SWITCHGRASS AND ALFALFA AS CELLULOSIC BIOFUELS: POSSIBILITIES AND LIMITS

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ABSTRACT

Perennial crops which produce high cellulose yields have the potential as non-fossil fuel energy sources for the future, due to a number of environmental benefits, and potentially higher energy yields compared with grains. However, considerable technical barriers for cellulosic conversion to fuel remain. From an agronomic perspective, alfalfa and switchgrass have important positive features as cellulosic feedstocks. They are both perennials which have environmental advantages and are high yielding in California. Alfalfa has the advantage of zero N fertilizer requirement, wide adaptation, known production systems, and significant environmental benefits. In the past 2 years, we have experimented with switchgrass under irrigation at 4 locations in California, and yields of 10-15 tons/acre appear to be feasible in the first year of production. A 'high productivity' multiple-use scenario for irrigated biofuels appears more appropriate than 'low input' strategies. This could be accomplished through different cuts for different purposes, or leaf-stem fractionation. This concept has the advantage of producing multiple-value streams, avoiding the food-food conflict, stabilizing supply, and increasing options for growers. The high demand for all forage crops (even straws) for other purposes will present an economic challenge for biofuel feedstocks. Potential cellulosic crops should be evaluated carefully from a range of perspectives, including water and N use, environmental impacts, and whole-system viability, to develop sustainable systems for the future.

Keywords: *Panicum virgatum*, *Medicago sativa*, energy crops, alternative crops

INTRODUCTION

There is no question that developing alternative energy solutions is one of the most pressing issues of our time. This is not only due to the eventual depletion of fossil fuels that all expect, but the continual and dramatic rise in fossil fuel demand worldwide.

The world population has grown from about 3 billion in 1955 to 6 billion currently, and is expected to grow to 9 billion by 2050, a span of approximately 4 generations. In addition to numbers of people, the per-capita energy consumption is also rising in many countries, a question of lifestyle and economic development. It is well known that Americans use more energy per-capita than other countries, but this is not a US-only phenomenon. Burke (2008 quoted by Friedman, 2008) conceptualized energy use as equivalent to a single American, and the country of America as an 'Americum'– that is 350 million people

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making above $15,000/year, with a developed economy and a penchant for consumerism. For many years there were only perhaps two 'Americums' in the world, one in North America and one in Europe, but in the past decade or so, China and India have each given birth to an 'Americum', due to the rise in prosperity and middle class in those countries, with a concurrent demand for energy. For example, China expects to construct 40 airports in the next several years, and Moscow now has 3 million cars, ten times as many in 1995. Many expect the world to have essentially 8-9 'Americums' in terms of energy and consumer demand by 2030 (Friedman, 2008).

The conversion of corn to ethanol (the dominant biofuel) has come into criticism for a range of reasons. Issues include the question of net energy yield (which may be marginal by some calculations), impact on land, soil erosion, fertilizer and water resources, questions about true impacts on global climate change, and impacts on human food production and prices. Perennial cellulosic biofuel scenarios have much higher (theoretical) energy yields, and avoid some but not all of these limitations. Biofuels need to be examined carefully for their practical viability and potential positive and negative features. Here, I explore the criteria for selection of cellulosic biofuels and the various possibilities for alfalfa and switchgrass grown under irrigation.

TYPES OF BIOFUEL CANDIDATES

Biofuels can be divided into the following categories:

- **Biodiesel Crops** (high oil crops that can be converted to diesel)
  - Canola, camelina, soybean, sunflower, jatropha, used frying oils
- **Grain Ethanol Crops** (starchy grains converted to sugar, then fermented)
  - Corn, sorghum, millets, other starchy grains
- **Sugar Ethanol Crops** (crops directly producing sugar then fermented)
  - Sugarcane, sugarbeet, sweet sorghum
- **Cellulosic Ethanol and Combustion Crops** (waste materials and dedicated energy crops)
  - Wood wastes, municipal wastes, poplar, switchgrass, corn & grain stovers, alfalfa, annuals and perennials.

Several of these options may have multiple energy pathways – for example, sugar crops such as sugarcane can provide both sugar for fermentation, and fibrous cellulosic component for either burning or fuel production. Forage growers will be primarily interested in cellulosic biofuel crops, since they fit into the harvesting systems that have been fully developed for hay and forage crops.

The potential viability of cellulosic feedstocks for energy conversion depends upon a series of criteria, but begins with their current economic value or lack of value. There is a likely hierarchy of potential feedstocks (see text box): those potential feedstocks with zero or negative value (e.g. they cost money to dispose of), and which required less concentration or transportation

Probable hierarchy of cellulosic sources for energy conversion:

- Municipal Wastes
- Forest by-products
- Agricultural Wastes
- Stovers, straws
- Dedicated annual and perennial cellulosic crops, including rapidly-growing trees

infrastructure (e.g. those such as municipal wastes already concentrated or piles of forestry by-products), are likely to be favored initially. However, if some of the ambitious billion-ton governmental goals listed by Perlack (2005) are to be achieved, dedicated energy crops must also be considered. This study estimates that 35% of the nation's biomass needs will need to be satisfied by dedicated perennial cellulosic crops, in addition to stovers, straws, agricultural and forestry wastes, and municipal waste streams. This paper is limited to cellulosic energy crop candidates, and here we consider primarily alfalfa and switchgrass.

CRITERIA FOR SELECTION AND SUSTAINABILITY OF CELLULOSIC FEEDSTOCKS

Don't Start with the Answer—Keep asking the Question! Although some proponents of biofuels may promote their favorite species, the appropriate choice of cellulosic species for a region is not immediately apparent. Side-by side comparisons are rare, particularly across a range of resource inputs and environments. Furthermore, analysis of the strengths and weaknesses of each choice, and the practical viability of such feedstocks under farming conditions are often lacking.

The most important criteria for selection of cellulosic biofuels are provided in the Table 1. It is clear that some species have significant advantages using one or more criteria, but no species has a complete advantage in all areas, and some have significant drawbacks. For example, most of the proposed cellulosic biofuels are grasses, which (contrary to some claims) require N fertilizers to maximize yields on almost all soil types. Alfalfa, fescue and bermudagrass may prove to be lower yielding than some of the tall tropical C4 grasses (such as elephantgrass), but have strong multiple-use scenarios and developed infrastructure, and are easy to establish and harvest.

Environmental Criteria are Important. Although the first most obvious criteria for a successful biofuel is high yield potential and high conversion output, there are several additional important criteria which must be considered when a species is selected. Environmental criteria (ecosystem services and lack of negative impacts) may be more important than other features, given the importance of global climate change issues, resource limitations, and government policy on crop choice. There have been frequently-voiced concerns about the environmental impacts of biofuels (Pimentel and Patzek, 2005). None of these factors are, by themselves, solely determinant, but must be weighed in the context of the whole system that can be actually implemented by farmers.

THE IMPORTANCE OF WATER AND NITROGEN

Water. Irrigation water, its availability, cost, and quality are the key determining features of western agriculture, indeed worldwide. Irrigation water determines cropping patterns, crop choice, and economics of crop production in the West. Water limitations are a key aspect of the environmental impacts of crops and will likely curtail biofuel production in many parts of India and China (http://www.iwmi.cgiar.org/). Water scarcity is a great concern for California, but large scale production of biomass for energy in this region will require at least some irrigation (Ercoli et al., 1999).

Table 1. Criteria for Species Selection of Cellulosic Biofuels:

- **High Biomass Yields.** High yields would reduce the cropping area needed for biofuels plants, and increase efficiency of resource use. This is likely to be one of the most important characteristics of biomass crops, but not the only one – yields must be considered along with resource use and other factors.
- **Quality of Conversion.** Not all cellulosic materials can be converted into biofuel with the same efficiency—cellulose is always entertwined with other compounds in the cell wall which differ by species. Conversion is also affected by supply of nutrients and water, and is also likely to be highly affected by plant stage at harvest.
- **Water Use Efficiency, Water Flexibility, and Salt Tolerance.** In the western US, the maximum DM produced per unit water may be more important than simply yield/unit land area. Crop survival through temporary droughts, and flexibility of water use can be more important than other factors. Salt tolerance would enable biofuels to be grown on marginal soils and with waste water.
- **Nitrogen Requirement.** N is the most frequently limiting nutrient in the earth's crust. N requirement is a major limiting factor due to its high fossil-fuel footprint and significant economic impact, influencing conversion and emissions. Crops with lower N requirements (such as alfalfa) may be favored.
- **Impact upon food production.** Candidate species which has less impact upon food production will be favored, particularly areas that are key food producing areas, such as California. Crops with do not compete with food acreage or water, or can be integrated with food production may be favored.
- **Multiple-use Scenarios.** Biofuels which can produce multiple economic or food products coupled with cellulosic feedstocks have advantages from both an economic and policy perspective. Some of the most successful crops (e.g. soybean) have multiple utilization patterns, which strengthen their economic viability.
- **Adaptation to Farming Systems.** Candidate species which can easily be adapted to existing farming systems, equipment, transport and crop rotation patterns have advantages over those which require significantly different equipment or changes in cropping patterns.
- **Utilization of waste/resource efficiency.** Species adapted to wastewater and salty conditions, poor soils, or utilize otherwise-wasted resources will be favored over those which compete directly for good soils and water.
- **Resistance to stress, weed, disease, insects, and production on poor soils.** Species which have high resistance to stress, pathogens, pests, and weeds, and ability to be produced under stressful conditions (heat, cold), or on poor soils would be favored.
- **Environmental risk.** Species which present significant environmental hazard, such as invasive weedy characteristics or other negative environmental features present new risks, even if they may be useful as biofuels.
- **Infrastructure Support.** Some crops have a well-developed seed industry, approved chemicals, commercial equipment, and lots of University research data to support their production. These crops will have early advantages for production.
- **Ecosystem Services.** The relative ability of a species to sequester additional soil carbon, reduce air pollution potential, conserve soil or other resources, provide CO_2 greenhouse gas benefits, and provide wildlife habitat provide additional benefits which would favor their selection

IRRIGATED BIOFUELS?

Whether California's $37 + billion irrigated food production system, could or should absorb biofuels is an open question. This is also the case in other irrigated regions. There are factors and arguments in that would either favor or reduce the viability of biofuels in irrigated systems. Irrigation water, its availability, cost, and quality are the key determining features of western agriculture, indeed worldwide. Irrigation water determines cropping patterns, crop choice, and economics of crop production in the West.

Are Irrigated Biofuels a Non-Starter? Not necessarily. Some would claim that biofuels should always be conceived for marginal areas, in rainfed regions. This is what we might call a 'low input' model – that biofuels should be produced on marginal soils without much N or water input. This is the predominant thinking behind the switchgrass efforts in the Midwest and South (note-the N aspect of this scenario should be questioned for any region, since most grasses respond to N fertilizer applications). While Production of biofuels in rainfed non-irrigated areas has some obvious advantages in terms of cost and resources, this doesn't necessarily eliminate the possibility of production in higher-yielding regions. The uncertainty of rainfall creates significant challenges to reliable feestock production in marginal rainfed regions; low yield or crop failure is a hazard, and makes investment in processing plants more risky for those regions. This is a major advantage of irrigation.

A 'High Yield' Model. California is the highest-value agricultural producer in the nation, with many important food crops, such as tomato, vegetables, nuts, wine grapes and fruits, beef, and dairy products. Yet in spite of these high-value crops, we also have more than 500,000 acres of irrigated pasture, 800,000 acres of small grains, 750,000 acres of corn for grain or silage, and about 1.4 million acres of hay crops, including alfalfa, and many acres of oilseeds, cotton, sugar crops, and other crops. These have significant uses and value, but some are frequently considered 'low value' crops. The point is that if economically-viable scenarios can be developed with comparable income potential to these crops, or could be grown to complement these crops, irrigated biofuels may have a place. This might be better conceptualized as a 'High-yielding', high value model, not a 'low input' scenario. Generally, once irrigation systems are developed, they are no longer 'low input'.

Thus, irrigation of biofuel production should not be eliminated out of hand, but presents its own challenges in terms of efficiency, supply, economics and competition for water with food crops. Selecting for biomass crops with high water-use efficiencies are critical to the success of biomass feedstock production in both irrigated and non-irrigated regions. There are

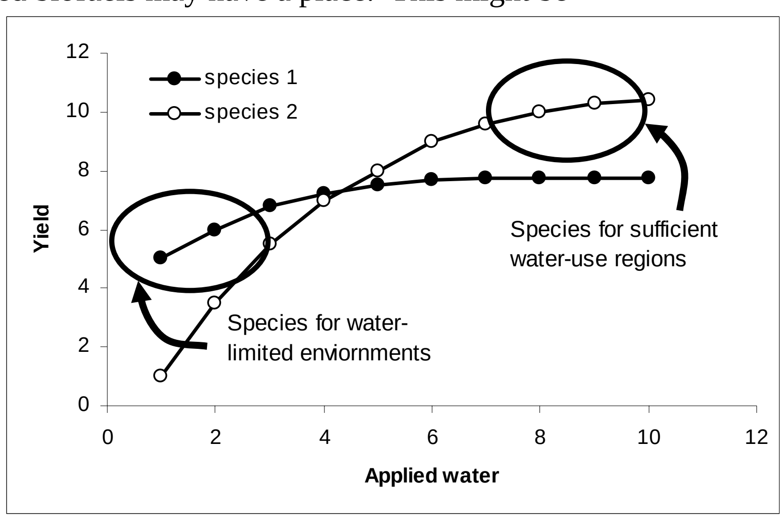


Figure 1. Hypothetical differences in biofuel response to irrigation water. While species 2 might be chosen for a plentiful irrigation water region, species 1 might be chosen for water-scarce areas, in spite of its lower yield

several scenarios for selection of species for different water-use scenarios (Figure 1).

Salinity. In addition to water quantity, it will be important to determine if water supplies of degraded quality (salinity or trace element issues) can be suitable for production of any of these biofuel crops. The San Joaquin Valley is among the most productive farming areas in the United States and yet salt buildup in these soils is threatening its productivity and sustainability (Schoups et al., 2005). It's estimated that from 200,000 to 300,000 acres in California are now classified as saline. Furthermore, in California approximately 240,000 acre ft of recycled water was used for agricultural irrigation in 2003. By 2010, the goal is to dispose of 1 million acre ft. of municipal waste water (www.swrcb.ca.gov/recycling/munirec.html); enough to irrigate approximately 300,000 acres of land. The production of perennial grasses and legumes biofuels on marginal lands (specifically salt affected) presents a potential win-win situation.

Nitrogen. Nitrogen (N) fertilizers are one of the key inputs for non-leguminous forage crops. Following water, N is the next most limiting growth factor in the production of food, feed and fiber crops. A vast amount of the energy costs for the production of biofuels is associated with fertilizer N inputs, and may constitute as much as 30% of the total energy budget for corn and switchgrass (Pimentel and Patzek, 2006). Such heavy reliance on N does not only negatively affect the environment, but also greatly reduces net energy outputs. Currently, the total synthetic N-fertilizer production for agricultural use passes 90 million tonnes of N annually. Unfortunately, a substantial quantity (e.g. 50%) of fertilizer-N is not used by the crop (Ladha et al., 2006), and can be lost in the form of various forms such as N_2O gas, NH_3, or leached from the soil as NO_3, causing contamination of ground water. N fertilizers are a major economic factor as well. Thus, for the production of feedstocks, high fertilizer-N use efficiencies are important. Additionally, legumes which do not require N fertilizers should be strongly considered.

THE ADVANTAGES OF PERENNIALS

Perennial crops, such as switchgrass and alfalfa, have some important advantages in the context of biofuels that need to be understood, particularly in comparison with annuals:

- Stand establishment costs are amortized over much longer period than annuals
- No tillage is required after establishment, reducing fossil fuel demand
- Rapid spring growth – maximizing photosynthesis over the season
- Rapid canopy closure to maximize solar energy capture.
- Deep roots of perennials improve nutrient uptake and drought avoidance
- High water use efficiency due to early rapid growth, high yields, and deep roots
- Efficient use of seasonal rainfall vs. irrigation.
- High N-use efficiency due to the same factors (alfalfa does not require N fertilizers)
- Protection of soil from Erosion (wind or water)
- Perennials suppress weeds – little need for chemical weed control measures
- Low insect pest infestation and low pesticide requirements
- Sequestration of carbon in plant perennial roots and soil rhizosphere
- Provision of wildlife benefits to landscapes

The major disadvantage of perennials is the lack of flexibility in switching crops, if water limitations occur. Long stand establishment periods for crops such as switchgrass and Miscanthus may be major limitations for some environments (not the case with alfalfa). Additionally, annuals often have very high growth rates within short periods of time compared with some perennial crops—thus their relative productivity should be measured and compared.

THE POTENTIAL OF ALFALFA AND SWITCHGRASS AS BIOFUELS

Alfalfa

Alfalfa is a well-known crop in the US and California. It is the 4^{th} largest crop in acreage in the US, and sometimes 3^{rd} largest in value, and is the highest-acreage crop in California. It was likely worth over $1 billion in 2008 in this state.

Yield potential of alfalfa under irrigation using current cutting schedules and varieties is well known. We have measured 12-16 tons/acre dry matter on small-plot trials with the best varieties, although average farmer yields are closer to 8.0 t/a in long-seasoned environments, such as California's Central Valley or deserts (statewide average is approximately 7.4 tons/a). Good growers on good soils can routinely attain 10-12 tons/acre in high-yielding areas. In shorter-seasoned environments, alfalfa yields are lower, more in the 4-8 t/acre range. Arizona maximum yields have been reported at nearly 24 tons/acre, but those are under very unusual long seasoned conditions with careful management. Cutting schedules have a very large influence on yield – as a result, average farmer yields have not increased for probably at least 10-20 years, largely due to shorter cutting schedules which improve quality for animal production, but reduce yields. Longer cutting schedules of alfalfa should increase yields a minimum of one ton/acre per year.

We routinely publish alfalfa yields from our variety trials at http://alfalfa.ucdavis.edu
In reports on biofuels, especially those with limited field testing or grower experience, it is important to differentiate between 'yield potential' or maximum yields, and those which actually can be attained by farmers or measured in experimental plots.

Important Advantages: Alfalfa is the most widely-adapted, highest yielding perennial legume (to my knowledge) in North America, probably the world. Its major advantage over grasses (as a biofuel) is the complete lack of need for N fertilizers from soil or fertilizer sources. This is due to an efficient system of biological N_2 fixation, which takes N from the air and makes it available to the plant. This seems to be a major issue overlooked by those promoting grasses as biofuels – since as energy prices rise, this will undoubtedly be a more important factor. N fertilizers require considerable fossil fuels for maximizing yields, a major issue with sustainability. From 2007 to 2008, prices of N fertilizers have approximately doubled – this alone should increase public interest in our crops that are effective N fixers. Additionally, alfalfa has a well developed infrastructure of seed companies, crop protection tools, farmer and research knowledge, equipment, and service providers, and significant wildlife benefits.
Disadvantages: The first and most obvious disadvantage of alfalfa is probably economic – there are many other uses for alfalfa, and it is a crop under high demand. However, this is

both a strength and a disadvantage—presumably acreage could expand to meet additional demand for other uses such as biofuels—and multiple applications would benefit growers by stabilizing the economics of crop production. Although economically, it is difficult to envision alfalfa as an energy feedstock when its worth exceeds $200/ton as a forage, economics are (as we all know) subject to change and to regional differences. Other potential disadvantages are lower yields compared with some grasses, and problems with conversion efficiency due to the high N content – however, these two issues have not been fully explored experimentally.

The most reasonable scenario for alfalfa as a feedstock is the 'multiple use' scenario – the fractionation of alfalfa into leaf-stem fractions, or the designation of some cuttings for cellulose, and some for high quality forage. This would serve two purposes: 1) Improve the quality and value of some cuttings of alfalfa, and 2) Lower the N content of the high stem fraction. If alfalfa were to be grown as a biofuel, it would almost necessarily have to be grown as a multiple-use crop, since in our irrigated environment, at least 4 cuts are appropriate, and there would be some harvests that would be absolutely appropriate as a forage (and not as a biofuel), and other cuts where biofuels might be of stronger interest.

Switchgrass

Switchgrass (*Panicum virgatum* L.) is a hardy, perennial warm-season rhizomatous grass which is native to north America. It can grow 4-7 feet tall, The leaves are 30-90 cm long, with a prominent midrib. Switchgrass uses C4 carbon fixation, which means that it is a fairly efficient at photosynthesis, and has advantages in conditions of drought and high temperature. Its flowers have a well-developed panicle, often up to 60 cm long. Also, unlike corn, switchgrass can grow on marginal lands and requires little fertilizer to survive. Switchgrass is not the only candidate as a cellulosic biofuel, but has been widely promoted as the most important candidate, especially for marginal lands.

In 2007, we planted 4 research trials in California on good soils on the UC research stations. This was in cooperation with Ceres, Inc., based in Thousand Oaks, CA.
In this study, we are evaluating the different lines, including new selections, and the adaptation of switchgrass under irrigated conditions to several locations within California. These 4 sites represent a wide diversity of environments, from North to South. *1) Tulelake* (Intermountain Research and Extension Center, Tulelake, CA). This is a cooler, short-season intermountain environment near the Oregon border. *2) Davis* (Plant Sciences Research Farm). This is a Sacramento Valley location (N. Central Valley), with generally cool night temperatures, but hot daytime temperatures. *3) Five Points* (West Side Research and Extension Center, Five Points). This is on fertile soils with hot temperatures, little night cooling. *4) El Centro.* (Desert Research and Extension Center, Holtville, CA). This is a very hot desert climate, with mild winters and scorching hot summers, and somewhat more salt-affected.

Preliminary Yield Estimates: Establishment of switchgrasss was successful, and several of the released and experimental lines performed well at all locations. Preliminary yields were highest in cooler areas in the establishment year (2007), but the warmer portions of the state showed higher yields in 2008. It is important not to make decisions based upon seeding year conditions, since second and third year yields are likely to be higher than seeding-year yields. The second year yields are not presented here in completion, since harvest is not yet completed as of mid-November. However, these trials have enabled us to gain a preliminary look at the yield potential of switchgrass under irrigation. From these trials, it appears as if the yield potential of switchgrass is in the 10-15 tons/acre range in the highest yielding environments (Five Points, Davis, El Centro), and could be higher. These were 2-cut systems at Davis and Five Points, a 1 cut system at Tulelake, and a 3-cut system at El Centro. The crops generally performed well, with good agronomic characteristics, but we observed some lodging at West Side site.

Advantages. The preliminary advantages of switchgrass appear to be its high yield, and adaptation to several environments. It has performed well under hot conditions. Several of the trial exhibited excellent soil cover, with few weed problems after full establishment. Switchgrass may be most appropriately managed as a 2 to 3 cut system in the warmer areas of California under irrigation.

Disadvantages. We have conducted some work on the N needs of switchgrass. In the first full year of production, it has responded to N fertilizers, at least to a degree (data mot shown). A major disadvantage of switchgrass is that it is currently listed as a class B invasive weed, which may limit its acceptability in California (growers should contact their county agricultural commissioner).

THE MULTIPLE-USE CONCEPT

It is important to understand the importance of multiple use scenarios with these two candidate biofuels. This could take two forms:

- Differentiation by Cutting (e.g. 1 harvest for a quality forage, and a 1 harvest for a cellulosic biofuel, or several cuts for either purpose)
- Fractionation of the crop into leaf stem fraction (high leaf fraction for animal feed or other food application, and into a high stem fraction for cellulosic biofuel).

This concept has the advantage of allowing a cellulosic cropping system to simultaneously produce food (as a forage crop, fed to dairy or other animals), as well as provide a cellulosic feedstock for energy production.

This is a ‘High Yield’ concept as distinct from the ‘marginal production’ scenario described earlier. Recent study in Nebraska reported average on-farm yields as 2.3 t/a to 4.9 tons/acre, and produced 540% more renewable than non-renewable energy consumed (Smer et al., 2007). This appears to be appropriate for these prairie environs and could be a reasonable ‘low input’ scenario for many regions. Here is a question: why not produce 8-16 tons/acre yields under a ‘high input’ scenario, and use half for forage and half for cellulosic biofuel? Under irrigation, almost by definition, growers must discover ways to obtain ‘more crop per drop’ and maximize returns, since inputs are necessarily a part of their system. Thus it is a different philosophy than minimizing inputs in a ‘low input’ scenario.

The multiple-use scenario has several additional advantages:

1. Lowers farmer Risk. Crops have higher viability for growers if there are several outlets for their sale. This induces farmers to take a risk on planting a new crop with uncertain markets.
2. Flexibility of markets. Overproduction for biofuel purposes would create inventory and cost issues for buyers.
3. Two income streams. Whether it is the farmer or processor who realizes the added value, fractionation of a crop should improve value for that crop.
4. Reduces the 'food vs. fuel' debate which has characterized other biofuel discussion. In this case, we are trying to incorporate biofuels into food production systems.

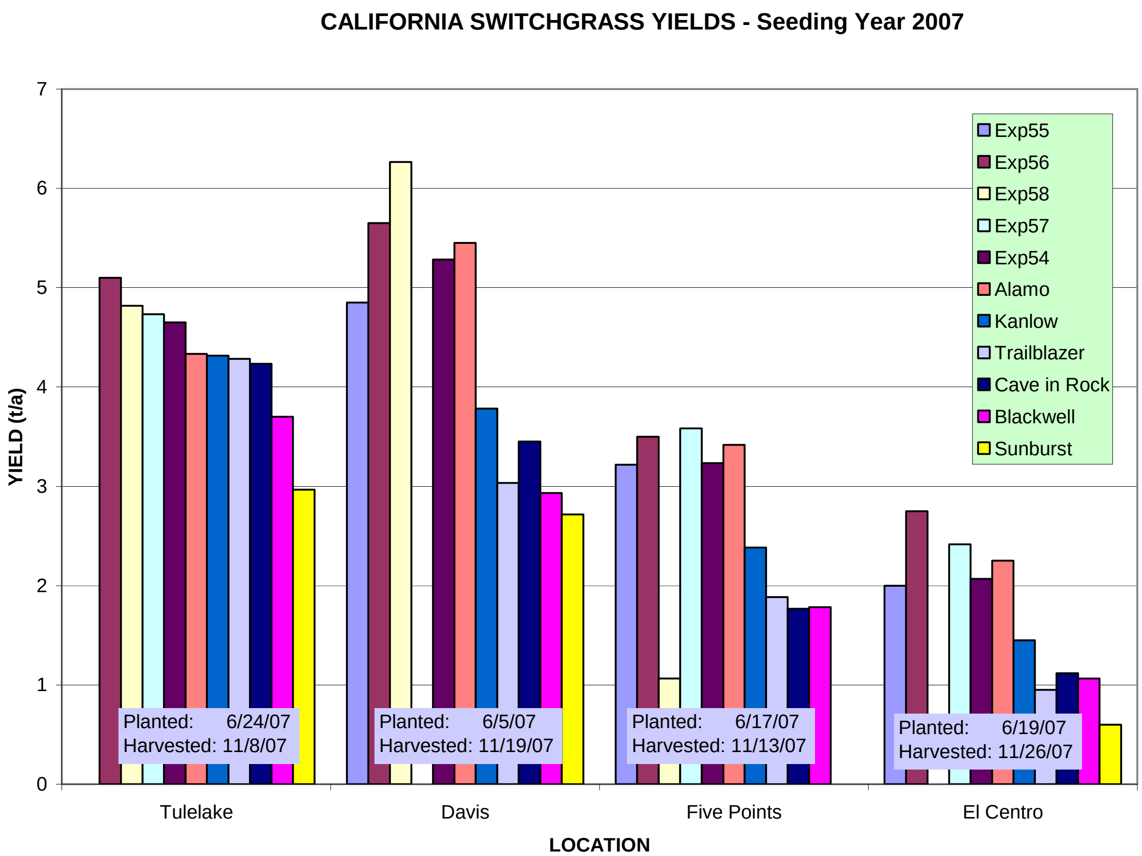
CELLULOSIC BIOFUEL PROVISIONS IN THE 2008 FARM BILL

Farmers should be aware that the farm bill, the Food, Conservation and Energy Act of 2008, H.R. 2419, includes a new income tax credit for the producers of cellulosic alcohol and other cellulosic biofuels. The credit is a max. of $1.01 per gallon. The credit will apply to fuel produced after 2008 and before 2013. The bill also includes the Bioenergy Program for Advanced Biofuels (Section 9005). This establishes the Bioenergy Program for Advanced Biofuels that provides payments to producers to support and expand production for advanced biofuels.

The Biomass Crop Assistance Program (BCAP) (Section 9011): Establishes the Biomass Crop Assistance Program to encourage biomass production or biomass conversion facility construction with contracts which will enable producers to receive financial assistance for crop establishment costs and annual payments for biomass production. Producers must be within economically practicable distance from a biomass facility. It also provides payments to eligible entities to assist with costs for collection, harvest, storage and transportation to a biomass conversion facility. The Energy Independence and Security Act of 2007 (H.R. 6), signed into law in December 2007, contains a number of incentives designed to spur cellulosic ethanol production. Further information on government incentives can be found at: http://www.ethanolrfa.org/resource/cellulosic/

SUMMARY

Experimentation with biofuels are an important aspect of exploration new cropping alternatives for California farmers. Their success will depend upon a range of criteria and factors, many of which are not fully known as of yet. Preliminary yield performance data on switchgrass indicates an excellent yield potential for this crop in several CA environment under irrigation. Alfalfa is a well-known crop, with known yield and utilization patterns, and should remain a candidate as a biofuels. Both of these crops are candidates for multiple-use scenarios for utilization, and have significant soil conservation and environmental advantages.



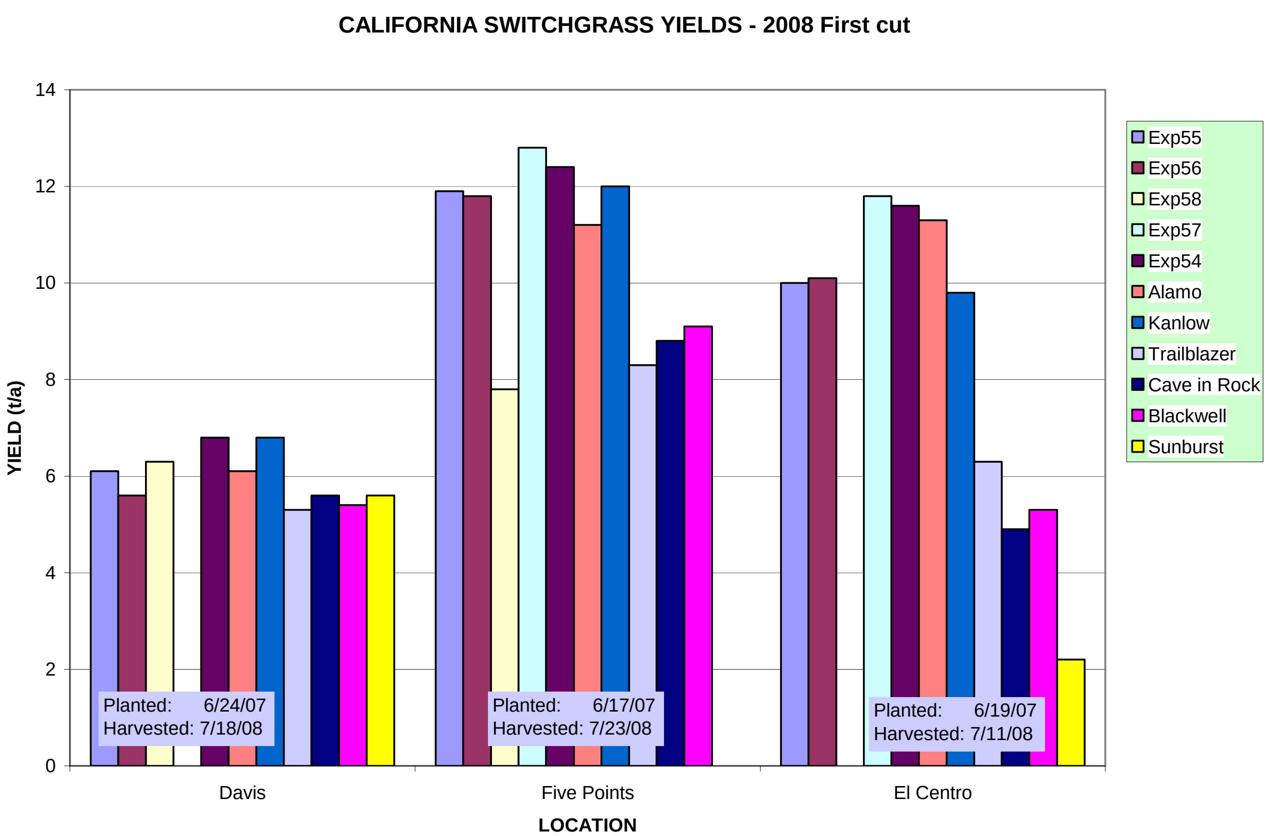


Figure 3. Preliminary Switchgrass yields under irrigation at 4 California locations (2007-2008). Note – this data does not include the final yield harvests for 2008.

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