SESSION 7: OPEN SESSION

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ADVANCED TECHNOLOGY AND MODELING SUPPORT BIOFUEL PRODUCTION FROM BEETS IN CALIFORNIA

Soutien de la production de biocarburant provenant de betteraves sucrières par technologie avancée et modélisation en Californie / Unterstützung der Produktion von Biokraftstoff aus Zuckerrüben in Kalifornien durch fortschrittliche Technologie und Modellierung

ABSTRACT

A farmer owned cooperative has formed to create ethanol from sugar (energy) beets in California's San Joaquin Valley. If successful, beets will be planted and harvested year-round, ethanol will be made directly from ground roots, and several energy by-products from crop biomass will be created in an integrated biorefinery. California's Low Carbon Fuel Standard (LCFS) encourages production of ethanol from beets with the lowest associated fuel carbon intensity (CI: g CO_{2eq} MJ^{-1} of energy) and greenhouse gas (GHG) emissions. Integrated economic optimization and life cycle modeling (LCA) based on actual production data and biorefinery design is being used to optimize crop rotations and agronomic practices, and to quantify and minimize fuel CI and correlated GHG emissions. Initial CI estimates for beet production are reported as 17 g CO_{eq} MJ^{-1}, and for the fuel including transportation and biorefinery GHG emissions are reported to be 26 g CO_{2eq} MJ^{-1}, based on estimated average daily root and sugar yields of 90 t ha^{-1} and 14.8 t $ha^{-1}$for 330+ days per year, without accounting for indirect land use change emissions (ILUC). Depending on the success of enzymatic digestion of root marc, ethanol yields are estimated to be 9000 to 11200 L ha^{-1}. Crop substitution, needed for ILUC estimates, is quantified. New technology that reduces GHG emissions per ton of roots such as herbicide tolerance, reduced tillage, precision application of fertilizer, and drip and digitally managed overhead irrigation systems all are encouraged by the need to reduce biofuel CI and can be quantified at the cropping system level using the modeling approach described. New uses for sugar beets and new processing technology may make possible expanded beet production in many locations without sugar factories for markets, and provide an important new pathway for sugar beet cultivation in the future.

INTRODUCTION

Since 1870, 11 sugar factories have been built throughout California. But he last sugar beet factory in northern California closed in 2008, ending more than 140 years of beet production in the region, and leaving only one operating in the state, in Brawley, California. Subsequently, a farmer-owned cooperative formed in the same San Joaquin Valley region to develop an alternative biofuel business based on making ethanol from sugar beets to support resumption of beet production. This group is constructing a pilot scale facility to manufacture 3.84 Ml/y of ethanol starting in fall 2014 using novel technology. A second, privately held group has also begun developing a sugar beet –based ethanol business further north near Stockton, California.

Several factors make possible the use of beets for biofuels in California: (1) The state's Low Carbon Fuel Standard (LCFS)[1], which is feedstock neutral and rewards efficient feed stock production financially, (2) increasing and large root and sugar yields combined with improving resource use efficiency based on new technology, (3) prospects for 12 month harvesting, and (4) the use of new transformation technology to convert beets to ethanol. Crop rotations including beets are evaluated using an economic optimization model, and greenhouse gas emissions are accounted using life cycle assessment (LCA). Together, these methods allow the economic price and location within California of

[1] http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

areas most suitable for beet production to be determined together with regionally-specific estimates of the carbon costs of feedstock production. Crop displacement is accurately estimated by the model and provides a precise basis for more accurate Indirect Land Use Change (ILUC) values. Data used by the optimization model is also needed for Life Cycle Assessment, and can be used to track improvement over time in resource use efficiency (RUE) at both the crop and cropping system levels on participating farms, and for other factors related to sustainability assessment.

Policy background

Two major regulations influence biofuel production in the United States (table 1). At the national level, the US EPA enforces the Renewable Fuel Standard[2], which mandates minimum amounts of alternative fuels, and minimum thresholds for greenhouse gas reductions (GHG) compared to conventional gasoline and diesel fuels. California has a different regulation in addition, called the Low Carbon Fuel Standard. This requires a 10% reduction in fuel GHG emissions by 2020, and allows obligated parties to determine how to achieve that goal. In effect, this means that alternative fuels with very low GHG emissions levels are encouraged, and that increasing resource use efficiency in feedstock production is stimulated and rewarded. Credits from both regulations can be combined and provide additional financial incentives. Together, all of these policies create an opportunity within California for innovative alternative fuel production businesses to develop. The low carbon fuel standard does not distinguish between food and non-food feedstocks. Instead, the most efficient feedstocks that result in biofuels with lowest GHG emissions per unit of fuel regardless of type are encouraged.

Increasing yields, improving resource use efficiency (RUE)

As in other areas, sugar beet root and sugar yields have increased over time in California (fig. 1) and now occur at quite high yield levels, especially for 9 to 10 month long crops (fig. 2). Increasing yields, while minimizing the resources used to achieve the same or higher yields makes possible the use of crops, including beets, for bioenergy purposes. The greater the difference between the energy costs of feedstock production and the energy yields derived from the feedstock, the lower the GHG emissions associated with that feedstock and the greater value it has in the market place. Less is needed per liter to allow fuel to meet the 10% transportation fuel carbon intensity[3] reduction mandated by the LCFS.

As yields increase, the proportion of energy and the costs of production associated with tillage, stand establishment, background fertilization with P materials, and the fixed costs of ownership and management decline as a proportion of total crop costs (DE WIT, 1992). Variable inputs, like fertilizer N and irrigation may increase with yield, but the financial incentive provided by the LCFS to minimize feedstock and fuel CI supports efforts by agronomists and farmers to achieve maximum yields at the minimum level of input use needed for optimum yields.

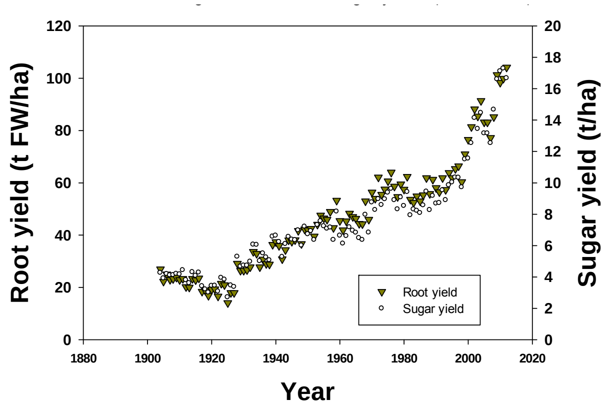


Fig. 1: Long-term trends in California for root FW and gross sugar yields from 1907 to 2012. From 2008, only yields from the Imperial Valley are available. Increasing yields support increases in resource use efficiency. Data from the California Beet Growers Association and other sources (PANELLA *et al.*, 2014).

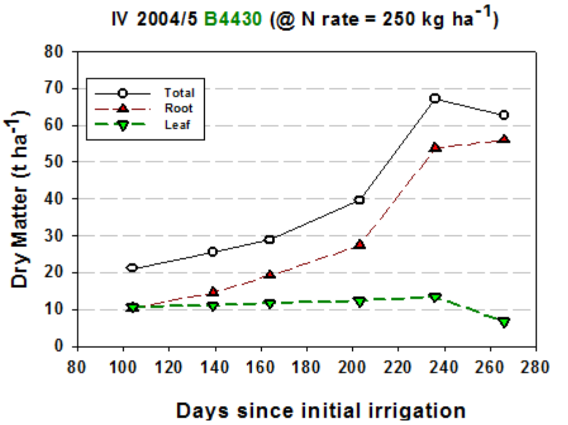
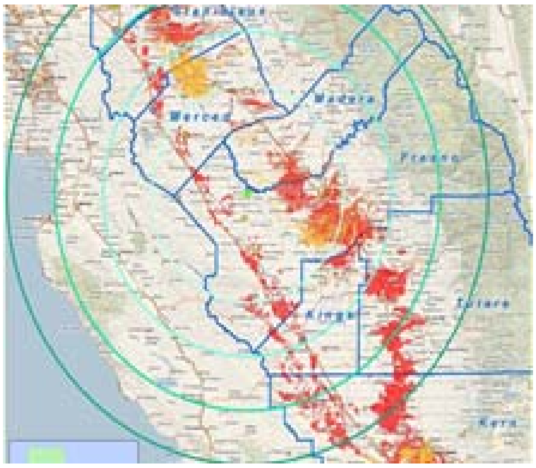


Fig. 2: Dry matter content of a nine month crop harvested in July in the Imperial Valley from research trials at the UC-Desert Research and Extension Center. Root FW yields equaled 157 t/ha in these plots. Based on these yields, estimated per ha ethanol yields equal approximately 16,000 L ha^{-1} (KAFFKA data, based on KAFFKA, 2007).

[2] http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm
[3] CI: calculated as $gCO_{2eq}\ MJ^{-1}$

Year round harvesting and root quality

California has a Mediterranean to semi-arid climate that allows year-round sugar beet growth. Historically, beet production in the central valley of California required some crops to be grown for 12 months, with planting occurring in late spring followed by harvest the following spring. These beets allowed the sugar factories to begin operation in April after the winter rainy season ended and continued through October or early November. Also supporting the factory were crops planted in autumn and harvested the next summer, and others planted in early winter and harvested the following autumn. Harvest ended in autumn because most beets were produced on clay soils and rainfall in fall made fields too wet for harvest. The development of self-propelled harvesters in Europe that can safely be used on moister soils, and a shift to production on coarse textured soils for late fall-winter harvest, will allow year-round harvesting under most normal circumstances in California for the first time (fig. 3A, B).



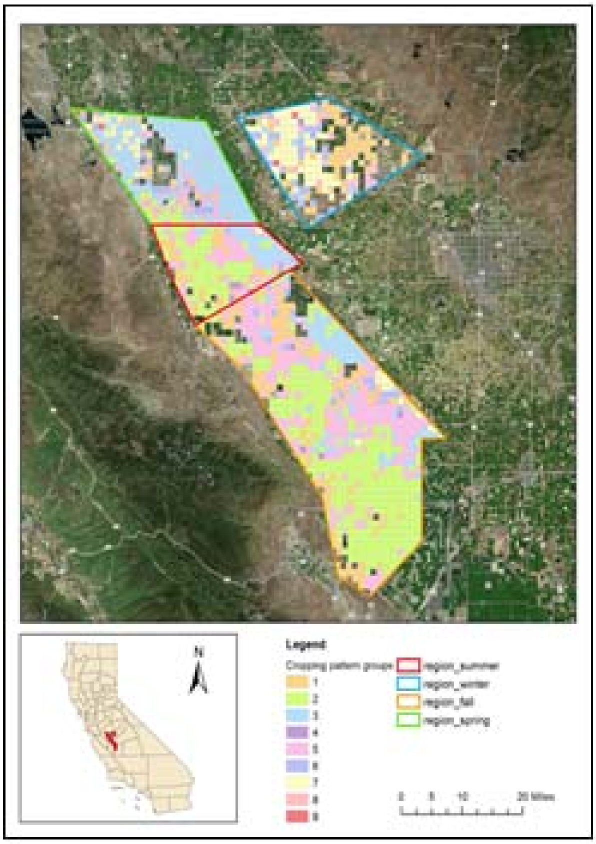


Fig. 3a: Location of Mendota biorefinery and coarse textured soils (colored) suitable for winter (rainy-season) harvest. Four harvest. 3B: Four anticipated seasonal harvest regions and distinctive cropping systems with each area. In each system, beets will be planted and harvested at different times, and affect cropping patterns differently. Based on KAFFKA *et al*., 2014.

A second important factor that contributes to the possibility for year-round harvest is the relative influence of root quality. Declining root quality, harmful from a sugar refining perspective may not be as disadvantageous when beets are used for other purposes. When sugar factories were operating, declining root quality in autumn led to reduced sugar recovery and an end to harvest in mid-October to early November, before weather conditions forced an end to the harvest campaign. Root quality declined in autumn as roots increased N uptake and accumulation after the hot summer (fig. 4), reducing the recoverable sugar yield. Similar declines in quality occur in sugar beet producing regions with mild autumn periods, especially in Mediterranean regions (BARABANTI *et al.*, 2007). However, yeast used for ethanol production require nutrients, including N. The impurities in beets reduce the needs for inputs to support yeast activity. Similarly for bacterial cultures present in anaerobic digestion (AD) systems, impurities do not reduce, but may increase biogas yield and can be recovered and recycled as fertilizer for succeeding crops (SUHARTINI *et al.*, 2014; DEMIRAL & SCHERER, 2011). Declining root quality in autumn is expected to have a less adverse effect on ethanol yield. Unrecovered root DM can also be used in an associated AD system for biogas recovery, and nutrients in AD effluents can be recycled as fertilizer.

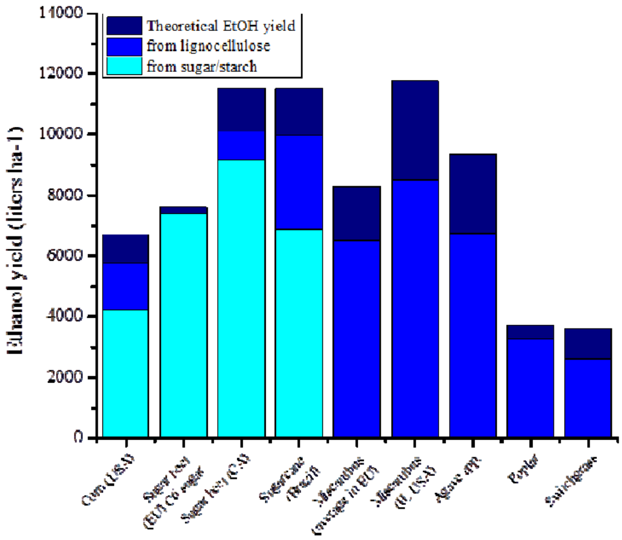


Fig. 4: Potential ethanol yields and technological availability for selected feedstocks. Crops like beets can be produced in California (Sugar beet CA) with high yields and efficiency and manufactured into fuels using current or near-term technology at yields equal to or greater than other feedstocks. Cellulosic or low quality feedstock sources have been slow to enter the market, and are less likely to be produced. Light blue: current or simple technology; mid-blue: new or pilot-scale technology; dark blue: no current technology available-the theoretical conversion limit. Data from diverse sources (KAFFKA *et al.*, 2014).

New analyses, new technology

Because public policy issues strongly influence the use of crops for energy, analytical models and methods of carbon intensity measurement are needed to help achieve policy objectives, including GHG reductions and sustainability. The current pathway for ethanol production from beet sugar used in Europe involves using surplus sugar stored as thick juice and conversion to ethanol. This pathway involves accounting for all the energy costs of large scale sugary refineries and results in fuel CI values based on attributional life cycle assessment (ALCA) that are commonly estimated in the range of approximately 40 to 50 as gCO_{2eq} MJ^{-1} (DEVRIES, 2012; IEU, 2014). ALEXIADES (2014) report 26.5 gCO_{2eq} MJ^{-1} as a preliminary estimate for ethanol produced from beets in the San Joaquin Valley. These values place ethanol derived from beet sugar in a more competitive position than most ethanol from maize, and average values for sugarcane ethanol according the California Air Resources Board accounting (table 1). In the San Joaquin Valley however, there are no operating sugar refineries or any surplus sugar. Alternative methods for processing beet roots for ethanol and other bio-products are needed.

Table 1: California ARB CI Look-up Table (gCO_{2eq}/MJ) [Selected Values, March 2014)

Pathway	Direct	ILUC	Total
CARBOB (gasoline)	**99**		**99**
Corn EtOH (Midwest avg.)	**69.4**	**30 (24)**	**99.4 (93.4)**
CA avg.	**65.66**	**30**	**95.66**
CA dry mill/wet DDGS	**50.7**	**30**	**80.7**
Brazilian avg. sugarcane	**27.4**	**46 (22)**	**73.4 (49.4)**
Br. Sugarcane with energy credit	**12.4**	**46 (22)**	**58.4 (34.4)**
Dairy digester gas (CNG)	**13.45**	**0**	**13.45**
Land-fill gas	**11.26**	**0**	**11.26**
Used cooking oil to biodiesel	**11.76**	**0**	**11.76**
corn oil from DDGS	**5.9**	**0**	**5.9**

Source: http://www.arb.ca.gov/fuels/lcfs/workgroups/workgroups.htm#pathways

To assess the likelihood of bioenergy crop adoption in diverse regions of the state, a multi-region, multi-input and multi-output model that was developed for California, the Biomass Crop Adoption Model (BCAM) was used. This model uses positive mathematical programming (PMP) methods to capture local marginal cost information to calibrate the model to previously observed cropping patterns in the region (KAFFKA *et al.*, 2014; KAFFKA & JENNER, 2011; HOWITT, 1995). Cropping patterns are based upon farmers' choices and behavior in the near recent past throughout California. The outcome is an estimate of the economic conditions and crop substitution patterns resulting from adoption of likely bioenergy feedstocks crops in the state, based on existing location-specific conditions found across the state. Besides adoption prices, model results include crop substitution, and a range of crop displacement and adoption effects, some of which are complex. Model details are provided in KAFFKA *et al.,* (2014) and KAFFKA & JENNER (2011). Predicted beet crop adoption by region and price, and crop displacement are presented in table 2. New ethanol production businesses in both the Sacramento Valley and San Joaquin Valley regions have been announced, consistent with model predicttions about the competitiveness of beet crops in these regions that once included sugar factories.

To create ethanol, roots must be processed in ways that minimize the energy required and maximize the recovery of ethanol and other valuable bio-products. Two different pathways are being investigated in California for ethanol from beets (table 3, Scenarios 2 and 3), but there are others that have been proposed in the literature that involve separating sugar from beets, without additional steps needed to refine sugar for human consumption. If one or more of these technologies prove viable, it would potentially expand the use and land area devoted to beet crops in many areas of the world.

Table 3 lists the comparisons of selected alternative sugar beet processing technologies versus those used at a traditional sugar factory. Beet pretreatment is similar for most selected alternative processes as found at conventional sugar factories and is well-known. It involves washing and slicing the washed beets into cossettes. Sugar is extracted from cossettes by diffusion in hot water with pH control to prevent sugar inversion, producing raw juice. Thick juice follows after removal of the molasses fraction and evaporation of water. After decolorization, thick juice is further dehydrated and stored for later processing (ASADI, 2007). The conventional sugar process produces crystalline sugar with molasses and beet pulp residues for animal feed. A conventional sugar factory has the option to put thick juice in storage and process it later in the year after the harvest period. Thick juice storage is common in all sugar operations with short harvest periods and allows longer factory operation. In the EU, some thick juice is converted back to ethanol.

The proposed Tracy ethanol plant will rely on a process that ferments raw juice to ethanol, sparing all other additional steps associated with the manufacture of food grade sugar. Raw beet juice can be fermented with high efficiency and alcohol concentration could reach 15% v/v. From juice to ethanol, all fermentable sugars could be used for ethanol production (not only sucrose).

Table 2a:. Crop adoption and location from the BCAM model (2007 prices), KAFFKA *et al.*, 2014.

Price of Sugarbeet ($/ton)	Sacramento Valley	Northern San Joaquin Valley	Sothern San Joaquin Valley	Cumulative Adoption
$ 37.80	1,568			1,568
$ 37.90	44,470			46,039
$ 38.50		13,457		59,495
$ 39.00		44,470		103,966
$ 39.40	94,688			198,654
$ 39.70	3,339			201,993
$ 39.80	109,588			311,581
$ 39.85		10,025		321,606
$ 39.90	3,076			324,682
$ 51.45			9,433	334,115
$ 51.90			396	334,511
$ 53.20			2,530	337,041
Total acres adopted in each region	256,730	67,952	12,358	

Table 2b: Crops displaced by location from the BCAM model (Kaffka *et al.*, 2014).

Sacramento Valley			Northern San Joaquin Valley			Southern San Joaquin Valley		
Cotton	-68.54%	160,474	Sudan hay	-100.00%	16,876	Bean	-100.00%	17,932
Corn silage	-60.91%	102,314	Bean	-28.73%	11,990	Cotton	-3.48%	5,158
Oat hay	-11.08%	10,302	Corn	-6.58%	9,913	Oat hay	-6.72%	2,013
Rice	-11.07%	1,985	Rice	-0.19%	743	Corn silage	-0.26%	239
Bean	-1.62%	862	Wheat	-0.80%	691	Barley	-1.23%	92
An increase in crop production due to the adoption of sugarbeet (acres)								
Broccoli	0.19%	21	Oat hay	4.07%	3,755			
Wheat	2.07%	1,288						

Table 3: Alternative sugar recovery or energy production processes versus traditional sugar factory operation

Scenarios	pretreatment	Conversion (steps)	Product(s)	Byproduct(s)
1. Conventional sugar factory1.	Receiving---storage---washing, slicing	Diffusion---Raw juice---Thick juice---(decolorization)---crystallization	Crystalline sugar	Molasses, beet pulp for feed
2. Delta Dis-tillers Beets (Tracey, California) ethanol plant[2]	As above	Diffusion---Raw juice----ethanol fermentation + distillation	ethanol	Molasses, beet pulp, (CO_2)
3. Mendota bioenergy[3]	Washing, grinding, enzymatic liquifaction	Liquefaction (enzymatic hydrolysis & fermentation) + distillation	Ethanol, biogas	Effluent from anaerobic digestion as fertilizer
		Molasses---biogas		
4. Small-scale biorefinery[4]	Washing, slicing	Diffusion---Raw juice---Thick juice + ethanol---special crystallization	Crystalline sugar, ethanol	Molasses; industrial chemicals
5. TNO [5]	Washing, slicing	Diffusion---Raw juice---Thick juice + small particles for selective absorption @ 35°C ---release sugar @ 90°C	Crystalline sugar	Molasses; industrial chemicals

1. ASADI, 2007; 2. http://deltadistillerbeets.com/ ; 3. http://www.mendotabeetenergy.com/; see also http://cnas.tamu.edu/confsummaries/TheinMaungBiofuelFeasibilityPaper.pdf.; 4. BRUINS, M. E. & J. P. M. SANDERS (2012). "Small-scale processing of biomass for biorefinery." Biofuels, Bioproducts and Biorefining 6(2): 135-145. ; 5. TNO: https://www.tno.nl/content.cfm?context=kennis&content=IP_patent&laag1=17&item_id=17&Taal=2

Other processes modify the crystallization step via using different additional anti-solvents or adsorbents as listed in scenarios 4 and 5, respectively. Both scenarios 4 and 5 reduce the amount of water to be evaporated for sugar crystallization. In Scenario 4, ethanol is added to reduce the solubility of sugar in water. In Scenario 5, sugar is selectively adsorbed to special particles and then desorbed, evaporated and crystallized to separate sugar from water and other impurities. Both scenarios 4 and 5 could reduce the energy cost of processing since the water amount that must be evaporated would be reduced dramatically.

Scenario 3 is a different ethanol plant from Scenario 2, in that it involves different pre-treatments. Compared to sugar extraction processes, the whole beet is ground and liquefied using enzymes, which makes more sugars available for fermentation other than only the water soluble sugars. This scenario also eliminates diffusion, evaporation, and crystallization, with associated energy savings. This simplified pre-treatment and fermentation technology could improve overall efficiency compared to diffusion-based processes. Stillage from the process enters an anaerobic digestion system together with other biomass to create biogas. Water and nutrients are recycled.

Sugar can also be used to create numerous useful products, many with higher values than fuels. A partial list includes pectin, a number of organic acids (1,4 diacids: succinic, fumaric and malic, 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, and levulinic acid; several alcohols/polyols: ethanol, butanol, glycerol, sorbitol, and xylitol/arabinitol; and actones:3-hydroxybutyrolactone, furfural (WERPY & PETERSEN, 2004). The manufacture of bioproducts from sucrose represents a promising pathway for sugar beet producers and businesses in the future.

With the high yields of beets in California and increasing resource use efficiency, large yields of ethanol or other products per ha are possible that compare favorably or are superior to many crops that are commonly discussed as ideal bioenergy feedstocks (fig. 5). In addition, the relatively easy and inexpensive recovery of sugar from beets in an ideal form (sucrose) for subsequent transformation makes beets ideal feedstock. The capital costs of the technology needed and availability in the near term makes beet-based processes advantageous compared to other types of crop-based biomass that rely on newer, more capital-intensive transformation processes based on recalcitrant cellulosic biomass. The processes being developed in California have been evaluated at pilot scale or will soon be evaluated at pilot scale (KAFFKA *et al.*, 2014). The capital costs for construction of full-scale biorefineries are expected to be much lower than for cellulosic biorefineries.

Beets may be among the most favorable feedstocks for conversion to ethanol. By storing sucrose, the basic energy source for yeast is already present. An absence of lignin makes the fiber fraction of beets highly fermentable. Conversion is simpler and less likely to require expensive capital expenditures. Year round supply in California further enhances efficiency by allowing a biorefinery to operate year round and concentrate on a consistent feedstock. If low carbon intensity feedstocks can be produced, a reliable market for these fuels will be supported by the state's LCFS. Alternative sugar extraction technologies, or root processing methods, should allow other regions to support beet-based bioenergy and bio-product businesses as well, and is a promising pathway for the future.

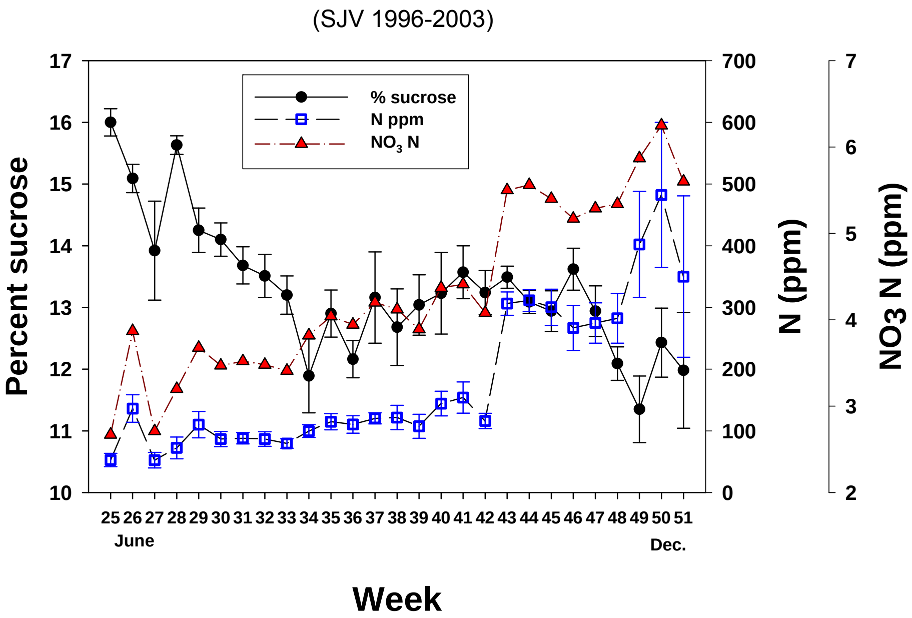


Fig. 5: Root quality characteristics of all commercial contracts in the northern San Joaquin Valley supporting the Spreckels Sugar Factory at Mendota during 1996-2003. Averaged by week. Error bars are standard errors. By October, root sucrose content declined and impurities increased. Similar responses have been reported in other locations with Mediterranean climates. (Spreckels Sugar Company data).

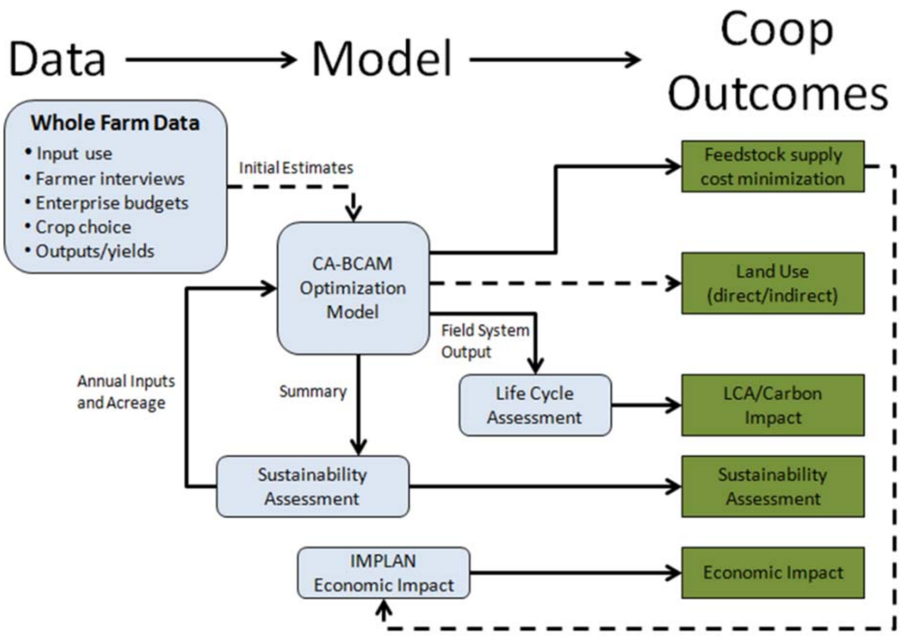


Fig. 6: Data on crop inputs and yields from all the crops produced on farms where energy beets will be grown can be used to quantify actual attributional carbon costs (ALCA) and the consequential costs of changes to farming systems, including crop substitution. Specificity is needed for the performance standard characteristics of the LCFS to be effective. The same information needed for Carbon Intensity calculations also can be used for sustainability assessment (Kaffka *et al.*, 2014).

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