

**Energy Crop Assessment in California Using  
Optimization Modeling**

**DRAFT REPORT**

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## **Task 3.2.1 Energy Crop Assessment in California Using Economic Optimization**

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### **ABSTRACT**

This work reports on the use of a positive mathematical programming model created to analyze economically optimal crop rotations on California's diverse farms. The objective of this work was to identify realistic opportunities and likely locations for purpose-grown biofuel feedstock crop production in California. The analysis is limited to annual and short-lived perennial crops like alfalfa produced on irrigated farmland in California. Diverse, regionally-specific cropping systems were identified using ten years of recent data on crop production from the California Department of Pesticide Regulation. Using cluster analysis techniques, 45 distinct cropping systems were identified throughout the state using this data, some including up to 14 crops. Locally specific crop budgets were created for each region, and used with the optimization model. Prices for the biofuel crops were increased iteratively and entry prices, acreage amounts and locations for crop adoption identified. Changes in water use were calculated. Results are reported for 5 different crops, two new and three traditional, in the 45 regions identified. These were canola (new), sweet sorghum (new), sugar beets, safflower, and bermuada grass. Different regions of the state are most likely to be locations for both the new and traditional crops as their relative value increases, compared to other current crops in the rotation. When relative prices are sufficiently favorable, some new crops result in widespread adoption and a decrease in overall irrigation water use. This work supports other types of analyses, including estimates of the potential effects on wildlife using cultivated regions of the state by scientists at the Bren School at UC Santa Barabara, also supported by this PIER contract.

**Keywords: bioenergy, biomass, energy, crop, economic, optimization**

Suggested citation: California Biomass Collaboartive, Energy Crop Assessment in California Using Economic Optimization. Draft project Report. CEC Contract No: 500-2011-XXX

## **INTRODUCTION 1**

### **Objectives 1.1**

Environmental, economic, and political concerns about the production and use of fossil fuels have led to a renewed interest in biofuels derived from dedicated energy crops or crop residues nationally and in California. In California, the Governor's Executive Order S-06-06 sets goals for increasing reliance on in-state production of biofuels, specifically that California should produce at least 20 percent of the biofuels consumed in the state by 2010, 40 percent by 2020, and 75% by 2050. The California, Low Carbon Fuel Standard mandates a reduction in the green house gas intensity of transportation fuels, while federal law, Energy Independence and Security Act, 2007, sets targets for the use of biofuels in the United States. Production of biofuels from crops or crop residues provides an economic opportunity for some farmers, and reduces dependence on foreign oil imports.

The state of California currently uses approximately 1 billion gallons of ethanol each year, with another 4 millions gallons of biodiesel (California Biomass Collaborative 2006). California imports more than 95 percent of the biofuels used in-state (California Energy Commission 2007). To meet local biofuel production goals, hundreds of thousands of acres need to be dedicated to producing biofuel feedstocks to meet even the short-term goals. Every crop that is being examined as a biofuel feedstock will have different energy characteristics and different land and water requirements.

The California Biomass Collaborative (CBC) provided initial coarse-scale estimates for biofuel production in California from crops and crop residues. This current study provides an improved, quantitative estimate of the likelihood of farmers producing crops for biofuel manufacture, as well as, the locations within the state with the greatest likelihood of this occurring.

Besides providing food, feed, fiber and now fuels, agricultural and other managed landscapes also serve other purposes such as wildlife management or environmental remediation. For example, planting perennial crops like switchgrass on idle cropland in some parts of the United States may improve habitat quality for some species (Perlack et al. 2005). The biodiversity value of such restored lands would also increase. Some energy crop types are salt-tolerant and could help restore habitat quality by remediating high-salinity soils and associated pollution of wetlands in arid regions (Bañuelos 2006, California Biomass Collaborative 2006; Jenkins et al., 2010; Kaffka, 2010).

To provide a basis for estimating potential changes associated with farmed landscapes in California, the CBC has developed a whole farm economic optimization model to predict purpose grown biofuel feedstock production and estimate crop land cover. The model simulates current farm structure and economic conditions throughout California on irrigated lands used for annual or short-lived perennial crops, and accounts for significant regional differences among farms. Its primary purpose is to predict the profit at which new crops or crop residue harvested for biofuels and other energy purposes enter cropping systems, and which crop activities are displaced.

### **Changing cropping patterns 1.2**

Land devoted to crops in California is constantly changing. These changes are due to locally-specific dynamics of profitability and demand of crop production. New crops are introduced,

marginally productive land is brought in and out of production, and commercial development may remove land from production. The development of new local demand for biofuels processing indicate that construction of a Midwest ethanol plant could raise the local price of corn 5.9 cents per bushel in a 150-mile radius of the plant, and up to 12.5 cents per bushel at the plant site itself (McNew and Griffith, 2005). In California, over the last decade, sugarbeet processing plants have closed in Woodland, Tracy and most recently in Mendota. This eliminated sugarbeet production in northern California where it had been profitable since 1870, due to the loss of a market for the crop. Land values or unique climate conditions influence the location of crops. Only the highest valued crops are grown on the coastal areas in part because land rental rates are 4 to 5 times greater than land rental rates in the Central Valley, and several high value vegetable crops can be grown in a single season, providing greater revenue than a single, lower valued crop. Fluctuating demand or changes in the conditions of trade for natural fibers like cotton influences the output price, as well as the competitive advantage of international sources of cotton that influence the competitive position of California cotton growers.

### **Crop acreage increasing 1.2.1**

Two crops that have increased in the last fifty years in California are corn silage and rice (USDA, NASS. 2010). Corn silage has increased dramatically in the last 50 years from less than 100,000 acres in 1960 to nearly 500,000 acres in 2010, while acreage used for corn grain has been declining for the last 30 years. Rice acres have fluctuated over time but since the mid-1980s, have tended to increase slowly from less than 300,000 acres in 1960 to just under 600,000 acres in 2010. Irrigated crops, especially annual crops, have had some challenges in California in the Central Valley due to water use restrictions in recent years.

### **Crop acreage that is not increasing 1.2.2**

A number of crop acreages are declining. Wheat acreage rose in the 1980's due to international policy disagreements with Russia to over 1 million acres of wheat, but in contrast to rice, has declined slowly since the mid-1980s to around 400,000 acres. Dry edible bean acreage has also declined. In 1960, California dry edible bean acreage was over 200,000 acres annually. Since 2000, it has been below 100,000 acres, though acreage for the last three years may be lower due to irrigation restrictions. Similarly, California sugarbeet acreage has dropped from over 300,000 acres in the 1970's to approximately 25,000 acres produced for the last factory in Brawley in the Imperial Valley. As noted, this is due to the closure of sugar factories around the state. Upland cotton acreage is currently being produced at a fraction of the historical annual acreage. For more than 20 years, over 1 million acres of cotton were planted in California. Currently cotton production occurs on approximately 200,000 acres. Pima cotton has increase gradually for the last 20 years. Recent disruption of some of the international cotton production has caused the price of cotton to increase. This may shift some cotton production back to California.

More generally, all cropland acres are declining in California (USDA, NRCS. 2009). More dramatic however is the shift from cultivated cropland to non-cultivated cropland. This appears is due to the shift from annual crops to perennial woody crops like vineyards, fruit and nut trees. The 1 million acres of cropland were generally lost to development. Other land for urban development was converted from rangeland and forestland increasing the total land converted to development to up to 2 million acres since 1985.

## **Regional Resource Variation 1.2**

To manage the large data sets and capture the resource variability, California was divided into five unique production regions. These regions are identified as: Northern California (NCA), Central California (CEN), Southern San Joaquin Valley (SJV), Southern-most California (SCA), and Coastal California (COA, Figure 1).

The framework of this regionally-specific, cropping system optimization analysis facilitates the capture of the great variability of farming conditions and farming systems present in California. To characterize the diversity of California farms and farming regions, additional data is provided. Tables 1 and 2 compare a variety of agricultural demographics, resources, and economics for farms in each region (USDA, NASS, 2009; USDA, NASS, 2010; CIMIS, 2010). The primary point of these two tables is to illustrate the regional variability in resources required to generate a relatively equivalent amount of economic value (Table 2, right-hand column).

The cropland used in the model is represented in the column, 'Annual Crop Acres,' which included only 4.9 million acres, of the total 9.5 million cropland acres in California (Table 1). The nursery and greenhouse acres and the perennial fruits, nuts and berry crops were not considered in this analysis primarily because these crop choices are made on long-term investments rather than on an annual basis. In four of the five regions the annual vegetable, grains, oilseeds, and hay crops accounted for less than 40 percent of the production value (Figure 2, USDA, NASS, 2009). The category most sensitive to energy crop adoption was the grains, oilseeds, and hay category, due to its lower value of production. The majority of value was in the perennial fruit and nuts, berries, nursery, and greenhouse crops, but these were not included in the analysis.

Additional production factors are presented in Table 2. Nearly all the cropland in the study area is under irrigation. Areas that are highly prized as living areas compete heavily for cropland. Irrigated cropland rental rates are also presented by region in Table 2. In the larger production areas: NCA, CEN, and SSJ; the land rental rates are the lowest as well as the annual value of production. In the Imperial Valley region (SCA) and the Central Coastal zone (COA) land rental rates are much higher than the other three regions. In the COA, the average land rental rates are over \$1,000 per acre. It is difficult with these values to produce a lower-valued energy crops.

### ***Northern California (NCA) 1.2.1***

In this study the NCA region includes 29 counties, most of which are north of the Sacramento River, but the Delta area in San Joaquin County was also included (Table 1). The NCA Region also receives the heaviest annual rainfall in the states. Redding, CA, has an average annual precipitation of 39.4 inches (CIMIS, 2010). Sacramento, CA in the lower part of the region has an average annual precipitation of 17.8 inches, which is less than half of the rainfall in the northern part of the NCA region. Rainfall is sufficient to supply water for rainfed crops in the northern half of the NCA region. There is also sufficient moisture to allow production of crops with demanding water needs such as rice.

### ***Central California (CEN) 1.2.2***

The CEN Region includes 9 counties in the northern Central Valley. It also includes the counties east of the Central Valley in which little crop production occurs. The average annual precipitation in Fresno, CA is 11.2 inches (CIMIS, 2010). Rainfall in this CEN region is insufficient for rainfed crops and requires access to reliable quantities of irrigated water to produce the valuable food crops.

### *Southern San Joaquin (SSJ) 1.2.3*

The SSJ region includes only 3 large and productive counties. Bakersfield, CA has an average annual precipitation of 6.5 inches. Rainfall in this SSJ region is insufficient for rainfed crops and requires access to reliable quantities of irrigated water to produce the valuable food crops.

### *Southern-most California (SCA) 1.2.4*

The SCA region includes 6 counties, but only two have large crop producing areas. El Centro, CA, has an average annual precipitation of 2.9 inches. Rainfall in this SCA region is very limited and access to reliable quantities of irrigated water is required to produce the valuable food crops.

### *Central Coast (COA) 1.2.5*

The COA region includes 11 counties. The coastal regions receive higher rainfall than most of the growing areas and the temperatures are more moderate year-round than the other areas. Monterey, CA, has an average annual precipitation of 20.3 inches. Crop production in this area competes with urban needs. The areas land rent of more than \$1,000 limits crop production here to those food crops of highest value.

## **2. RESOURCES AND METHODS**

To model the crop cover shifts from economically-driven cropping pattern decisions, three datasets have been developed. The cropping systems clusters represent the cropping choice decisions. The production area was defined by the historical acres recorded in the County Agricultural Commissioner (CAC) datasets. Then the economic factors were contributed by the development of regionally-adjusted enterprise budgets. In addition to the three sources of data utilized, the Positive Mathematic Programming model (PMP) is also described along with the basic economic assumptions that were utilized.

### **2.1 Establishing Cropping Systems/Patterns**

The first dataset is based on the historical representation of cropping pattern choice throughout the State on 640 acre sections. The universe of crop choices is based on the 24 crops utilized in the non-metric multidimensional scaling and cluster analysis of the California pesticide use database described below. The second dataset is the historical crop acreage data developed by the California Agricultural Commissioners. The third dataset is based on the economic crop enterprise budgets developed from the University of California-Davis, Cost and Return Studies, on-farm interviews, and best professional judgment.

Alonso and Kaffka (2009) partitioned data from the California Department of Pesticide Regulation (DPR) into 5 principal cropping regions: Northern California, Central California, Southern San Joaquin Valley, Southern-most California, and Coastal California. For each region, a matrix of section by crop frequency was created. These matrixes included the 640 acre sections devoted to agriculture and the frequency of the 24 most important crops in California from 1998 to 2007. The crops utilized were alfalfa, barley, beans, bermudagrass, broccoli, carrot, corn, cotton, forage-fodder grasses, garlic, lettuce, melons, oat, onion, potato, rape, rice, ryegrass, safflower, sorghum, sudangrass, sugarbeet, tomato and wheat. The matrix for each region was used to perform non-metric multidimensional scaling in R (The R foundation for Statistical Computing 2005) using Manhattan distance. The dimensions (axes) representing a good solution

for each data set were used to perform a cluster analysis in JMP (SAS Institute Inc. 2007) to group the sections in each region based on crop frequencies. The resulting clusters include sections with similar cropping patterns (Figure 3).

The individual crop frequency scores of the cluster analysis were used to weight the acreage allocation across in production areas. Many of the 24 crops did not play a significant role in the production system. Predominate crops within each crop cluster were determined by identifying the fewest number of crops that accounted for 90 percent of the crop frequency. Those crops that fit this criterion established the cropping pattern for the cluster. Once the number of crops was determined, the prominent crops were rescaled by 90 percent so that the cropping pattern crops summed to 100 percent.

Wheat is frequently double-cropped. If crop acres are reported on the basis of one crop per acre, then multiple crops per acre distort that relationship. Crops that are frequently double cropped with wheat are dry edible beans, melons and sudangrass. The sum of these crop acres were used to weight and reduce the wheat double-crop acreage to avoid counting the acreage twice. In the NCA Region for example, wheat acreage used in the distribution allocation was reduced to 76.8 percent of the total wheat production acreage.

The current cropping patterns for each cluster in the northern region of California are presented in Table 3. Each cluster indicates the predominant cropping patterns for each hypothetical, representative farm (1 cluster = 1 representative farm). Fifteen of the initial twenty-four crops are grown in the northern region. Table 3 is derived from the weighted frequency values from the cluster analysis. Each column in Table 3 represents the fewest crops that achieve 90 percent of the frequency distribution for each of the corresponding clusters.

## **2.2 Establishing Historical Acreage by County and Crop**

The Department of Pesticide Regulation (DPR) dataset contains the acreage data for each crop within a designated 640-acre section. Complications with consistent applicability of the DPR acreage data created challenges in this analysis. To address this limitation, the historical crop data in the California, County Agricultural Commission dataset (CAC) was developed as an alternative benchmark for comparison with the DPR acreage. CAC historical acreage data for all the available crops was collected and sorted. Current county-level acreage data represents the average of five years (2004-2008). Crops that had multiple markets such as corn for grain and silage were separated and summed for the total acreage by the various crop markets. The market-specific information about specific crops is used to create technical and economic variation across regions for the enterprise budgets in the economic optimization.

The cropping pattern information developed in the 14 county, DPR data was expanded to the CAC historical data for the 29 counties in the northern California region. The multidimensional scaling and cluster analysis determined the cross-cluster relationships across the 14 counties in the northern California region of the DPR data. This county-specific cropping pattern data can be exported to non-DPR counties based on similar historical CAC cropping data. The cropping pattern/cluster information for the DPR northern California region data is summarized in Table 4.

The cropping pattern data contained within specific clusters in each DPR county served as proxies for the cropping pattern information in the non-DPR dataset counties within the region. The cluster distribution information within each county was assigned to counties with similar crop production activities. Each cluster contains inherent information on irrigation districts,



water price, soil fertility, etc. The county-level information in Table 4 sums to 100 percent horizontally by row. The total acres by cluster for all 29 counties in the region are reported in the last row of Table 4. Once all the counties contained a cropping system distribution, the clusters were paired with the historical CAC data.

### **2.3 Establishing Crop Enterprise Budget Data**

Budgets were developed for each of the 24 crops in the DPR data. The foundation for the economic enterprise budgets was the UC-Davis Cost and Return Studies (C&SR). Enterprise budgets, whether derived from individual farm data, the UC-Davis C&SR, or from other production specialists, were standardized for the time and location-specific components. The budgets were adjusted for price levels and regional economic and technical effects are being incorporated into the budgets.

The UC-Davis, C&SR enterprise budgets are rigorously established to represent realistic economic costs of each commodity they represent. The objective of the C&RS however is not the same as this purpose-grown crop adoption modeling. Therefore some of the fixed cost assumptions were modified. The CBC model works most effectively on relative changes rather than absolute changes. Therefore a number of assumptions and 'adjustments' in the C&RS budgets have been relaxed to permit the budgets to be equitable across the state and to interact appropriately across regions.

#### **2.3.1 Relaxation of "economic costs"**

Economic costs include variable and fixed costs. The goal is to develop realistic metrics for comparison of alternative use of capital (opportunity costs). It is not uncommon to have negative enterprise budgets. When all the fixed costs are accounted for, many crops will not provide a return that will justify investing in the capital required to produce these crops. There are numerous reasons why this occurs. Some are economic (it is better to partially utilize some resources so they can be provide a greater return for other enterprises in the system). Some reasons may not be economic (i.e., "It is what we have always done"). For the purposes of the C&RS, it is accurate to develop realistic budgets that produce negative profits for some crop enterprises.

The goal of this project is not to determine if farm capital could be better used in non-farm investments. This project targets the relative changes in existing crop production systems. This is a different question/challenge. Reflecting negative economic costs for specific crop production activities will simply drop them from the model (even though for non-economic cost reasons, the negative-return crops are still being produced in California). Therefore crops that are grown in California will all have non-negative crop values in this relative cropping system model. Every crop that has a negative return in the final per-acre profit estimate is set to a value of \$5 profit per acre to keep it in the model until a crop of higher value replaces it.

#### **2.3.2 Adjustment for time-dependent price levels**

USDA ERS has indexed fertilizer costs as well as farm output prices (USDA, ERS. 2010a). These indices are used to adjust various C&RS budgets to the cost of living, price level adjustments for the year in which each budget was created. Individual year budgets were adjusted up or down relative to the year. The Budget reference year for the current CBC cropping model is now 2007. This allows the budgets to be standardized across the system and to capture prices and costs that do not reflect the economic shock of the 2008-2009 sudden oil price increase and recent recession.

The fertilizer costs were assumed to be a proxy for all crop input prices. Non-energy derived costs will be lower, while some fossil-fuel derived costs will likely be higher.

It should also be noted that all crop and input prices and costs have been set to 2007 price levels. When costs and revenues from 2007 are compared to current values, the current prices will be inflated compared to the model 2007 prices. The comparison will not be an 'apples to apples' comparison, unless the current prices are deflated to 2007 levels also.

### **2.3.3 Adjustment for regional yield, price and input cost effects**

The California Agricultural Commissioner data (CAC) 2004-2008 production summaries include county-level yield and price estimates. These 5-year summaries are aggregated for each region to establish regional differences. For each crop, the region with the most representative and complete enterprise budget is used as the base index reference region (the index denominator). Yield and price are adjusted to an index value of 1.0. The other regional yields and prices are either higher or lower than 1.0. Each region was indexed based on real historical data.

Regional adjustments on production costs were indexed with water prices/costs and land rental values. The highest price for water occurred in the south San Joaquin Valley. The highest amount of water used was in the Imperial Valley region, and the highest land rental rates occurred along the coast of California. While every budget followed this protocol initially, when unusual numbers occurred more information was sought from farm advisors and crop scientists to get better values.

The protocol for establishing/tuning multiple crops within local cropping systems (DPR clusters) with similar and different crops across California production regions is as follows:

1. Build appropriate crop budget based on UC-Davis C&RS.
2. Adjust/Standardize values across time to 2007 output prices and input costs.
3. Adjust/Standardize values across region based on historical differences in yield and output prices described in the CAC county-level data.
4. Assign a per-acre profit of \$5 per acre for any crop that is already being grown in California. This allows currently grown crops to remain in the model until an alternative of higher value appears.

Over 90 regionally-specific crop enterprise budgets were developed for this analysis.

### **2.3.4 Energy Crop Enterprise Budgets**

Five energy crops were examined: canola, sweet sorghum, sugarbeets, safflower, and bermudagrass. The first two: canola, a winter annual oilseed crop, and sweet sorghum, a summer annual grass sugar and fiber crop; currently are not commercially produced in California. The other three: sugarbeets, safflower, and bermudagrass; are all currently commercially produced in the state. The currently grown crops relied on budgets developed for existing cropping systems. Commercial production budgets were constructed for canola and sweet sorghum. The base crop used for canola was wheat, but information from safflower production was also studied. Water use and crop timing were based on wheat. Yield variation across California was based on limited yield trials and professional experience (S. Kaffka, unpublished). The base crop for sweet sorghum was corn silage. Professional judgments were made based on limited field trials and the variation in crop habit from corn silage. For both canola and sweet sorghum, conservative values were used for yields.

The market price of canola, \$340/ton, was used as a base price in the analysis. This compares with upward pressure on vegetable oil and prices above \$360/ton reported by USDA the last 2 production years USDA, ERS, 2010b. Sweet sorghum prices more closely reflected corn silage prices than other crops.

## 2.4 Regional Economic Biofuel Crop Optimization

The Positive Mathematical Programming (PMP), profit optimization model is ideally adapted for the regional, multi-crop, crop cover modeling using the DPR data (Howitt, 1995). Existing crops in the cropping rotation are constrained by the opportunity cost of adopting the next additional unit of production. These marginal opportunity coefficients are created for the crops currently in production and the energy production is not currently a production objective.

The new crop alternatives are drawn into the model by holding the non-linear coefficients of the existing cropping system constant while incrementally increasing the revenue for the energy crops. The new (bioenergy) crop alternative is typically a linear form of the 'profit = (revenue – cost)' equation. This can cause some distortion in the extremes, but was generally considered to represent the seasonal crop selection activities.

For the energy crops that are already in production: bermudagrass, sugarbeets, and safflower; there was no linear component. The revenues were adjusted by incrementally increasing the output price for the energy crop. The PMP function does not operate correctly unless the all of the original crops are used as input information in the optimization model.

The functional form of the profit optimization model (used in the analysis) is presented below.

$$\begin{aligned}
 & \text{Production function} \\
 & \text{Max} \sum_{e,g,i,j} \left[ \sum_i (P_{g,i,j} \times (\beta_{g,i,j} - \omega_{g,i,j} X_{g,i,j}) - C_{g,i,j}) X_{g,i,j} \right] \text{ PMP function} \\
 & \quad + \sum_e (P_{e,g,j} Y_{e,g,j} - C_{e,g,j}) X_{e,g,j} \text{ Energy crop function} \\
 & \text{Subject to: } \sum_i \sum_e X_{g,i,e,j} \leq \overline{R}_{g,j} \quad j = \{A(\text{acres}), w(\text{ac-ft of water})\}
 \end{aligned}$$

$P_{e,g,i,j}$  = farm price of crop  $i$ , and energy crop  $e$ , in region  $g$ , and resource,  $j$ .

$Y_{e,g,i,j}$  = yield of crop,  $i$ , and energy crop  $e$ , in region,  $g$ , and resource,  $j$ .

$\overline{R}_{g,j}$  = acres of crop  $j$  in region  $g$ .

$X_{e,g,i,j}$  = level of input  $r$  applied to energy crop  $e$ , in region  $g$  for crop  $i$ .

$\beta_{g,i,j}$  = intercept of the quadratic (marginal) curve of crop,  $i$ , in region,  $g$ , resource,  $j$ .

$\omega_{g,i,j}$  = slope of quadratic (marginal) curve of crop,  $i$ , in region,  $g$ , and resource,  $j$ .

It is common in bioenergy supply and demand discussions to discuss the components of profit: yield, output price, and input costs. This analysis, however, maximizes profit, which is an aggregate of those three factors. There is a direct relationship between change to yield and price, and a change in profit (same sign). There is an inverse relationship between change to input costs and profit (opposite sign). Therefore there is a need to discuss the results in terms of a change in profit rather than the individual factors of yield, price and cost.

Profit,  $\pi$ , is equal to the revenue,  $R$ , minus the costs,  $C$ , or  $\pi = R - C$ . The revenue is the output price,  $P$ , times the yield,  $Y$ . For each crop these are summed across all outputs (grain + straw, cotton lint + cotton seed, etc.). In this model, all these values reflect a 'per-acre' basis.

$$\pi = \sum_i (P_i * Y_i) - C \quad \text{where } i = \text{individual outputs}$$

In the model it is easy to independently change  $P$ ,  $Y$ , or  $C$ , holding the other factors constant. This shows the role each independent component plays on the profit. In real life, all three of these factors are changing at the same time.

Since canola and sweet sorghum do not have a history of commercial production in California, there is considerable uncertainty about the actual values. The component that can easily be inferred from other regions is the output price,  $P$ . The yield under commercial production can be considerably more variable than those conducted under structured research conditions. The costs of crop production based on conditions in other states and countries are more highly variable to conditions in California. Variability and uncertainty increases moving from the output price to yield to inputs costs. The model results are generated as profit with no attempt to infer impact on  $P$ ,  $Y$ , or  $C$ .

In this analysis the sensitivity analysis has been conducted on profit,  $\pi$ . In the initial conditions canola and sweet sorghum are set to a profit = \$0 (Revenue = Costs). This makes some intuitive sense in that if these crops were profitable now, they would already be in commercial production.

Canola and sweet sorghum have different profit structures. A 10 percent increase in profit for canola, as entered in the initial model level, is \$34/acre. For sweet sorghum a 10 percent increase in profit, at the initial levels of \$26/ton and 30 tons/acre, is \$78/acre. Comparison of a 10 percent increase in profit, revenue, and costs, for these two crops creates a lop-sided comparison.

To overcome this profit percentage-bias between crops and facilitate the comparison of a producer's next incremental source of potential profit, marginal profit level increases of \$20/acre and \$40/acre were considered. This increased profit represents a long-run average increase, not a seasonal, one-time increase. This long-run average profit designation redirects the results to the net benefit and away from the individual causal effects of  $P$ ,  $Y$ , and  $C$ .

The PMP model requires the cropping system to be calibrated initially. The PMP production function intercept,  $\beta$ , and slope,  $\omega$ , are then calculated from the shadow values of the base system.<sup>1</sup> This allows the acreage values for each crop to vary with a change in price, while holding the marginal values of the base system constant. The non-linear curvature adds flexibility to the straight linear, non-PMP, function.

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<sup>1</sup> Shadow prices reflect the marginal or opportunity cost utilizing the next available unit. The PMP model converts these opportunity costs into a quadratic function that preserves core relationship information within the system as new crops are introduced.

Once the cropping system model PMP coefficients were established, incremental increases in profit were optimized by adjusting the output price at specified increments. The model structure allows the output price and the input costs to be varied. Yield values are replaced with the PMP production function.

Table 5 contains the input factors for the nine cropping system/clusters in the Northern California (NCA) Region as an example. For illustration purposes the profit of each crop is also presented in the table. On the righthand side of Table 5 are the crop timing factors. The '1' indicates when the crop is being grown in the field. The '0' indicates the field is not in production. The last 5 rows of Table 5 describe input factors for the five energy crops considered in this analysis. Canola and Sweet Sorghum are not currently grown commercially in California, while the other three crops are currently grown in various locations. Acres were used in the cluster-level analyses, so the acres for each crop were not included at the regional level.

The results reflect changes in the 45 cropping pattern clusters from an iterative increase in the profit of the five energy crops examined: canola, sweet sorghum, sugarbeets, safflower, and bermudagrass. A priority was placed on the inter-regional relationships than on the absolute price levels. Price levels will change over time, but price differences between regions will likely change less. The subsequent use of different prices and yields will produce different results.

For each energy crop the profit was iteratively increased to an additional \$40 per acre profit (GAMS, 2010). This process was repeated for all 5 energy crops in the 45 clusters.

Figure 4 illustrates the average profit/acre (\$/acre) of the 45 cropping system clusters for the 4.9 million acres of California that were modeled. Figure 4 shows the diversity of annual crop production in the state. Profit per acre for each cluster ranges from less than \$100 per acre to more than \$650 per acre. The highest profit values were achieved in the coastal area (COA), followed by the very southern production area (SCA). The lowest values were produced in the northern and central areas (NCA and CEN). Crop numbers per cluster ranged from 2 crops per cluster to 15 crops per cluster. The size of the circles in Figure 4 is based on total acres included in the cluster. Some illustrative references are included in the chart to provide perspective.

## **2.5 Implications of a Relative Increase in Profit**

The profit metric used in this analysis is a stable profit, rather than a volatile, random annual profit. An increase of \$20 per acre profit indicates that the profit per acre will increase with certainty, or at the very least, with confidence by that amount. It is not a seasonal variation. This can be interpreted as a certain contract price to produce an energy crop, or it could be a long-term, well-established, average price.

The impact of a \$20 or \$40 per acre profit is different if the average profit for a cluster is \$100 per acre or \$600 per acre. A \$20 profit increase is 20 percent of an average profit of \$100. The same energy crop profit of \$20 per acre is only 3 percent of a \$600 profit. The establishment of a long-term average profit of \$20 per acre would also require very high profits for a few years of continuously higher profits for more years. Based on the number of crops and profit per acre for each cluster it is easier to appreciate the diversity and challenge in moving purpose-grown energy crops into the California agricultural production system.

For this analysis \$20 per acre is considered meaningful. A \$40 per acre is possible, but in this model, considered an upper limit. The nature of the model structure makes it most meaningful for smaller changes in profit than for larger changes.

### **3 RESULTS**

Profit, a function of yield, output price, and input costs, represents a long-term average rather than a seasonal price. Once the PMP model was calibrated for each cropping system cluster the energy crop profit was increased from \$0 to \$40 per acre profit and reoptimized each time. The results of acreage and water-use changes were tabulated for each iterative increase in energy crop profit. The output of the incremental price increases for each cropping pattern cluster was summarized for each of the five energy crops at the \$20/acre profit increase and the \$40/acre profit levels.

#### **3.1 Cropping Pattern Clusters within the Region**

The output from 45 systems, 22 historical crops, 5 energy crops, across 40 different energy crop prices is not easy to discuss concisely. The localized nature of this cropping system cluster approach allows the advantages of this analysis to be highlighted for one region before summarizing the state-level impacts.

Summaries for canola adoption in the nine clusters of the NCA region at a \$20/acre profit increase are presented in Table 6. Acreage changes are presented for each crop for the region (left) and then by cluster (moving toward the right). Decreases in acreage are shown as negative numbers in parentheses. Acreage increases are positive values without parentheses. The top row gives the total acres in the region and each cluster, while the bottom row gives the change in regional and cluster water use. For the \$20 per acre increase in canola profit, there were no decreases in water usage in any cluster in the NCA region.

Table 7 presents the same acreage and water change information from a \$40/acre increase in canola profit in the NCA region. In addition, to following the same layout as Table 6, Table 7 includes the acreage share of each cluster within the region. So for Cluster #1, (NCA-C1), the 476,419 acres represent 31 percent of the total 1,538,984 acres used in this analysis in the NCA region. As canola production became more profitable, water use declined significantly at the \$40/acre profit with canola. This is largely due to a low water use requirement for canola production in the northern region.

For the region, with an assured increase in profit of \$40 per acre, Canola acreage increased to 413,000 acres with large reductions in oats (124,000 acres) and wheat (113,000 acres). Dry edible beans and corn grain accounted for another 121,000 acres. Areas such as NCA-C3 which is principally a rice production rotation saw limited changes in crop production.

##### **3.1.1 Canola-Adoption Rates**

The local effects between cropping pattern clusters within larger regions of the state are a compelling part of this analysis. Broader policy questions often call for better aggregate numbers for the states, but state-level values generally mask the details of local impacts. In Figure 5, rate of canola adoption for each cluster the NCA region are plotted (share of canola acres/crop acres within the cluster). Canola adoption behaves differently based on the collection of crops within each cropping pattern cluster, as well as the profit of each crop relative to the energy crop profit.

Cluster 1, CAN-C1 is the cluster at the far right in Figure 5. It accounts for 31 percent (478,419 acres) of the regional 1,538,974 acres. Canola enters the C1 rotation at a price of \$361/ton – just above the \$20/acre profit level of \$360/ton. Canola also enters C1 rotation at a canola acreage share of 23.8 percent, or at an acreage-level of 113,000 acres.

Another significant cluster is CAN-C3. This canola price response curve is at the other extreme on the left-hand side of the chart. This crop cluster contains over 95 percent irrigated rice on 332,839 acres. Canola initially enters the cluster at \$351/ton and at only 0.1 percent of the cluster acres in canola. The canola acreage in Cluster 3 never gets above 2.2 percent of the cropland acreage within the cluster. Cluster 3 has a slope of an \$18-increase for every percentage of canola acres the cluster produces. When the canola acreage share increases by 2 percent the canola profit increases by \$36/ton. This can be contrasted with the slope for Cluster 1 of \$0.77 per increase in canola share. From the time canola enters the rotation of Cluster 1 at \$361/ton and reaches the \$40/acre profit of \$380/ton, the share of canola acres increases from 23.8 percent to 47.6 percent.

The other cluster of significant size is Cluster 4. Canola enters the rotation at a price of \$363 and an acreage share of 11.2 percent. It has a relatively steep slope of \$1.61/ton per increase in canola acreage share. These different slopes and entry levels are all determined by the characteristics of each cluster related to profit/acre of each crop, total acres and timing of each crop, and water levels of crop. Cluster CAN-C1 has the greatest variety of crops and variety of crop profits. CAN-C3 has almost no variability in crops or crop profits, so as long as rice profit is greater than canola, canola does not enter the Cluster 3 rotation.

These three clusters: C1, C3, and C4; account for 70 percent of the 1.5 million acres of cropland in this NCA Region.

### **3.1.2 Water-Use and Canola Adoption**

The average water-use in the NCA Region is 2.6 acre-feet of water for all the crops and all the acres. However when the water-use is looked at by individual cluster, the water-use ranges from 2.0 acre-feet of water to 4.1 acre-feet of water. Water-use does not change for any of the clusters at the \$20/acre profit level.

Above that profit level most of the clusters begin to lower their water-use requirement as more acreage of canola is adopted. In the clusters with significant rice crops, Cluster 3 and 6, the rice acreage uses the water not because of the entry of canola into the rotation, to increase rice production. Cluster 7 also produces significant rice production, but the additional production of melons competes with rice for increased profit. As increased canola profit approaches \$40/acre, water-use within Cluster 7 also declines.

### **3.2 Cluster-specific sweet sorghum adoption in the SSJ Region**

For contrast with the discussion on the NCA Region and canola adoption, the sweet sorghum adoption activities are compared in the South San Joaquin (SSJ) Region. While the NCA Region of California is large and heterogeneous, the SSJ Region is large and more homogeneous.

The homogeneity of the SSJ cropping clusters is even more apparent in comparison of the sweet sorghum adoption rates Figure 6. Sweet sorghum production in the SSJ Region enters the crop rotations at the same profit level, \$6.25/ton; and at between 1.5 and 3.0 percent of the cropping cluster share in six of the eight cropping clusters. The addition of sweet sorghum into the rotation occurs at similar rates (slopes). The one anomaly is that Cluster 6 did not reach a level in

which sweet sorghum entered the rotation at profits below \$40/acre (zero acres of sweet sorghum were planted).

Energy crop adoption water-use within each cluster is determined by the crop composition, the amount of acres, and the profit per acre of these crops. Each cropping cluster within each region has a different resource base. Therefore as they are optimized independently, they will produce different results.

### **3.3 State and Regional Impacts of Increased Profit and Bioenergy Crop Adoption**

This California Bioenergy Crop Model does an excellent job of optimizing the local resource development opportunities within each cluster. It also does a good job modeling state and regional levels by simply aggregating up from the cluster level. Each of the five energy crops: canola, sweet sorghum, sugar beets, safflower, and bermudagrass; were analyzed separately. The state and regional-level aggregation are reasonable estimates, but as purpose-grown energy crop production evolves in California the resulting production will be a mix of multiple energy crops at the same time.

Figure 7 illustrates how the different regions responded to each energy crop introduced. No crops were adopted in the central coast region (COA) given the assumptions used in the model. Earlier it was noted that the NCA region cropping systems were more heterogeneous than the SSJ region cropping systems. The SSJ region was also more adoptive of all five crops. For 4 of the 5 crops, the SSJ region adopted the greatest acreage of the other regions. The NCA region responded only to canola acreage production at the \$20 per acre profit-level. Sugarbeets were the most responsive to the conditions available in the CEN (northern San Joaquin Valley). The CEN region really only responded to sugarbeets and sugarbeet adoption really only occurred in the CEN region. Safflower and canola had similar adoption responses in all the regions, but the NCA region.

The \$20 per acre profit-level is more representative of current conditions than the results of the \$40 per acre profit-level. Most of the crops did respond to greater acreage adoption at the higher \$40 profit-level. Sugarbeets was less responsive to increased profits than the other crops. Doubling the profit per acre from \$20 to \$40 only increased sugarbeet production in the CEN region by about 20 percent.



## 4 DISCUSSION

The principal intent of this analysis was to develop the appropriate data and a model framework that allowed the examination of local attributes on the decisions that farmers may make. Each cluster represents a farm or a cropping system and is based on historical data in California. This analysis was conducted on 45 cropping systems clusters that are graphically displayed in Figure 4. Figure 9 compares just two of those regions on the basis of average water-use per cluster instead of profit per acre per cluster.

Figures 5 and 6 made the point that the composition of natural resources, crops, and economics vary between regions and clusters. Figure 9 illustrates that the crop number and water use in the NCA region are more variable than the crop number and water use in the SSJ region. In the NCA region, the left-most cluster contains only 3 crops, but it has the highest water use (Nearly all rice production). The right-most cluster is also in the NCA region has 14 crops and the lowest water use - just over 2 acre-feet. The clusters of the SSJ region are more homogeneous having 6 or 10 crops per cluster and an irrigation water-use of 3.5 acre-feet. Water use matters in the shifting of crops and also which crops shift in and out of a cropping system.

Natural resource availability and economic viability play a significant role in influencing crop selection and production. Modeling this variability in disaggregated cropping systems provides a more complete reference to bioenergy crop adoption than is possible with fewer aggregated crops.

State level impacts are also successfully modeled in this analysis. With each aggregation from cluster to region to state, however local variability and focus is lost. Figure 8 illustrates the crop changes at the \$20 per acre profit level for canola adoption in the state of California. With all sectors aggregated to up to the state level, the crops that moved out of historical rotations were very similar for all the energy crops. Economic profitability played a significant role in bioenergy crop adoption. It was fairly consistent that lower-valued crops left the rotation as the profit from energy crops increased. The rank of number of acres of a crop which left the system, varied some between energy crops.

The other notable observation in the adoption of bioenergy crops was that water use of the historical cropping system and the incoming energy crop also influenced bioenergy crop adoption. Total available water was constrained to the amount required for the historical cropping systems. The two oilseed crops: canola and safflower; required less than 0.5 acre-feet in the northern California. The other crops: sugarbeets, sweet sorghum, and bermudagrass used much larger quantities of water. When large enough acreage of the oilseeds was adopted, the water saved in each cluster was reallocated to other high-valued crops that had a higher water requirement. When large acreage of the sugar and fiber crops was adopted, some acreage in the cluster was fallowed to supply water for all the higher valued crops.

## 5 CONCLUSIONS

The California Bioenergy Crop Adoption Model was effective at capturing the current economic decision criteria, local natural resource variation aggregated up to regional and state-level effects.

The most compelling shifts are apparent within the local (sub-regional) cropping pattern clusters. Each of the 45 independent cropping pattern clusters has a unique response to an economic profit incentive from energy crop production. While some of the clusters respond similarly to adoption of the same energy crop, many of them respond quite differently. These energy crop adoption factors include cropping pattern mix, as well as the profits for each crop in the cluster, acreage allocation within the cluster, and water-use of existing crops and the incoming energy crop.

Each cropping pattern cluster was modeled over an incremental increase in profit from a purpose-grown energy crop. The five energy crops included in this analysis are: canola, sweet sorghum, sugarbeets, safflower, and bermudagrass. Each energy crop was modeled separately, as if only one energy crop could be added to any given cropping pattern cluster. This increased profit represents the additional incentive required to move a farmer from existing cropping rotations to one that included a energy crop.

The cluster-specific, profit-derived impacts were aggregated to the regional level and compared across the five established regions in the state. The third level of aggregation examined was the overall impact of the economic analysis for each cluster, summed to the state level.

The oilseed crops, canola and safflower, required lower amounts of water for production than the other three crops: sweet sorghum, sugarbeets, and bermudagrass. Because the water-use levels were constrained by the existing use from historically grown crops, as the profit level of these oilseed crops increased, the cumulative, average water-use requirements across a cluster often decreased.

When other energy crops increased, different effects were observed. As the average water-use by individual crops increased with increased profit levels, total planted acreage declined. These non-oilseed crops could become profitable enough to require some cropland to be fallowed in order to realize the higher profit from crops that required higher levels of water.

These results are dependent on the conditions of the analysis which included:

- Historical crop displacement in existing cultivated cropland. The current analysis does not include perennial fruit/nut trees, vine crops, dryland rangeland, or irrigated pastures. As the model continues to develop, these will be added.
- A spatial component where the energy crops is introduced and the historical crops that are displaced in the rotation. For instance, energy crops that displace cotton will only reflect the model results if the energy crop is grown where the cotton was historically grown.
- All enterprise budgets adjusted to the price and yield levels of 2007. In addition regional prices differences are based on historical regional differences. As real prices shift, the results of the analysis will also shift.

Until more research is conducted on the agronomics of energy crops there will be some uncertainty that the model acreage displaced by an energy crop can actually support the

production of an energy crop. The current analysis is based on economics, water-use and acreage. Some field conditions and crop adaptation constraints may interfere with energy crop production. This will continue to be monitored and the subject of crop production research.

This analysis illustrated that when local resources are optimized based on local land and water-use constraints, compelling information on requisite profit levels can be established.

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Figure 1 Five cropping regions used as a crop production framework for bioenergy crop adoption

**Table 1: Regional summary of crop acres, counties and clusters in both the Census of Agriculture and the Department of Pesticide Regulation (DPR)**

Region	Farms	Crop Acres (Census of Ag 2007) <sup>a</sup>	Annual Crop Acres <sup>b</sup>	Total Counties	DPR Counties	Crop Clusters
Northern CA (NCA)	30,601	3,190,441	1,538,971	29	14	9
Central CA (CEN)	15,994	2,314,332	1,193,056	9	5	9
South SJV (SSJ)	8,486	2,094,486	1,193,752	3	3	8
Southern CA (SCA)	14,066	818,787	599,237	6	2	6
Coastal CA (COA)	11,886	1,038,340	395,633	11	6	13
<b>Totals</b>	<b>81,033</b>	<b>9,456,386</b>	<b>4,920,650</b>			<b>45</b>

<sup>a</sup> USDA, NASS 2009, 2007 Census of Agriculture

<sup>b</sup> Summarized from model acreage data synthesized from CAC, 2010 and DPR, 2009 data

**Table 2: Regional summary of precipitation, irrigated acres, rental rates and total crop value 2007 Census of Agriculture, other annual data**

Region	Annual Precipitation <sup>a</sup> (location:inches)	Irrigated Acres (%) <sup>b</sup>	Irrigated Crop Rental Rate <sup>c</sup> (\$/acre)	Total Value of Crop Production 2007 (\$1,000)
Northern CA (NCA)	Redding: 39.4	85.7%	\$264	\$4,522,114
(NCA, continued)	Sacramento: 17.8			
Central CA (CEN)	Fresno: 11.2	95.4%	\$250	\$4,756,520
South SJV (SSJ)	Bakersfield: 6.5	83.9%	\$222	\$4,410,224
Southern CA (SCA)	El Centro: 2.9	82.4%	\$492	\$3,270,154
Coastal CA (COA)	Monterey: 20.3	60.8%	\$1,041	\$5,947,494

<sup>a</sup> CIMIS, 2010

<sup>b</sup> USDA, NASS 2009, 2007 Census of Agriculture

<sup>c</sup> USDA, NASS 2010, 2008 land rental rates

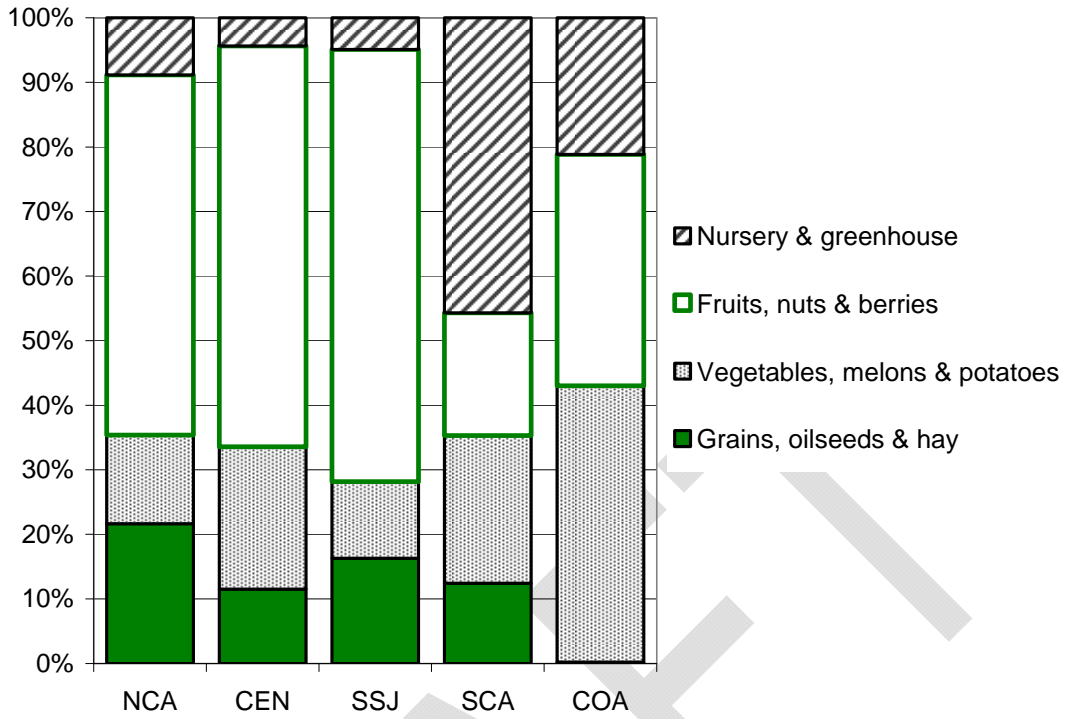
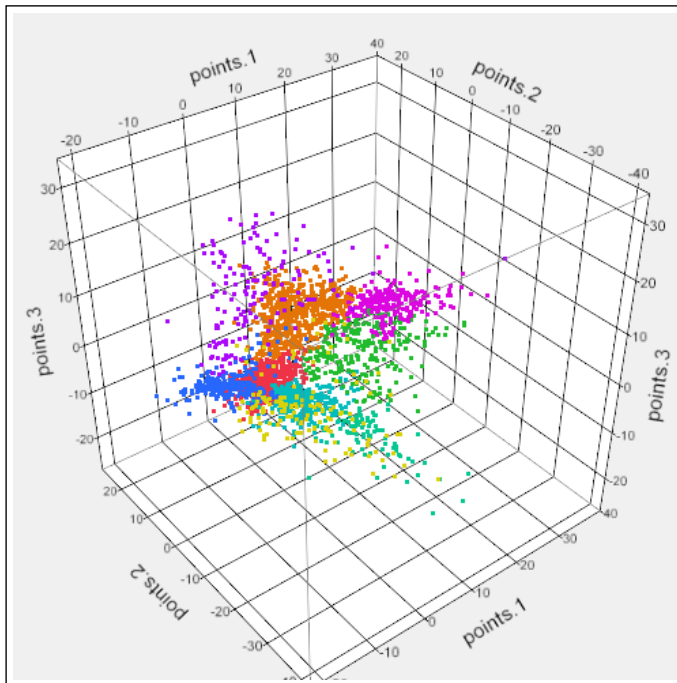


Figure 2: Distribution of regional crops by value of production



**Figure 3** Nine cropping system clusters from the NCA Region in 3-dimensional space



**Table 3: Nine predominant cropping patterns for each cluster/hypothetical farm (CL = Cluster), NCA Region**

	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9
<b>Alfalfa</b>	11.1%	23.5%		50.8%		30.6%	2.4%	2.1%	33.8%
<b>Barley</b>	2.8%				1.0%			2.9%	
<b>Beans</b>	6.3%	6.3%		3.0%	12.9%	2.0%	11.0%	8.6%	5.8%
<b>Corn</b>	27.5%	13.6%	2.9%	17.4%	13.7%	6.7%	5.6%	24.6%	10.5%
<b>Melons</b>	3.2%	3.0%			6.1%		10.1%	5.1%	2.2%
<b>Oats</b>	18.5%	2.8%		8.8%	2.1%	5.8%		3.0%	3.5%
<b>Onion</b>	1.6%	2.5%			3.6%			2.7%	1.9%
<b>Potato</b>	1.6%							1.9%	
<b>Rice</b>	4.6%		95.0%		1.2%	43.6%	32.0%	1.8%	
<b>Safflower</b>	2.3%	4.6%		1.9%	5.5%	1.8%	10.2%	4.6%	4.6%
<b>Sorghum</b>				2.0%				1.6%	
<b>Sudangrass</b>	3.6%								
<b>Sugarbeet</b>		1.9%		2.3%	1.2%			1.7%	2.1%
<b>Tomato</b>	3.5%	25.7%		5.3%	32.0%	2.9%	11.2%	17.5%	22.3%
<b>Wheat</b>	13.5%	16.2%	2.1%	8.7%	20.7%	6.7%	17.5%	21.9%	13.5%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

**Table 4: Cropping pattern/cluster relationships contained within each county of the NCA Region**

	CL 1	CL 2	CL 3	CL 4	CL 5	CL 6	CL 7	CL 8	CL 9
<b>Amador</b>	66.7%			33.3%					
<b>Butte</b>	30.6%	0.2%	53.8%	3.1%		4.3%		7.66%	0.2%
<b>Glenn</b>	24.8%	0.8%	35.0%	18.6%	0.6%	10.4%	1.5%	6.99%	1.3%
<b>Humboldt</b>	100.0%								
<b>Lake</b>	87.0%		4.3%	8.7%					
<b>Lassen</b>	57.6%			42.4%					
<b>Placer</b>	33.7%		65.2%					1.12%	
<b>Sacramento</b>	47.0%	7.8%	5.6%	18.5%	1.9%	1.3%	0.9%	15.36%	1.6%
<b>San Joaquin</b>	33.0%	10.7%	1.1%	22.7%	3.4%	1.1%	0.2%	15.13%	12.6%
<b>Solano</b>	36.5%	8.2%		31.4%	2.0%			10.48%	11.3%
<b>Sutter</b>	15.4%	1.2%	41.4%	4.1%	3.2%	8.1%	21.9%	4.54%	0.2%
<b>Tehama</b>	76.4%	0.6%	2.8%	18.0%				2.25%	
<b>Yolo</b>	22.5%	16.6%	11.3%	13.9%	4.3%	7.0%	4.3%	5.53%	14.5%
<b>Yuba</b>	23.0%		72.4%	1.3%		2.6%		0.66%	
<b>29-County Acres</b>	476,419	82,923	332,849	261,446	33,975	68,550	95,470	109,203	78,148

**Table 5. Input factors: yield, price, cost, water, profit, and crop timing factors; for NCA Region.**

	Yield	Unit	Price	Input Costs	Land	H <sub>2</sub> O	Profit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alfalfa, SAC	7.0	tons	\$171.45	\$725.19	0.0	3.63	\$474.98	1	1	1	1	1	1	1	1	1	1	1	1
Alfalfa, IMT	5.0	tons	\$150.00	\$605.90	0.0	2.33	\$144.10	1	1	1	1	1	1	1	1	1	1	1	1
Barley	2.7	tons	\$176.90	\$374.93	0.0	0.00	\$24.14	1	1	1	1	1	1	0	0	0	0	1	1
Dry Beans	1.3	tons	\$655.38	\$788.24	0.0	2.67	\$30.99	0	0	1	1	1	1	1	1	0	0	0	0
Corn, grain	5.5	tons	\$134.44	\$674.85	0.0	3.10	\$64.56	0	0	0	1	1	1	1	1	1	0	0	0
Corn, silage	33.0	tons	\$25.21	\$769.98	0.0	3.33	\$61.85	0	0	0	0	1	1	1	1	0	0	0	0
Melons	680	box	\$2.50	\$1,387.00	0.0	1.50	\$284.88	0	0	0	1	1	1	1	1	1	0	0	0
Oat Hay	2.6	tons	\$134.21	\$335.91	0.0	0.00	\$19.09	1	1	1	1	1	0	0	0	0	1	1	1
Onions, IMT	454	cwt	\$4.95	\$2,159.67	0.0	2.92	\$87.71	0	0	0	1	1	1	1	1	1	1	0	0
Onions, SAC	458	cwt	\$10.69	\$3,528.76	0.0	2.92	\$1,369.09	1	1	1	1	1	1	1	0	0	1	1	1
Potatoes	20.0	tons	\$126.04	\$2,307.30	0.0	2.67	\$213.41	0	0	0	1	1	1	1	1	1	1	0	0
Wild Rice, IMT	0.8	tons	\$1,264.39	\$908.24	0.0	4.17	\$40.05	1	1	1	1	1	1	1	1	1	1	1	1
Rice, SAC	83.0	cwt	\$15.50	\$1,181.23	0.0	4.25	\$105.27	0	0	0	1	1	1	1	1	1	1	0	0
Safflower	1.2	tons	\$361.45	\$366.08	0.0	0.50	\$67.67	0	0	1	1	1	1	1	1	0	0	0	0
Sorghum	5.0	tons	\$140.04	\$635.90	0.0	2.50	\$57.29	0	0	0	1	1	1	1	1	1	0	0	0
Sudangrass	5.3	tons	\$142.00	\$725.00	0.0	2.33	\$20.50	0	0	0	0	1	1	1	1	1	0	0	0
Sugarbeets	30.0	tons	\$37.87	\$1,094.10	0.0	3.00	\$41.90	1	1	1	1	1	1	1	1	1	1	0	0
Tomatoes	35.0	tons	\$58.82	\$1,864.37	0.0	3.50	\$194.21	0	0	0	1	1	1	1	1	0	0	0	0
Wheat	3.0	tons	\$156.20	\$434.36	0.0	0.50	\$34.24	1	1	1	1	1	1	0	0	0	0	1	1
Canola	1.0	tons	\$340.80	\$340.80	---	0.50	\$0.00	1	1	1	1	1	1	0	0	0	0	1	1
Sweet Sorghum	32.0	tons	\$26.00	\$832.00	---	2.00	\$0.00	0	0	0	1	1	1	1	1	1	0	0	0
Safflower	1.2	tons	\$361.45	\$433.75	---	0.50	\$0.00	0	0	1	1	1	1	1	1	0	0	0	0
Sugarbeet	30.0	tons	\$37.80	\$1,134.00	---	3.00	\$0.00	1	1	1	1	1	1	1	1	1	1	0	0
Bermudagrass	3.2	tons	\$170.00	\$554.75	---	4.00	-\$10.75	1	1	1	1	1	1	1	1	1	1	1	1

SAC = Sacramento Valley, IMT = Intermountain Valley

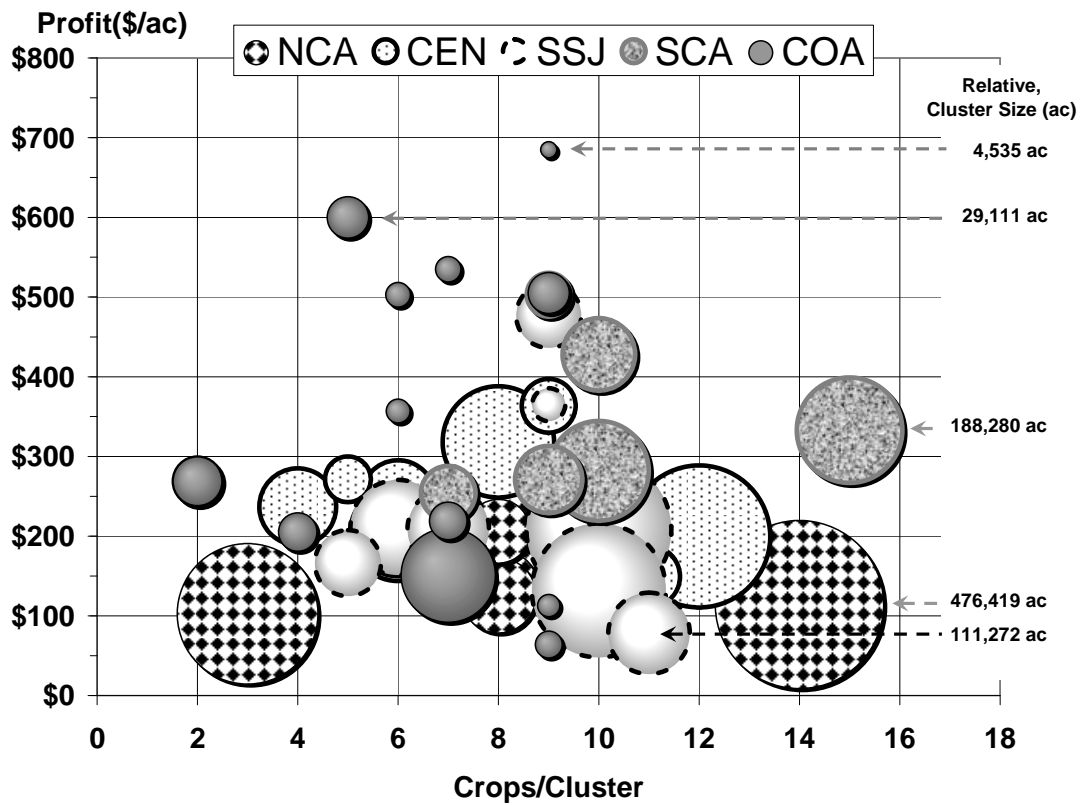


Figure 4: Average profit for all crops and acres in each of 45 cropping system clusters for all 5 regions. Size reflects cropland acres in each cluster with selected areas reported on the right hand side.

**Table 6: Net change in acreage by crop for a long-term, average \$20/acre increase in canola profit in the NCA Region**

1,538,984	Acres	476,419	82,923	332,849	261,446	33,975	68,550	95,470	109,203	78,148
Crop	NCA-ALL	NCA-C1	NCA-C2	NCA-C3	NCA-C4	NCA-C5	NCA-C6	NCA-C7	NCA-C8	NCA-C9
Alfalfa	0	0	0	0	0	0	0	0	0	0
Barley	(1,000)	(1,000)	0	0	0	0	0	0	0	0
Beans	(11,000)	(2,000)	0	0	0	0	(1,000)	(6,000)	0	(2,000)
Corn	(11,000)	(2,000)	0	(10,000)	0	0	0	0	0	1,000
Melons	0	0	0	0	0	0	0	0	0	0
Oats	(91,000)	(88,000)	0	0	0	0	(2,000)	0	0	(1,000)
Onions	0	0	0	0	0	0	0	0	0	0
Potatoes	0	0	0	0	0	0	0	0	0	0
<b>Rice</b>	<b>11,000</b>	<b>0</b>	<b>0</b>	<b>7,000</b>	<b>0</b>	<b>0</b>	<b>1,000</b>	<b>3,000</b>	<b>0</b>	<b>0</b>
Wild Rice	0	0	0	0	0	0	0	0	0	0
Safflower	(1,000)	0	0	0	0	0	0	(1,000)	0	0
Sorghum	0	0	0	0	0	0	0	0	0	0
Sugarbeets	0	0	0	0	0	0	0	0	0	0
Sudangrass	(17,000)	(17,000)	0	0	0	0	0	0	0	0
Tomatoes	0	0	0	0	0	0	0	0	0	0
Wheat	(10,000)	(2,000)	0	(1,000)	0	0	(1,000)	(3,000)	0	(3,000)
<b>Canola</b>	<b>132,000</b>	<b>113,000</b>	<b>0</b>	<b>4,000</b>	<b>0</b>	<b>0</b>	<b>4,000</b>	<b>6,000</b>	<b>0</b>	<b>5,000</b>
Ac-ft of Water	0	0	0	0	0	0	0	0	0	0

\* Historical acres (top row) were summed as presented in the County Agriculture Commissioner (CAC) data. Optimized acreage data is rounded to nearest thousand to reflect the normal loss of significant digits in the programming model.

**Table 7: Net change in acreage by crop for a long-term, average \$40/acre increase in canola profit in the NCA Region**

Cluster share of region		31.0%	5.4%	21.6%	17.0%	2.2%	4.5%	6.2%	7.1%	5.1%
1,538,984	Acres	476,419	82,923	332,849	261,446	33,975	68,550	95,470	109,203	78,148
	NCA-ALL	NCA-C1	NCA-C2	NCA-C3	NCA-C4	NCA-C5	NCA-C6	NCA-C7	NCA-C8	NCA-C9
Alfalfa	(3,000)	(2,000)	0	0	(1,000)	0	0	0	0	0
Barley	(16,000)	(13,000)	0	0	0	0	0	0	(3,000)	0
Beans	(70,000)	(28,000)	(5,000)	0	(8,000)	(4,000)	(1,000)	(11,000)	(9,000)	(4,000)
Corn	(51,000)	(29,000)	(1,000)	(10,000)	(5,000)	(1,000)	(1,000)	0	(3,000)	(1,000)
Melons	(1,000)	(1,000)	0	0	0	0	0	0	0	0
Oats	(124,000)	(88,000)	(2,000)	0	(23,000)	(1,000)	(4,000)	0	(3,000)	(3,000)
Onions	0	0	0	0	0	0	0	0	0	0
Potatoes	0	0	0	0	0	0	0	0	0	0
<b>Rice</b>	<b>9,000</b>	<b>(2,000)</b>	<b>0</b>	<b>7,000</b>	<b>0</b>	<b>0</b>	<b>1,000</b>	<b>3,000</b>	<b>0</b>	<b>0</b>
Wild Rice	(4,000)	(4,000)	0	0	0	0	0	0	0	0
Safflower	(9,000)	(2,000)	(1,000)	0	(1,000)	0	0	(3,000)	(1,000)	(1,000)
Sorghum	(1,000)	0	0	0	(1,000)	0	0	0	0	0
Sugarbeets	(5,000)	0	(1,000)	0	(2,000)	0	0	0	(1,000)	(1,000)
Sudangrass	(17,000)	(17,000)	0	0	0	0	0	0	0	0
Tomatoes	(1,000)	(1,000)	0	0	0	0	0	0	0	0
Wheat	(113,000)	(45,000)	(10,000)	(4,000)	(17,000)	(5,000)	(3,000)	(6,000)	(17,000)	(6,000)
<b>Canola</b>	<b>413,000</b>	<b>233,000</b>	<b>21,000</b>	<b>7,000</b>	<b>59,000</b>	<b>12,000</b>	<b>8,000</b>	<b>18,000</b>	<b>39,000</b>	<b>16,000</b>
H <sub>2</sub> O, Ac-ft	(263,000)	(148,000)	(17,000)	0	(32,000)	(11,000)	0	(15,000)	(29,000)	(11,000)

\* Historical acres (top row) were summed as presented in the County Agriculture Commissioner (CAC) data. Optimized acreage data is rounded to nearest thousand to reflect the normal loss of significant digits in the programming model.

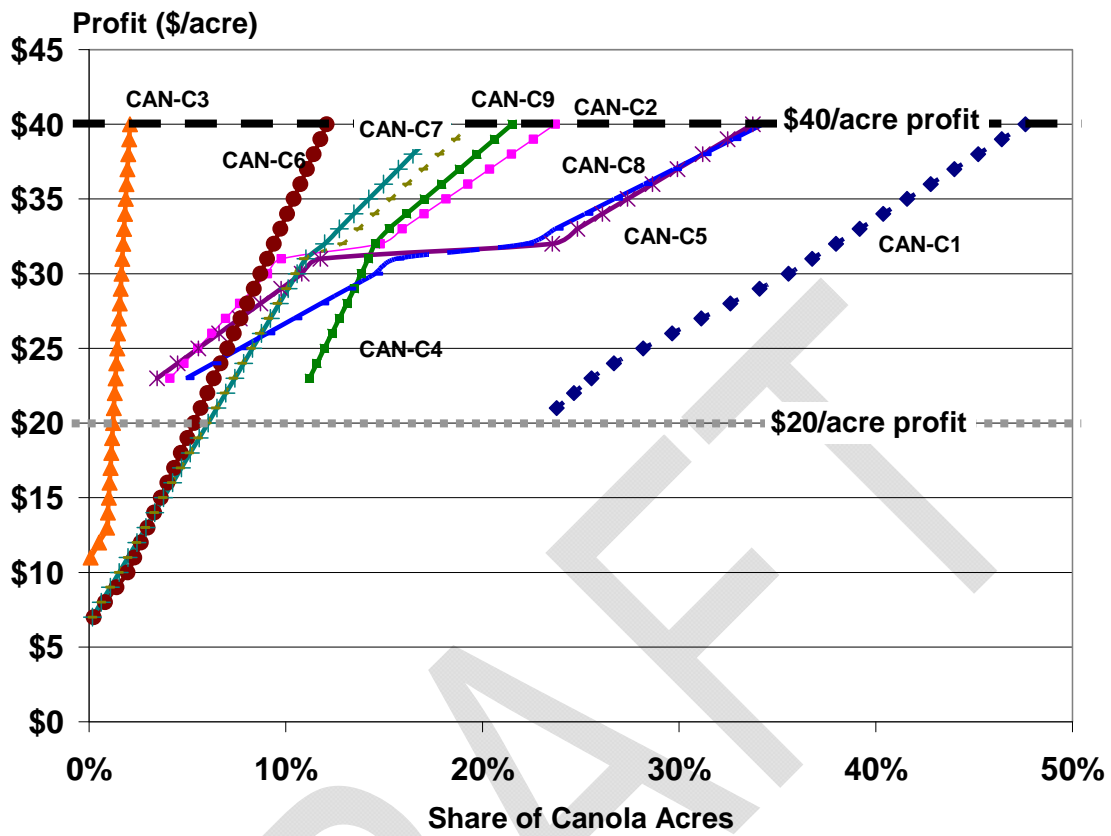


Figure 5: Canola adoption based on price of canola and canola acreage share of the cluster in Region NCA

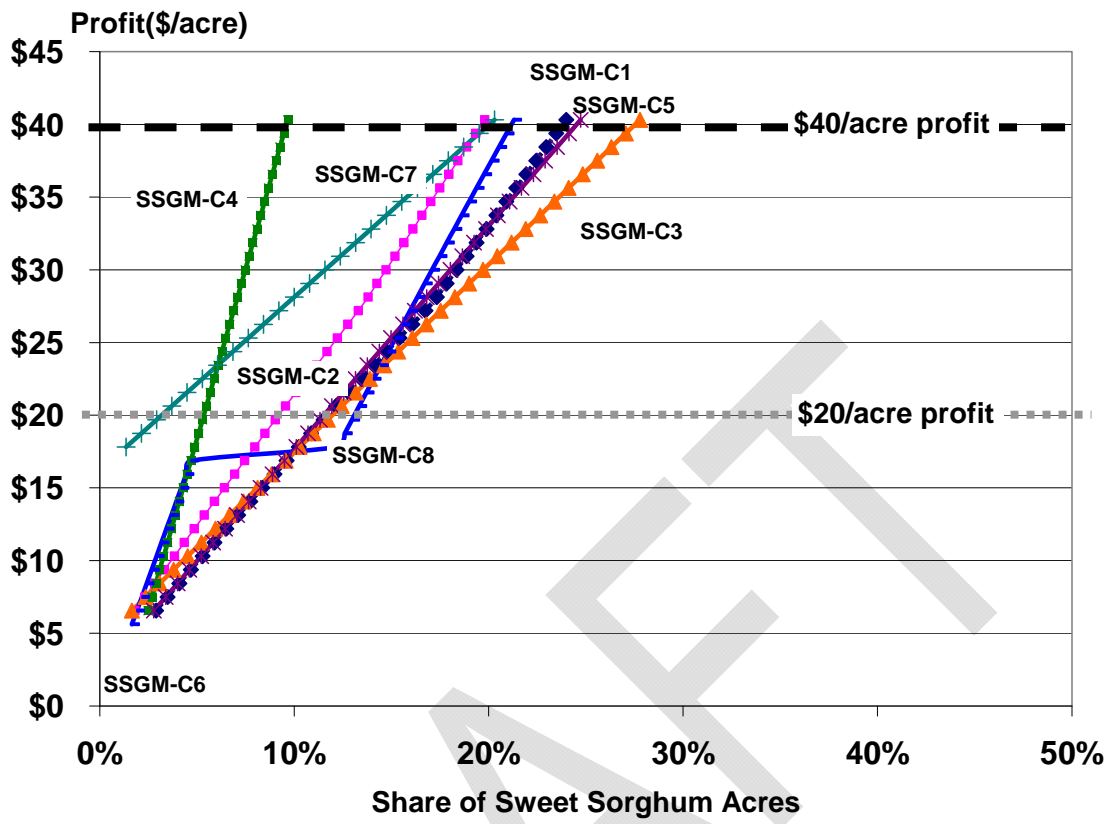


Figure 6: Sweet sorghum adoption based on price of sweet sorghum and sweet sorghum acreage share of the cluster in Region SSJ



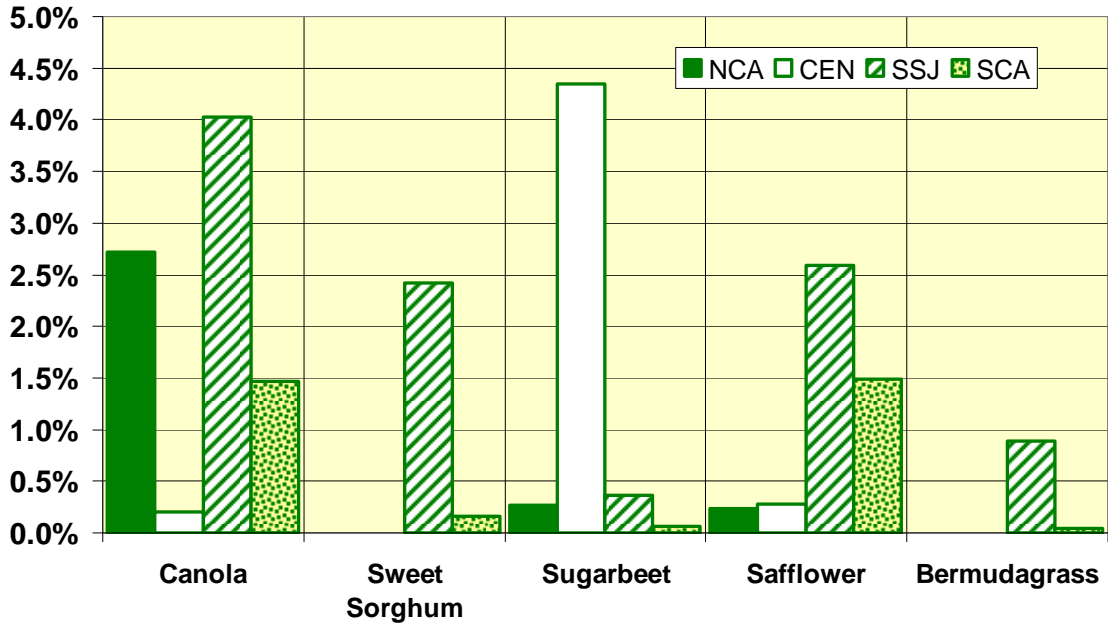


Figure 7: Region-level percent changes in canola production and water utilization at a long-term \$20/acre profit increase in canola

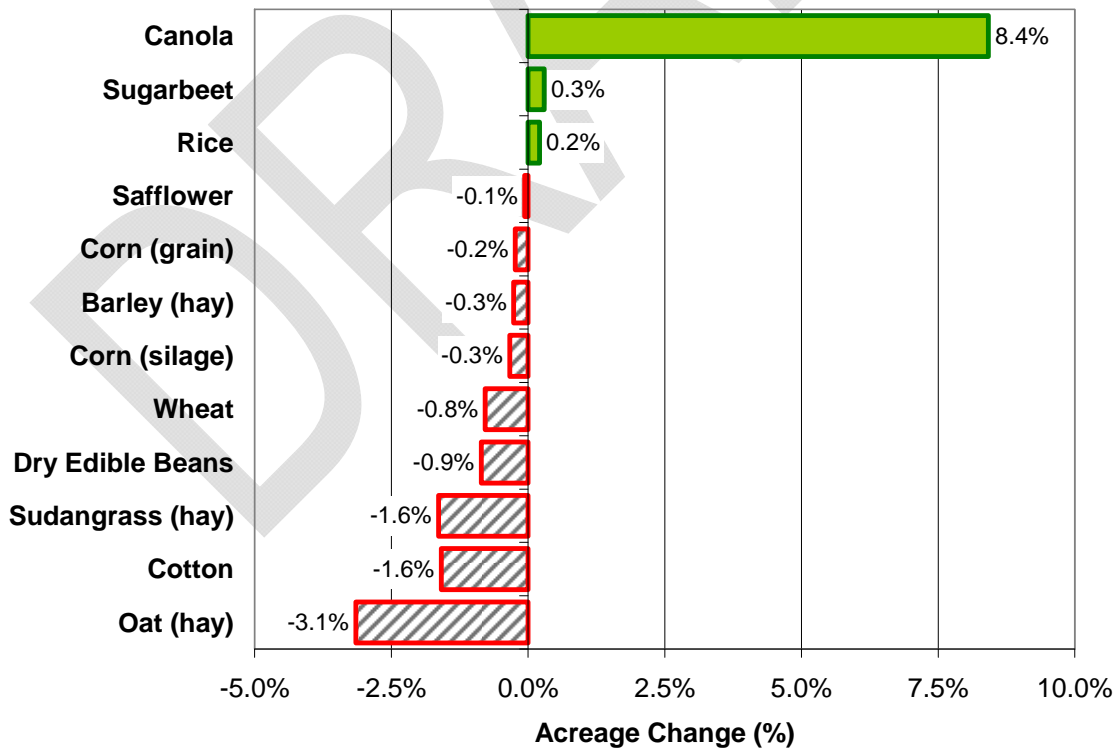


Figure 8 : State-level percent change in all crop production acres at a long-term \$20/acre profit increase in canola

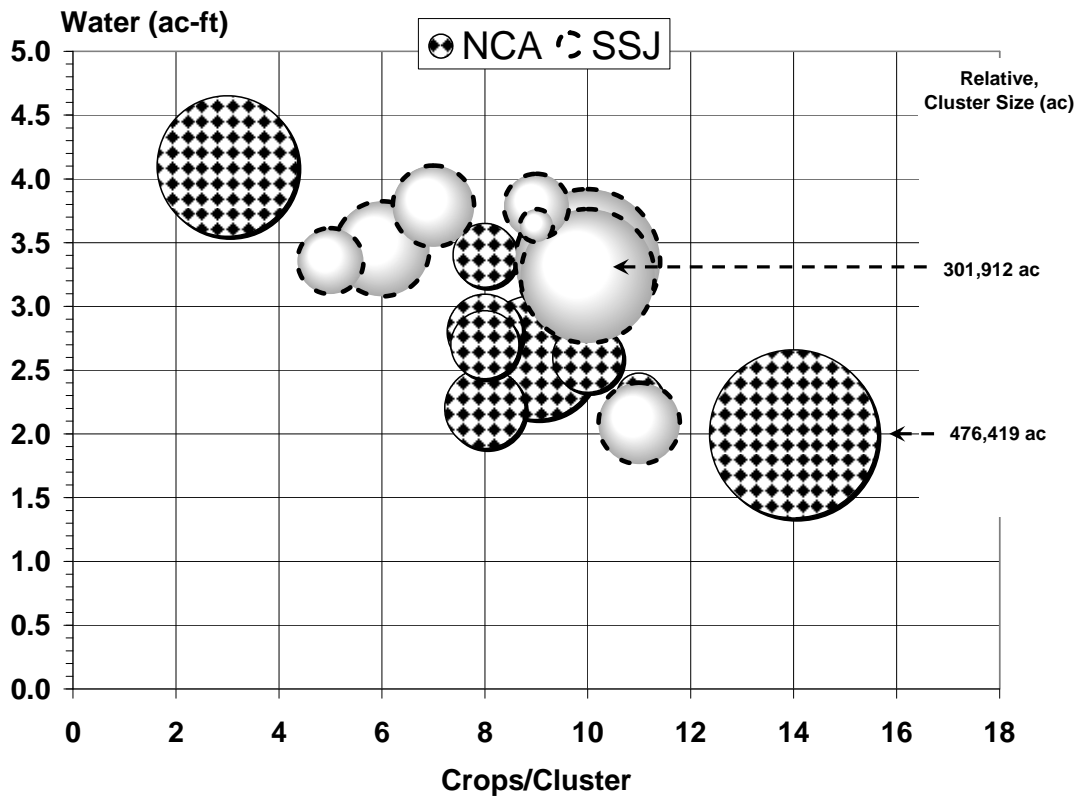


Figure 9: Comparison of crop number and water use for the NCA regional cropping clusters and the SSJ regional cropping clusters