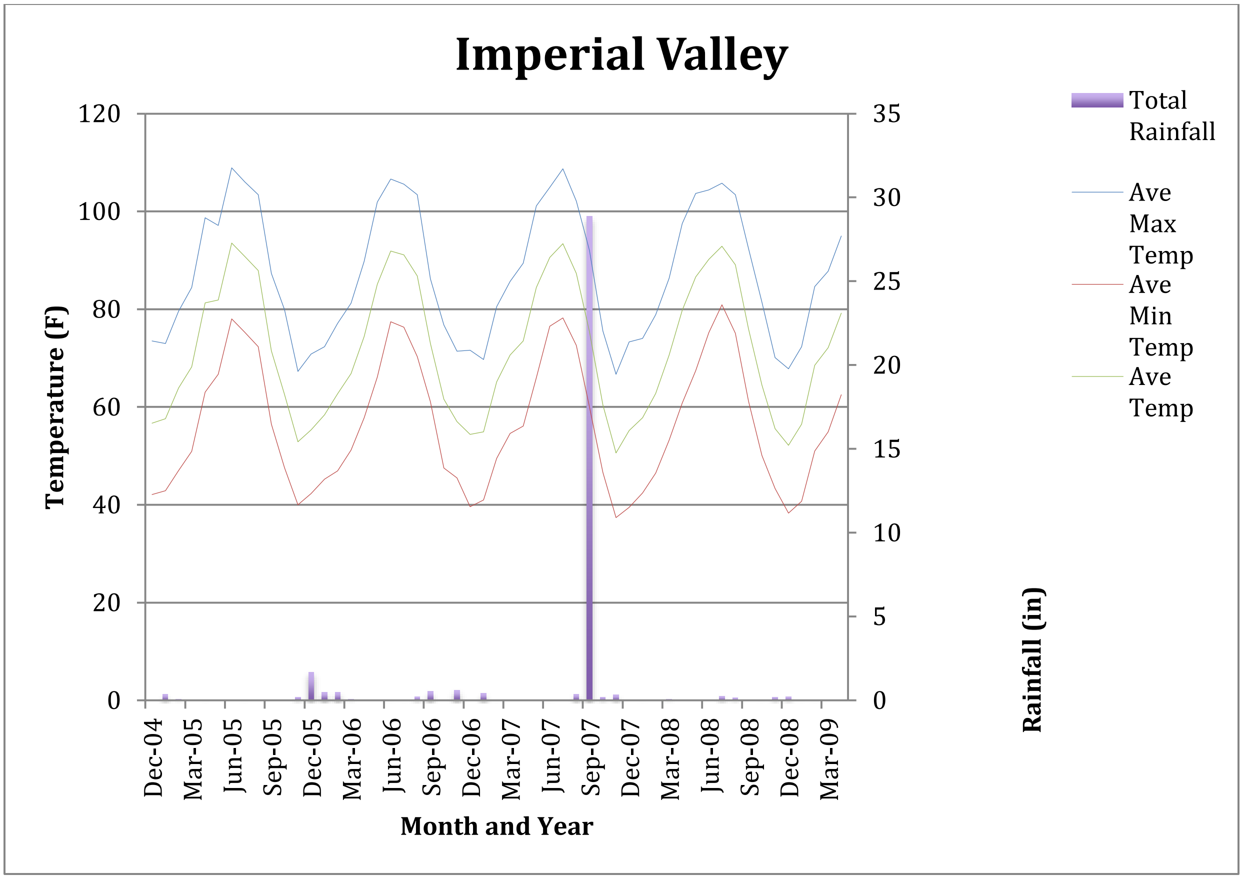
Average temperatures and rainfall at the Westside REC from January 2009 through May 2013.



Average temperatures and rainfall in Lockeford (PMC) from January 2009 through May 2013.



Average temperatures and rainfall in McArthur from January 2009 through May 2013.



Average temperatures and rainfall in the Imperial Valley between January 2009 and May 2013.

B. Appendix B: Canola pests and diseases

Flea beetles and cabbage worms

Green peach aphids and cabbage aphids

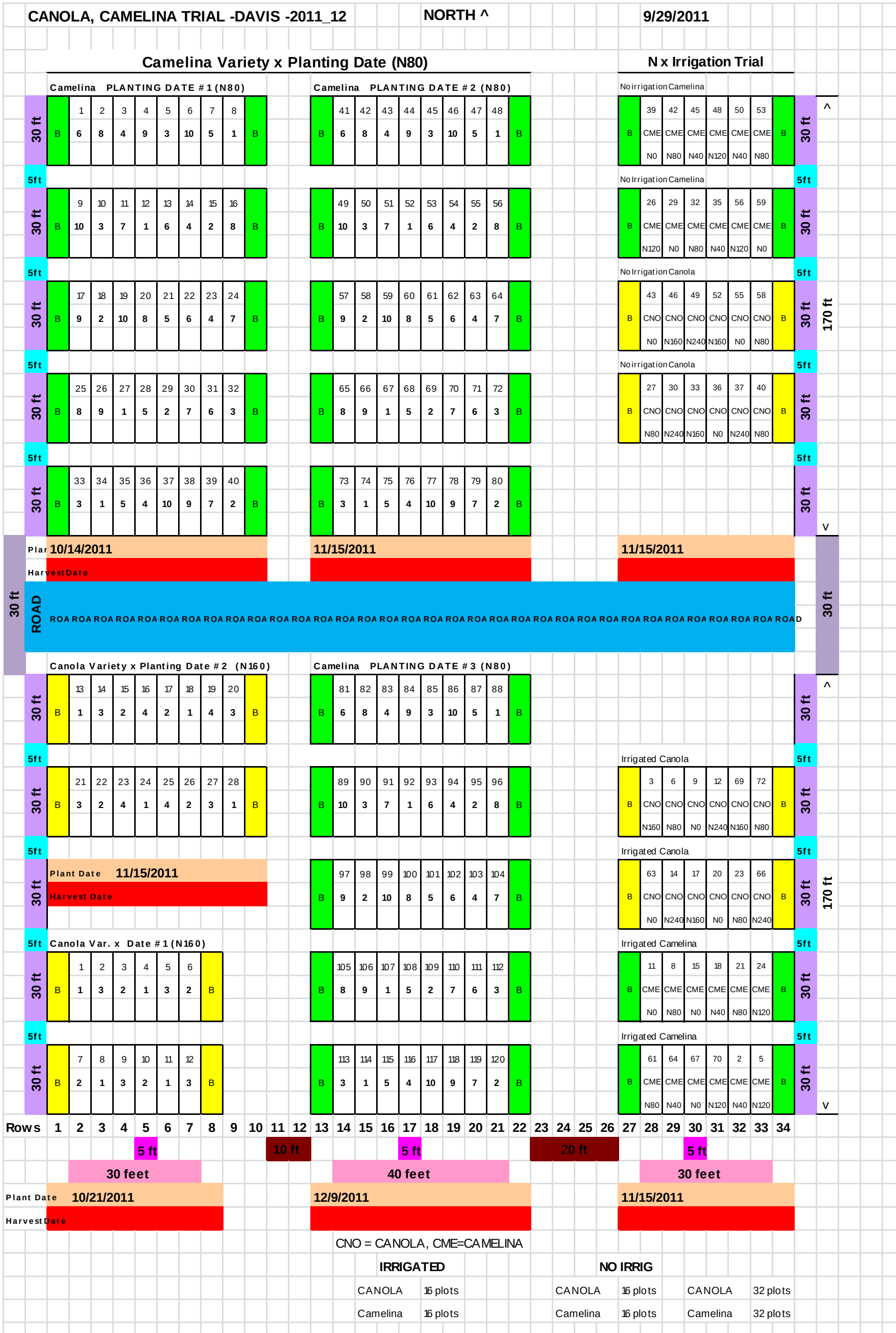
Schlerotinia

Alternaria

Phoma (blackleg)

Root knot (Meloidogyne sp.) and Cyst nematodes (Heterodera sp.)

C. Appendix C: Oilseed Plot Layouts and Plot Pictures



Typical oilseed plot layout at Davis or WSREC

Meadowfoam in March WSREC.

Camelina plots in March at WSREC.

Canola variety trials in early January and late April, 2012 (Cibus varieties).

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.

Figure 0.1 Camelina prior to harvest at Davis in May 2011.

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

D. Appendix D: Crop Selection Criteria

The California Energy Commission is working with the California Department of Food and Agriculture and the University of California Biomass Collaborative to undertake a three-year study evaluating potential biomass crops for California.

The objectives of the project are to demonstrate potential energy crops suitable for California and their associated by-products under commercial conditions; familiarize growers with these crops; determine the suitability of these crops for various energy and industrial markets; determine costs and energy balance of production; and identify land use impacts and barriers to commercialization.

The first task of the project was to determine the criteria for which potential crops should be selected to be included in the study. With input from the project leaders and the project's Technical Advisory Committee, five broad criteria were selected including: 1) near to mid-term economic viability, 2) agronomic suitability, 3) environmental suitability and 4) energy production and 5) other criteria. These are further elaborated below.

It is important to note that much of our knowledge regarding these specific crops in California is incomplete. This project will further our knowledge about these conditions. It is also expected that there is likely to be tradeoffs among all the criteria and that it is highly unlikely that a crop that satisfies all the criteria exists.

Potential Economic Viability

The economics of crop-based biofuels are influenced by multiple factors – including policy mandates and energy prices. For the purposes of this study – criteria includes:

Infrastructure support

New crops need to either fit into to existing infrastructure or require the establishment of new infrastructure, including harvesting, storage, transportation, seed availability, and processing. Crop energy transformation will occur using demonstrated technology or multiple thermal or biochemical pathways.

Potential Profitability

For both grower and biofuel producer; assessed through predictive economic analysis.

Agronomic Suitability

Crop has sufficient agronomic potential under California conditions, either broadly or locally, based on professional judgment

Regional suitability

Biofuel crop may be particularly well suited to a specific climatic zone or crop may be well-suited to a range of climatic zones.

Crop Rotations - Crop has ability to fit into or complement existing crop rotations.

Fertilizer/pesticide requirements – Crop has ability to use fertilizer efficiently; no requirement for potentially restricted pesticides.

Ability to integrate with food production –Crop may have the ability to be grown concurrently with food crops through double cropping or as a companion crop; for example a crop grown between rows of perennial crops such as almonds or grapes. Alternatively crops may complement and/or enhance the production of other crops, or biofuel crops may be simultaneously more resource use efficient.

Marginal Lands – Crop may be well suited to marginal lands – i.e. those soils that are impaired by drainage, salinity or other restrictions.

By-Products - Crop may have characteristics that allow for the production of by-products that have marketable industrial uses – such as oilseed meals for livestock feeding.

Environmental Suitability

Greenhouse gas/carbon savings - Biofuels carbon load and greenhouse gas release (production and consumption) should not exceed that of a like amount of fossil fuel production. Promising crops may require life cycle analyses.

Water use efficiency – Biofuel crop should be efficient at using water particularly in regions of California where access to irrigation water is limited – that is the crop should optimize yield per unit of applied water.

Water quality – Crops should pose no harmful effect on ground or surface water quality – and some crops may have potential to positively impact water quality with a deep rooting structure that can uptake nutrients or other constituents

Ability to use marginal water – Crop may have the ability to use potentially available water supplies such as saline or municipal reused water. This will depend on local and or regional conditions. In addition, it is possible that a biofuel crop may potentially be grown in dry land conditions – relying on rain-fed conditions as opposed to irrigated.

Invasiveness – Crop does not pose a significant threat of spreading, reproducing and becoming and environmental or economic nuisance.

Wildlife habitat – Crop may provide habitat to wildlife such as birds and beneficial inspects

Ability to act as refuge or host insects/diseases – Crop does not pose significant potential to act as a host to insects or diseases that can cause economic damage to neighboring crops, or it may act positively to provide habitat for beneficial insects.

Energy Production

Biofuel crops vary in the amount of energy produced per unit of land. Energy crop should reduce overall energy consumption and enhance energy security.

Quality of conversion – crop should produce more energy than is required to produce it.

Other Criteria

Additional criteria include:

Status of Current Research in California

In order to avoid duplication and make efficient use of research funds, assess whether there are other studies underway currently or recently completed that it would be duplicative to study.

Expressed interest either on behalf of growers or companies/biofuels producers or end-users.

Human Capital - Growers have sufficient knowledge or access to knowledge needed to undertake the cultivation of a new crop. Knowledge can be delivered through existing agricultural research and extension system.

Potential for adoption– Crop has potential for adoption in 5-10 years as opposed to a crop with a need for longer research time horizon.

E. Appendix E: Crop Identification and Suitability Analysis

Using the Crop Selection Criteria (Appendix D) a Crop Identification and Suitability Analysis was developed. A matrix analyzing potential crops against the criteria and includes thirty potential crops divided into oilseed crops (ten), starch/grain crops (six), sugar crops (four), and perennial grasses (nine).

Based on the analysis, five crops were selected for the project including camelina, canola, meadowfoam, sweet sorghum and sugarcane/energy cane.

Below is a brief summary of some of the identified crops.

OILSEED CROPS

Jatropha currently has active but limited research in California. Dr. Kaffka noted that previous trials in CA have been conducted with poor viability everywhere except Imperial Valley. It is a sub-tropical crop and not adapted to frost – though range expansion might be pursued. Though jatropha may grow well in parts of southern California, however, those areas have little farmland so that a reasonable economic return is unlikely.

The committee discussed whether glycerin is a marketable product; some argued it was a viable feed amendment and a dust control amendment – others said that producers have to pay to have it hauled away. It was acknowledged that US EPA accounts for glycerin as a marketable byproduct – and that it may be in transition. Concern was expressed about the potential for a glut of glycerin developing.

Canola oil has potential for marginal water use (using water of lesser quality) and it can alternate with wheat in dry farm rotation. It produces high quality oil for processing. Canola is well studied in Canada – where little else can grow. Australian researchers have been working on canola for the last 30 years, and we may be able to benefit from the germplasm developed. Canola also has the potential to be grown in young orchards. Camelina and meadow foam may also be intercropped (crops planted simultaneously in close proximity) with perennial crops like trees or vines.

Camelina is an industrial crop in the upper prairie states which has potential as a jet fuel and transportation vehicle fuel. It may likely never have as high yields as other crops but might use less water. It is relatively easy to grow but shatters readily.

Mustard is typically grown as a cover crop between vineyard rows, it is a relative of canola. Studies have shown that it is not viable as an oilseed crop and the by-products are poor cattle feed.

Meadowfoam may potential in California. Some original research was conducted in California over 20 years ago. It is viable, valuable hi-grade oil. There are some concerns about ability to harvest as specialized equipment may be necessary.

Castor Bean has potential to be blended however can't be legally processed in California due to production of ricin, a highly toxic and weaponizable extract of the plant.

Soybean does not have strong potential in California due to the arid climate which causes the seed to shatter. Spider mites are a heavy pest. There is little to no breeding work in California and the intense sunlight is also problematic.

SUGAR CROPS

Grain sorghum is bred for starch grain yield while sweet sorghum is produced for sugars and has little seed and is similar to sugarcane as an annual. New breeding work is also being conducted.

Sweet sorghum has expressed interest by industry and growers. This crop has the potential to be used like sugar beets with a long harvest season that may be conducted sequentially. It also has a number of by-products including fiber, wax and bagasse. Sweet sorghum's water requirement is less than corn's. More fertilizer and water requirement trials are needed.

Sugarcane and **energy cane** both have potential, but there is less knowledge. Sugarcane could be an important component to the low carbon fuel standard under development by the California Air Resources Board.

Sugar beets have been grown successfully in California though current production has dropped off. California has the highest beet yields worldwide. However this crop has been well studied – though the potential for ethanol conversion is not well known.