Biofuels Cropping Systems
Research and Extension Progress Report

WSU/USDA-ARS/WSDA

More than twenty WSU and USDA scientists located across Washington State have begun to evaluate numerous alternative crops that could feed biofuel production in the state. The project is evaluating crop adaptation and productivity in four major growing regions of Washington – eastern WA (high rainfall, and low to intermediate rainfall), central irrigated WA, and western WA. A primary challenge will be to compatibly fit these alternative crops into the predominant crop rotations of each region.

Improving economically and environmentally sustainable yield productivity and stability of these biofuel crops are principal goals. Further potential for developing value added bioproducts such as animal feed, fiber products, and biopesticides will improve the economic viability of these crops. The information gained from the multiple research projects will provide valuable insight to producers who are interested in growing biofuel crops but have not had relevant agronomic data from Washington available to support their efforts.

In the two rainfall zones of eastern Washington, canola, mustard and camelina are major oilseed crops being studied. Seed germination and seedling establishment in dry soils, crop winter hardiness and frost tolerance, disease and insect susceptibility, and drought stress tolerance are among the regional challenges for integrated management, variety selection and improvement. Other oilseed candidates include sunflower, flax, linola, safflower and lupine. Integration of these crops into the wheat-barley-legume and wheat-fallow rotations of eastern Washington will be a major factor in the success of any of the oilseeds. Researchers will also be defining unique fertility requirements, disease and weed pressures, and weed control options in this dryland region.

Irrigation water in the basins of central Washington reduces problems in crop establishment, but significant adoption of these oilseed crops is still dependent on their economic competitiveness with other high value crops that can be grown in the region. Researchers are defining fertilizer and irrigation management requirements and productivity of canola, camelina, sunflower, flax, safflower and soybean. Peanuts are another potentially viable biofuel crop being introduced into this region. Weed scientists will be conducting herbicide tolerance studies and oil composition analysis for these crops produced in central Washington as well as the other regions involved in the project.

In western Washington, research will focus on the organic production of canola, as well as basic agronomic production requirements for oilseed crops in this region. While there won’t likely be a premium for organic biodiesel, the organic canola meal will be in high demand with organic dairy producers. Another objective for this region will be ensuring that any increase in acreage will not jeopardize the integrity of the brassica seed production in the region.

Oilseed to biodiesel is the near term focus of this project, but cellulose to ethanol is on the horizon, and alternative crops to meet this future need are also being investigated. In the Columbia Basin, switchgrass and giant reed production and cultural requirements are being investigated. Both of these plants offer tremendous biomass production potential. Other perennial bunch grasses are being grown at the USDA Plant Materials Center. Crop straw residues from perennial and annual wheats will potentially provide cellulosic biomass sources, and are being evaluated in companion studies. The challenge will be to judiciously harvest straw while ensuring that soil quality is sustained.

The following pages are summaries from the individual projects of the Biofuels Workplan. They are organized by region, then by cross-cutting projects that address needs across the regions, and finally by affiliated projects. The summaries include what is known and what is not known about the agronomics and regional differences of multiple oilseed crops, as well as preliminary field observations of fall-seeded crops and laboratory research since the inception of the project in June 2007.

Bottom-line farm economics of these alternative crops are a critical factor in grower adoption of oilseed production. The economic and research findings will be conveyed to growers, biofuel industry and government agencies via field tours, workshops, and extension materials. Sustained research and extension efforts should give us a good opportunity to evaluate the feasibility of meeting some of our growing fuel needs with Washington grown crops.

Region 1 – Eastern Washington (high rainfall)
Canola and Camelina Variety Yields and Pathogen Susceptibility

Project PIs: Scot Hulbert, David Huggins

What is known:

Winter Brassicas have higher yield potential than spring cultivars but are very difficult to get stands established after legumes or cereals are harvested; the late plantings are still seedlings when winter weather starts, resulting in winter kill.

What is not known:

It is not known whether canola cultivars exist that are well adapted to rapid fall growth after late fall plantings, or winter survival as small seedlings. Planting methods that enhance winter survival of small seedlings are also not known. Experimental lines of winter camelina have been developed, but their performance in the high rainfall regions of eastern WA has not been tested.

Experimental design and preliminary observations:

We planted replicated trials of 64 winter canola varieties at the Palouse Conservation Field Station on September 20. The site was planted directly into spring wheat stubble with a direct seed drill. The ground was extremely dry, and sufficient rainfall to germinate the seeds was not achieved until October 4. As a result, the seedlings were still at the cotyledon stage when the first frost came three weeks later. The temperatures dropped to roughly 20^{o}F which killed the vast majority of the seedlings in all cultivars.   We will not know if some varieties are slightly better able to survive these conditions until early spring. The fall rains are not typically quite this late, and it is clearly not advisable to plant winter canola in a situation where the crop does not germinate until October. The second Reardon planting (planted September 17) may be a better test of whether some canola varieties are able to stand winter conditions as small plants. Most of these seedlings were only ~ one inch across in mid October.

Winter and spring camelina lines were planted adjacent to the winter canola trial at the PCFS. These were also planted with a direct seed drill, but the seed was placed near the soil surface. These were also only at the cotyledon stage when the first frost hit. Both the spring and winter types appeared to be unaffected by this first frost. This planting should be a good test of their winter survivability after very late fall plantings. We will plant spring types adjacent to these plantings in the spring, to compare the yield potential of the spring and winter types and the spring types at the two different planting dates.

We also examined the resistance/susceptibility of canola and other crucifer oilseed crops to two taxa of *Rhizoctonia solani*. One of the *R. solani* species causes root rot of wheat and can be particularly bad in direct seed systems. The other *R. solani* is known to be particularly severe in *Brassica* crops. All of the species and varieties we examined were susceptible to the fungi, including camelina, as well as yellow, brown and Ethiopian mustards. The hybrid cultivars Flash and Sitro, from the German company DSV, and the open-pollinated DeKalb variety CWH688 showed the most tolerance to the two *Rhizoctonia* strains in greenhouse tests, but these tests need to be repeated. Several fungicidal seed treatments were also tested, but were ineffective in reducing damping-off.

Region 2 – Eastern Washington
Canola and Camelina Variety Trials and Agronomic Research
Project PI: Scot Hulbert

What is known:

The winter growing season in this low to intermediate rainfall region is a unique environment for *Brassica* oilseed production and one that canola breeding programs around the world have not focused on. Winter canola performs well after summer fallow plantings if good stands can be established, but successful stand establishment has been sporadic for growers and researchers.

What is not known:

We don't know the best canola cultivars for this region, or whether some varieties do best at early or later planting dates.

Experimental design and preliminary observations:

We planted replicated trials of at least 64 winter canola varieties at Ralston and Reardan. The varieties included all the cultivars entered in the National Winter Canola Variety Trial. The Ralston site was cultivated in a summer fallow fashion and the Reardan site was a chem-fallow field. A third site, at Othello, was planted and irrigated. This is not the target environment for the dryland production region, but it guaranteed a good stand and will also provide information on what varieties are adapted to the region in general.

A good stand was achieved at Othello in a September 10 planting, but not at August 15 planting at Ralston. Our first planting at Reardan on August 17 resulted in an uneven stand. We replanted on September 17, and got a good stand. Stand counts were made in single rows of each of the plots at both Othello and Reardan. This will enable us to quantify winter survival for each cultivar in the trial. We saw variation for emergence at both Othello and Reardan. Cultivars also varied for fall seedling vigor and growth at Othello, and to a lesser extent at Reardan.

One thing we learned from these plantings is that none of the varieties will emerge through much more than an inch of soil. Even though the seed size varies considerably among the varieties, none emerged well in the first planting at Reardan or the Ralston site. In both cases the seeds were probably placed deeper than optimal.

Soil pathogens did not appear to play a large role in stand establishment in these fall plantings. Heat stress probably played a role in the poor emergence of the stand at Ralston.

A replicated camelina trial with 30 varieties and experimental lines was planted in Ralston in the Spring of 2006. They were planted directly into spring wheat stubble, without a fallow period. Two planting methods were used: 1) using a direct seed drill, and 2) broadcasting after fertilization with a direct seed drill. The broadcast plots had the best stands and yields were roughly 1400 lbs/acre with most varieties when planted this way.

Links to other related resources:

National Winter Canola Variety Trials in other parts of the country:
http://www.oznet.k-state.edu/library/crpsl2/samplers/srp954.asp

Region 2 – Eastern Washington

Rotation Benefits of Winter Canola in Wheat-Based Cropping Systems

Project PI: William Schillinger, WSU
Collaborators: Ann Kennedy, ARS; Doug Young, WSU; and Tim Paulitz ARS

What Is Known: Winter wheat (WW) – summer fallow has been the dominant crop rotation on 3.5 million acres of dry cropland in the low (less than 12 inches annual) precipitation in the Inland Pacific Northwest (PNW) since the land was taken out of native bunch grass and sage 125 years ago. In the 2.4 million acre intermediate (12-to 18-inches annual) precipitation zone of the Inland PNW, a 3-year winter wheat – spring cereal – summer fallow rotation is widely practiced. There is a need for alternative crops in both the low and intermediate precipitation zones to break disease and weed cycles that affect cereal production and to offer farmers economic opportunities with crops other than wheat and barley.

Winter canola (WC) has been evaluated under both dryland and irrigated conditions in the Inland PNW since the 1980s. I have conducted agronomy research on winter and spring canola for the past ten years. We know that: i) Achieving stands of winter canola on summer-fallowed soils can be difficult; ii) Grain yield potential of winter canola is much higher that that of spring canola or yellow mustard; iii) Yield potential of winter canola is often limited by hot (>90^0F) air temperatures during flowering stage of plant development; and iv) Winter canola extracts more water from the soil than does winter wheat. We also have some evidence that water infiltration into frozen soil is enhanced in fields with standing winter canola stubble (compared to winter wheat stubble) and suspect that this is due to preferential water flow in channels created by the tap root. One experiment conducted near Moscow, Idaho showed that spring canola provided a rotation benefit to the subsequent wheat crop yield compared to planting wheat back on wheat stubble. A farmer south of Ritzville, WA has grown winter canola for many years and claims that he obtains higher winter wheat grain yields when the previous crop is winter canola (with a year of fallow in between) compared to monoculture winter wheat.

What is not known: We need to identify whether improved soil physical, biological, or pathological factors may account for better water infiltration and increased wheat yield as affected by having winter canola in the crop rotation

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Current Research

Specific objectives are to determine the benefits of winter canola grown in (i) a 4-year WC-SF-WW-SF rotation compared to the traditional 2-year WW-SF rotation in the low-precipitation zone and, (ii) a 3-year WC-SW-SF rotation compared to a WW-SW-SF rotation in the intermediate precipitation zone on:

1. Grain yield of the subsequent winter wheat (low zone) or spring wheat (intermediate zone) crop.
2. Economic assessment of WC-SF-WW-SF versus WW-SF in the low-precipitation zone and WC-SW-chemical SF vs. WF-SW-chemical SF in the intermediate-precipitation zone.
3. Plant diseases of the subsequent winter wheat (low zone) or spring wheat (intermediate zone) crop.
4. Soil microbial changes after winter canola versus after winter wheat.
5. Soil water infiltration and frozen soil runoff after winter canola versus after winter wheat.

A 6-year experiment was initiated in 2005 at the Ron Jirava farm near Ritzville, WA. Average annual precipitation at the site is 11.5 inches. Seed-zone water at Ritzville is adequate in most years for establishment of winter wheat and winter canola into summer fallow. The experiment compares the 2-year WW-SF rotation to a 4-year WC-SF-WW-SF rotation. In late August, winter wheat and winter canola are planted into summer fallow in 16 by 200-ft plots with a John Deere HZ deep-furrow drill. Seeding rate for winter canola is 3 lbs/acre and for winter wheat 45 lbs/acre. Experimental design is a randomized complete block with 6 replications (total area per site is 0.9 acres). After grain harvest, the entire experiment area is left in summer fallow for the next 13 months, then planted to winter wheat. Nitrogen and sulfur (the same rate for WC and WW), based on soil test, is applied with shanks during May of the summer fallow year. Grain yield of WC and WW is determined using a plot combine. The four corners of the experiment sites are mapped with a global positioning unit so that the precise location of all plots can be determined for the ensuing SF and WW cycles.

A similar experiment was initiated in late-August 2007 at the Hal Johnson farm located NE of Davenport, WA. Average precipitation at this site is 17 inches. The traditional 3-year WW-SW-chemical SF rotation will be compared to a 3-year WC-SW-chemical SF rotation. All crops at the Davenport site will be produced using no-till. Experimental design, plot size, and grain harvest methodology will be the same as at the Ritzville site. Fertilizer rate, again based on soil test, will be somewhat higher than that used at Ritzville. Winter canola and winter wheat will be planted and fertilized with an 8-ft-wide no-till plot drill equipped with Kyle hoe-type openers. Computerized weather stations are in place at both sites.

In addition to grain yield, soil volumetric water content is measured in all plots at time of planting in late August, in mid March, and again at grain harvest. During the winter after the harvest of WC and WW, ponded water infiltration rate is determined in each plot within a 2-foot-diameter infiltrometer ring when surface soils are partially or completely frozen. Plant diseases (Paulitz) and soil microbial attributes (Kennedy) that include pH, electrical conductivity, and dehydrogenase enzyme activity are determined each year where the previous crop was either WC or WW. At the end of the study in 2011, an economic assessment of the two cropping systems will be conducted for both the low and intermediate precipitation sites by (Young) using standard enterprise budgeting procedures.

Region 2 – Eastern Washington

Camelina Agronomy and Cultivar Evaluation Research

Project PI: William Schillinger, WSU

What Is Known: Camelina is an ancient oilseed crop from Eastern Europe. Limited research from Montana in the past few years indicates that camelina is drought tolerant, does not require much nitrogen fertilizer, and does well on shallow or otherwise marginal soils. Several people feel that, if camelina has a fit in the Pacific Northwest, it will likely be in the low-precipitation region where winter wheat – summer fallow is the dominant crop rotation.

My first experience growing camelina was in 2007 with the varieties "Calena" and "Salena" on summer-fallowed ground at the WSU Dryland Research Station at Lind. Crop-year (Sept. 1 to Aug. 31) precipitation in 2007 was only 9.02 inches. I have grown numerous alternative crops for many years at Lind and surrounding area. Few of the alternative crops have shown much potential for this dry region. I was pleasantly surprised with camelina. On June 1, we had 99^0F air temperature and the camelina plants (as expected) aborted their flowers. Two days later we received 0.51 inches of rain and the daytime high air temperature was only 65^0F. With the rain and cool temperature, camelina started flowering again. The Calena produced 1400 lbs/a and the Salena 1250 lbs/a grain yield in 2007.

Stephen Guy from the University of Idaho has two years of experience growing camelina near Moscow (25 inch annual precipitation zone). His studies, to date, show that camelina has greater and more stable grain yield compared to both spring canola and yellow mustard.

What is not known:

- Camelina variety x planting date interactions,
- Seed bed establishment requirements for camelina
- N and S fertilizer requirements for camelina

Study 1: Planting date. Location: Lind (as well as Pendleton, Moscow, Corvallis). Two planting methods: direct drilling and broadcast + packing. Six planting dates: (1) As soon as rains start in the fall (generally around mid October or later), (2) November dormant (Thanksgiving week), (3) Winter dormant (Jan. 15 – Feb. 1), (4) Early (mid February), (5) Mid (March 1), and (6) Late (March 15).
Four replications of each planting date and planting method. Plant Calena variety at 4 lbs/acre with nitrogen @ 25 lbs/acre. Stand counts using quadrant method. Use Assure II to control downy brome. Grain yield with plot combine. Take samples from each treatment for oil content.

Study 2: Cultivar Evaluation. Location: Lind (as well as Pendleton, Moscow, Corvallis, and possibly Dusty or Ralston). Will evaluate 15 – 20 cultivars and numbered lines at each location. Four replications. March 1 planting date. Nitrogen @ 25 lbs/acre. Grain yield with plot combine.

Study 3: Fertilizer Rates. Location: Lind (as well as Pendleton, Moscow, Corvallis, and Davenport). Nitrogen rates are: 0, 10, 20, 30, 40, 50 lbs/acre. Sulfur will be applied to rates 2 and 4 (i.e., 10-0-0-8 and 30-0-0-8). Will use Calena variety @ 4 lbs/acre. March 1 seeding date. Four replications.
Note: The three camelina studies (above) will be conducted for a duration of three years. There will be differences in the timing of planting dates (Study 1) and in fertilizer rates (Study 3) across locations, but otherwise everything will be the same at all locations mentioned.

Study 4: Cropping systems. Location: Lind. New 6-year study was started in fall 2007 with a WW-C-SF rotation compared to WW-SF. RCB design with four replications. All phases of all treatments will appear each year. Total of 20 plots. Individual plot size is 30 x 250 ft. This study is unique to Lind.

Region 2 – Eastern Washington
Agronomic Management of Canola
Project PI: Frank Young

What is known:

A handful of growers have produced winter canola in the low-to-intermediate rainfall zones with yields sometimes surpassing 2000 pounds. It is also known that stand establishment is not uniform and yields are very inconsistent. Often times the crop has to be replanted in the fall or planted to spring canola the following March/April.

What is not known:

Optimum seeding date and rate of winter canola in the non-irrigated low-to-intermediate rainfall zone is not known. In addition, new planting methodology must be evaluated to improve stand establishment and seedling survival. The effect of population density and date of seeding on crop yield and quality as well as feedstock is unknown.

Objective: Determine optimum winter canola seeding date and rate and planting method to improve stand establishment, yield, quality, and profitability.

Current research and preliminary observations:

In August/September, 2007, we conducted preliminary experiments evaluating winter canola seeding date and rate of planting at Ralston (11.5 inches precipitation) and in the cold, snowy foothills of the Okanogan Highlands (10 to 14 inches). Seeding dates were August 12, 19, and 26 at Ralston and August 21 and September 4 at Okanogan. Seeding rates were 2, 4, and 6 pounds per acre. A modified H-Z deep furrow drill was used at both locations to seed winter canola. The modifications to the drill include a grass-seed box for accurate seeding rates, 13 to 15-in shovels to move dry soil, and 55-pound packer-wheels. During the three seeding dates at Ralston and the first seeding date at Okanogan, three of the four rows were set at normal depth (½ to ¾ inches into moisture) and the seed failed to emerge. However the fourth row was set to plant shallower (less than ½ inch into moisture) and these seed emerged, established, and the resulting plants have sufficient size to go into the winter. At the second seeding date at Okanogan, seeding depth was shallower than during the first date and considerably more plants emerged and established. We have counted plants in rows/treatments where sufficient plants emerged.

Field days: We will coordinate a field tour at both sites with the county extension specialist, grower cooperators, and WSU extension personnel (Hans Kok and Dennis Roe).

Region 3 – Irrigated Central Washington

Producing Switchgrass for Biofuel in Washington State

Project PI: Steven C. Fransen

What is known: The first investigation evaluating adaptability and productivity of switchgrass (*Panicum virgatum*) for biofuel in Washington State was initiated at WSU-Prosser in 2002. This perennial warm-season grass is native to the Midwestern U.S. but not to Washington. Switchgrass is grown under dryland conditions in the Midwest because of adequate summer rainfall for growth; it requires a full growing season to become established while the grass is developing a massive root system. After establishment biomass yields increase yearly as the grass transitions to adult crop plants. The 2002 switchgrass plots have not winterkilled even though winter temperatures have reached a –19F. Significant biomass yield differences are found from released varieties of both upland and lowland ecotypes at both Prosser and Paterson (in cooperation with Dr. Hal Collins, USDA-ARS). Contrary to popular belief, switchgrass in our region does require annual applications of nutrients to achieve high biomass yields from two harvests per season. First cutting harvest occurs in early to mid-July and the final biomass harvest in late September to mid-October.

What is not known: We do not know the water requirements and application timing for switchgrass in Washington State. Planting date, refining seeding rates and planting techniques, and rapid and successful stands during the establishment year are all issues that need additional research effort. Nutrient requirements may be higher than previously thought so new field and greenhouse/lab studies need to be initiated to refine recommendations. Ethanol or other bioenergy yields and efficiency must be determined from harvested switchgrass and other warm-season grasses if this new industry is to be sustainable. With continued investment in switchgrass cellulosic biofuel research we will be able to predict bioenergy returns using Near Infrared Reflectance Spectroscopy (NIRS) technology.

Current research: Two switchgrass cultivars and one Indiangrass cultivar will be planted in June 2008 at Othello to supplement the switchgrass research at Prosser and Paterson. The seed will be planted with a grass seed drill in large scale (> 1 acre) plots. We will also conduct a planting date study at Othello with switchgrass, Indiangrass, and bluestem in small plots. Measurements taken at the different sites will be water use efficiency (Prosser), nutrient uptake of nitrogen, phosphorus and potassium (Paterson), dry matter yield (all locations), storability using several methods (Othello), and potential ethanol and bioenergy production at all locations. Based on our earlier research findings and using conservative conversion rates, growing 75,000 acres of irrigated switchgrass would yield 60 million gallons of ethanol per year. With additional research we will have better data on yields and conversion rates for biomass grown in Washington State. With adequate funding for continued research and Extension programs both acres and gallons could dramatically increase in the next 10 years.

Resources: No relevant links to other switchgrass cellulosic biofuel research in the western U.S. are available at this time as our research is the first established in this region.
Two WSU Extension bulletins outlining the establishment period from seeding through the late seedling stages of growth are completed and should be available for growers establishing switchgrass in spring 2008. These bulletins will help growers who are familiar with growing cool-season grasses such as orchardgrass or timothy, but are new to growing perennial warm-season grasses.

Region 3 –Irrigated Central Washington

Nutrient and Water Use Efficiency of Oilseed Crops

Project PIs: An N. Hang, Harold P. Collins, Scot Hulbert

What is known: The irrigated areas of central Washington have the potential for a wide variety of oilseed crops due to the ability to provide fertilizer and water on a timely basis. We have conducted biofuel variety trials at Paterson, WA since 2004, focusing on spring-seeded oilseed crops the past few seasons. Oilseed crops included in our trials are camelina, crambe, canola, mustard, safflower, soybean and sunflower. Initial testing has shown winter canola will produce about 4000 to 6000 lbs seed /acre with a concentration of 43 to 45 % oil, safflower will also produced high seed yield with 40% oil (3000 to 6000 lbs/acre). Winter canola and safflower can produce from 1700 to 2500 lbs oil per acre if grown on loam soil with adequate water and nutrients. Spring canola yield varies with weather conditions. High heat during summer reduced spring canola pod fill and yield (1200 to 1800 lbs/acre of 38 to 40 % oil or 400 to 700 lbs oil per acre). Camelina produces well between 2000 to 3000 lbs/acre (35% oil) in 80 days or 700 to 1040 lbs oil per acre. Soybean yielded well in Washington, 3000 to 4000 lbs/acre containing 20% oil per acre (600 to 800 lbs oil per acre). Mustard can be grown for biofuel feedstock as spring canola but mustard has much lower oil than spring canola, averaging 25%. Crambe produced low yield and low oil concentration among all the oil producing crops tested.

What is not known:

- Information on planting date that minimizes summer heat to improve pod fill and development of spring canola is not available.
- Critical temperature for spring canola flowering.
- Critical temperature for seed germination of winter canola.
- Impacts of GMO canola
- Seeding rate of large and small seeded canola
- Camelina response to fertilizer, irrigation and its impact on other crops in rotation.
- Doubling cropping of camelina; fertilization, weed and increased pest problems.
- Safflower response to N fertilizer and its impact to the oil concentration and oil quality.
- Long-term rotational benefits of oilseed crops to high value vegetable crops in irrigated central Washington.
- Response of canola vs. rapeseed (high erucic acid variety) to variations in climate and influence on soil microbial communities.

Current research and preliminary observations: Four new winter canola varieties were planted along with 2 existing varieties in a randomized complete block design with four replications at Othello, WA. A second variety comparison trial was established in fall 2007 at Othello patterned after the canola variety trials in regions 1 and 2. Camelina will be planted early in the spring with a second seeding of camelina soon after harvest of the first crop to evaluate the potential of double cropping. Camelina response to irrigation is unknown, research is needed to obtain optimum water requirements for growers in Washington. Variable rates of water will be applied to plantings this spring in Prosser, WA. Safflower will be seeded in a randomized complete block design with various rates of N and irrigation to generate a response curve of safflower yield and seed quality.

Region 4 – Western Washington

Agronomics of Alternative Biofuel Crops; Organic Canola Trials

Project PIs: Tim Miller, Craig Cogger

What is known: Production of oilseed crops in western Washington has historically been very limited. Recent research has shown canola and mustard to be viable crops, but widely varying yields confirm the need for further investigation of basic agronomic information for these and other potential biofuel crops. There is high demand for organic canola meal for the dairy industry in Washington, and it is currently all imported. The opportunity for value-added canola production as well as reduced feed costs for Washington dairies from using in-state supplies of both organically and conventionally produced canola meal could be significant.

What is not known: We do not know if other oilseed crops such as camelina, flax, sunflower, and fall-seeded safflower can be successfully produced in western Washington. Optimum planting date, seeding rate, fertilizer and herbicide needs for canola, mustard, and the aforementioned biofuel crops also have not been determined for western Washington.

Current research and preliminary observations:

We planted canola on one date in early October 2007 at WSU Puyallup REC on certified organic ground. This is a preliminary trial evaluating response of fall seeded ‘Athena’ winter canola to organic fertilizer. Treatments include 1) 200 lb organic N (shrimp meal) applied at planting, 2) 67 lb organic N applied at planting with 133 lb to be topdressed in the spring, and 3) 0 lb N applied at planting with 200 lb organic N to be topdressed in the spring. All plots were hand seeded, and emergence appeared to be good, although the stands were uneven. The 200 lb fall N application had the poorest stands going into the winter. Four planting dates for a single variety of spring canola (bi-weekly beginning in April of 2008) will also be tested at Puyallup in 2008.

Five seed lines of safflower were tested in spring of 2007 at WSU Mount Vernon NWREC. All five lines grew well and produced flowers, but no seed was produced. These same five lines were planted in fall of 2007 to test for their winter-hardiness and to see if this results in plants flowering earlier in 2008 and producing harvestable seed.

We will plant four spring canola lines in Snohomish county (near Monroe), as well as camelina, flax and sunflower at WSU Mount Vernon to test viability of producing these crops in western WA. Camelina testing at these two locations will also include herbicide screening in cooperation with Joe Yenish and Ian Burke at Pullman.

Cross-Cutting Project 1
Oilseed Root Structure and Function

Project PIs: William Pan, Rich Koenig, Ron Bolton, Ashley Hammac

What is known

- Brassica tap roots anchor the plant and create root channels (Goodman et al., 2001)
- Brassica species have extensive root systems, including root hairs (Weiss, 1983)
- Brassica roots are efficient in the acquisition of N (Rossato et al., 2001) and P (Lambers et al., 2006)
- Brassica roots do not and flax roots do form functional mycorrhizal associations
- Brassica genotypes differ in P uptake efficiency

What is not known

- Environmental factors affecting root hair induction/elongation (nutrients, water, cold, heat)
- Why brassicas have extensive root systems and the implications for resource acquisition (nutrient, water)
- Net benefit of brassica roots on soil tilth (possible increased nutrient availability, aeration, infiltration, for crops following brassicas)
- Structural morphology of flax and camelina roots

Current research

Understanding root structure and function will improve oilseed crop production. Preliminary experiments are being conducted to observe changes in, and differences between, root growth and morphology of canola, camelina, flax, and wheat to prepare for a full scale experiment.

In the full scale experiment, we will compare roots/root hairs of different species (canola, camelina, flax, wheat, barley, lentil, chick pea) grown under controlled conditions. Treatments will consist of varying phosphorus (P) levels and placement. Roots will be digitally scanned to observe daily changes in and differences between roots of each species at each treatment level.

Information gained from this experiment will allow us to conduct further field research to examine optimum P rate and placement strategies, as well as P acquisition efficiency of oilseed crops. In addition, the field study may reveal beneficial effects of oilseed roots on soil such as increased infiltration and aeration, decreased soil erosion, bulk density, and nitrate leaching, and improved cereal P acquisition and rooting depth.

Resources

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Cross-Cutting Project 2
Weed Control in Biofuel Crops
Project PI: Joseph Yenish

Overview: The goal of this project is to evaluate labeled herbicides for weed control in the respective biofuel commodities and to evaluate additional herbicides for potential labeling.

Safflower: Since 1998, herbicide evaluation studies have been done at Ritzville and Lind WA. Efficacy and crop safety studies identified the value of labeled herbicides and potential herbicides as candidates for InterRegional-4 or other minor crop labeling programs. These include herbicides which are effective in controlling wild oat and other grass species and particularly troublesome broadleaf weeds such as Russian thistle.

Yellow Mustard: Also since 1998, herbicides have been evaluated for potential labeling in this commodity. In general, yellow mustard appears to be the most best suited in agronomic terms across the agroecological zones to date. Yellow mustard establishment is much more consistent that other Brassicaceae species of crops. Unfortunately, soil persistent herbicides used in cereal or grain legume production may limit the widespread production of this crop. The development of group 2 herbicide-tolerant yellow mustard varieties would improve the potential for yellow mustard production in eastern Washington. Current research funded by STEEP is evaluating the soil persistence potential of imazamox herbicide and the potential injury to yellow mustard. That research is being done collaboratively with the University of Idaho and Oregon State University.

Canola: Research evaluating herbicides for use in canola has been conducted since in 1998. This includes evaluation of weed management programs in winter and spring canola and has included the three herbicide resistant canola programs currently available in the U.S. Currently, Roundup-Ready canola systems provide the simplest and most consistent weed control in canola production. However, while genetically resistant herbicide crop technology continues to gain market acceptance, there is some hesitation by growers to adopt this technology. Variety development, soil persistent herbicide tolerance, and an evaluation of the economics of weed control in Brassicaceae crop producing systems needs to become a focus of the research.

Current and upcoming trials for 2008: Three experimental locations were established in the fall of 2007 for evaluation of weed management systems in fall-seeded canola. Unfortunately, one of these locations did not establish possibly due to soil persistent herbicides. Preemergence and fall postemergence treatments were applied in a timely manner. Spring postemergence applications will be made as appropriate. Additional spring canola, yellow mustard, camelina, and other crops will be included in studies planned for the spring of 2008. Future weed research topics if funding is available include determining yield loss due to weeds and establishing the critical weed-free period.

Cross-Cutting Project 3
Oilseed Crop Fertility

Project PIs: Richard Koenig, Robert Stevens, William Pan, Ashley Hammac

What is known. A review of the existing literature reveals that canola requires more nitrogen, phosphorus, potassium, and sulfur per unit of yield than cereals such as wheat or barley. Due in part to a low harvest index (proportion of aboveground plant dry matter that is seed) and high nutrient concentration in the residue, canola also leaves more nutrients in the field after harvest than comparable yields of cereals. Cycling of nutrients in this residue to subsequent crops is one important rotational benefit of canola. Fertilizer rates for canola are a function of residual soil nutrient levels and the yield potential of the site. For optimum yields, canola requires approximately 6 to 8 lbs of N supply (fertilizer+soil sources) per 100 lbs expected seed yield. Phosphorus, potassium, and sulfur recommendations can be based on soil test levels with interpretations similar to those of cereals. Canola has a lower tolerance of seed-placed starter fertilizers than cereals so rates of nitrogen+potassium should be below 5 lb/acre.

What is not known

- In existing literature, nitrogen recommendations for canola are somewhat variable, ranging from 4 to 11 lbs nitrogen supply per 100 lb seed yield.
- There is also debate over the optimum timing of nitrogen application for winter canola to ensure high yields but minimize the potential for winterkill.
- Optimal placement of banded fertilizer at planting and canola root responses to banded fertilizer is poorly understood.
- Nutrient impacts on canola winter hardiness and frost tolerance needs to be better defined.
- Little is known about how fertility management affects oil yield in oilseed crops since the majority of studies assess only management effects on seed yield.
- Little is known about camelina nutrient requirements to optimize oil yield.

Current research. This cross cutting project involves a series of experiments designed to assess canola and camelina seed and oil yield responses to nitrogen and sulfur rates, and nitrogen application timing. The study design is a randomized complete block with four replications at locations near Prosser, Davenport and Pullman, WA. Winter canola studies were initiated at each location in fall 2007. Spring canola and camelina studies are planned for 2008 at Davenport and Pullman. Camelina will also be sampled intensively over time and will also be quantified to develop baseline dry matter and nutrient uptake curves for this new crop.

Winter canola failed to establish at Pullman due to inadequate seed zone moisture. Establishment was spotty at Davenport but will likely result in sufficient stands for this study. Fall establishment of winter canola is a major challenge that will have to be overcome in order for this crop to be successfully grown in dryland environments.

Links to other extension resources on canola fertility

Ontario, Canada: http://www.omafra.gov.on.ca/english/crops/pub811/8fert.htm#table81
Great Plains, U.S.: http://www.oznet.ksu.edu/library/crpsl2/mf2734.pdf
North Dakota: http://www.ag.ndsu.edu/pubs/plantsci/soilfert/sf1122w.htm
Montana: http://landresources.montana.edu/FertilizerFacts
Oregon State University: http://extension.oregonstate.edu/catalog/pdf/em/em8943-e.pdf

Cross-Cutting Project 4

Oilseed Analysis

Project PI: Ian Burke

What is known:

Production environment has a measurable difference on seed oil content and quality. For instance, the same six soybean lines averaged 27% more oil in seeds from plants grown in Mississippi, where seed-fill temperature was 12 degrees F higher than those from Indiana. Similar variation can exist in Washington over much shorter distances.

Given the differences in agronomic zones of the four regional projects, differences in the seed oil content can be expected among each of the experimental locations.

What is not known:

Currently there is no information on the seed oil quantity and composition in response to the environmental conditions found in Washington. There is also no information on varietal differences within the several crops being evaluated for biofuel potential in response to the environmental conditions found in Washington.

Experimental design and preliminary observations:

Percent oil quantity and oil composition will be determined for all crops and varieties in support of Regional Projects 1-4 and Cross-Cutting Project 3. Researchers in those projects will collect the necessary samples. Oil quantity will be determined using a scaled oil extractor to simulate the process as it would occur on an industrial scale. Oil composition will be examined in both raw extracts and transesterfied extracts (transesterfication produces biodiesel) to determine potential markets for extracted oil and the potential for biodiesel production, respectively. Given the diversity of cropping sites, an assessment of environmental impacts on oil quantity and composition will be conducted to determine best environments for each crop and variety for biodiesel production and oil production in general. Specific varieties of each crop will be identified for suitability of biodiesel production.

Links to other related resources:

http://journeytoforever.org/biofuel_supply.html

Cross-Cutting Project 5

Literature Review, Economics, Outreach

Project PIs: Chad Kruger, Bill Pan, Karen Sowers, Jeff Canaan, Hans Kok, , Kate Painter,

Current Objectives:

- Complete a global oilseed production literature review. A literature review will provide a knowledge base to scientists with this project to identify any production issues specific to Washington State that may be similar in other areas of the world. This will be finished by July 2008 .
- Provide updated enterprise budgets for the major biofuel crops in this project. We will determine if there are economical benefits or drawbacks utilizing oilseeds in rotation at each of the sites based on current market prices and production costs. Economics of crop choice impacts on farm returns will be assessed.
- Develop educational materials and outreach events for producers, the general public, legislators, and other non-farm stakeholders. Future publications include extension bulletins and fact sheets, news releases, and research papers based on data from each of the regions. These will be written as information becomes available during the project. Outreach events will feature workshops, legislative tours and field days. The following field days are scheduled for 2008:

  Region 1:
  - ♦ June 26 – Direct Seed Cropping Systems Research Field Day, Palouse Conservation Field Station – Pullman (biofuels emphasis)

  Region 2:
  - ♦ May 2008 – Ralston
  - ♦ June 19 – Lind Field Day

  Region 3:
  - ♦ July 9 – Paterson

  Region 4:
  - ♦ July 31 – Puyallup Organic Farm Field Day and Resource Fair

Affiliated Project - *Arundo donax*

Arundo donax for biomass ethanol, fiber, carbon sequestration

Project PIs: William Pan, Bob Stevens, Troy Peters, Joe Yenish, Bob Parker, Bill McKean

What is known:

- Arundo donax is known as one of the highest cellulosic biomass producing plant species known, clearly higher than forage grasses, switchgrass and hybrid poplar. Recent studies at Prosser, WA
- Arundo has a perennial growth habit, does not produce seed under temperate growing conditions, reproduces vegetatively from apical internodes and root corms.
- Arundo is an invasive weed in many areas of the U.S., particularly where it was introduced to control erosion along stream banks.
- Available herbicides effectively control Arundo.
- Arundo is reported to be a C3 plant.
- Arundo forms an equally impressive below ground root biomass
- Arundo stands remain intact through harsh winter conditions, and when harvested, will re-grow in the spring.
- Initial baseline data on cellulose, lignin, hemicelluloses and ash composition, biomass yields in south Columbia Basin have been collected.
- Arundo may be a very appealing pulp fiber source for the PNW paper industry.

What is not known:

- What is the physiological and genetic basis for its extraordinary biomass yields, and are these traits transferrable to other crop species?
- Is there genetic diversity amongst ecotypes?
- What are the potential pathogens and insects in long term plantations? Thus far, we have observed little susceptibility in small plots of young plantations, increased pest pressures are likely in older and more widespread plantations.
- What are planting and harvesting techniques commercially available for large scale production?
- What are the proper agronomic management practices, storage, and transportation requirements to preserve biomass quality and prevent escapes?
- What carbon credits can be garnered for growing Arundo?
- What are the specific water, nutrient and plant spacings, number of cuttings required for optimal biomass production?

Current research: Two stands of Arundo donax have been established at Prosser WA. The first stand of 63 ft x 81 ft was established in March 2003 with stems and rhizomes collected from California. It was observed that a much higher percentage of rhizomes sprouted compared to the stems. A second larger stand (160 ft x 160 ft) was established in May 2006 using all rhizomes from California. Incomplete stand establishment was due to the presence of non-viable rhizomes and the late planting date. Transplants were made into these areas in an attempt to fill in the stand. This second stand was set up to establish plots for examining planting density, water and nutrient variables, as well as herbicide control treatments. The 2006 planting was established with two in row spacings (18 and 36 inches). In 2007, two irrigation regimes were imposed with half of the plots receiving replacement irrigation at 100% and half receiving 66% of replacement. First year yields have ranged from 2 to 11 tons/acre, second year yields have ranged 12 to 22 tons/acre, third year 15 to 25 tons/acre.

Funding This preliminary research has been supported by private gifts. We intend to apply for special grant funding to formerly initiate research on this promising biomass species.

Affiliated Project – Tall Wheatgrass

Tall Wheatgrass for long-term biofuel feedstock

Project PI: Mark Stannard, Pullman Plant Materials Center

What is Known: Tall wheatgrass (*Thinopyrum ponticum*), as its name implies, is a very tall grass that can be found in eastern Washington pastures, CRP fields, and wildlife refuge plantings. Some of the original 'Alkar' tall wheatgrass pasture plantings made over 50 years ago are alive and performing well. 'Alkar' was developed primarily for revegetating saline lowlands and was never intended to be a biofuel. Since the release of 'Alkar' in 1951, several cultivars have been registered. The most recent tall wheatgrass biotype/cultivar, 'Szarvasi 1' was developed in Hungary. 'Szarvasi 1' was developed specifically for the European Union biofuel market. Promotional literature suggests that 'Szarvasi 1' has an energy yield that compares favorably to brown coal. Testing of 'Szarvasi 1' in the United States has been very limited.

Stroh and Law (1967) measured 'Alkar' tall wheatgrass yields as high as 15,076 kg/ha at Pullman. Scheetz, Stannard, and Majerus conducted an irrigated pasture study at the Bridger, Montana Plant Materials Center in 1987-89 and reported that over 90% of the annual biomass of was attained in the first cutting. Stroh and Law measured lignin, crude fiber, and ash content of tall wheatgrass harvested at various cutting intensities. Lignin content was maximized by a single late cutting (9.65 %). Crude fiber content was maximized by a single late-season cutting (39.3 %). Ash content was least for a single late-season cutting (9.22%). They also determined that a 5 cm cutting height adversely impacted stand longevity, and a cutting height of 15 was optimal for yield and stand longevity.

What is Not Known: Which biotype/cultivar is best suited for Washington's environmental conditions? What variables can we modify to maximize production? Fertility, seeding dates, harvest dates, irrigation, and disease/weed management are variables that must be evaluated.

How much energy can we expect from a hectare of land? How much ash is produced? How efficient is it convert tall wheatgrass into a useable fuel? Is it a cost effective system? What is the most appropriate fuel type derived from tall wheatgrass?

Experimental Design and Preliminary Observations: A study was seeded on September 6, 2007 at the WSU IAREC (Rosa unit) by the Pullman Plant Materials Center.
RCB: 3 reps
Plot size: 8' x 20'
Treatments:
1) 'Largo' tall wg 6" row spacing
2) 'Jose' tall wg 6" row spacing
3) 'Alkar' tall wg 6" row spacing
4) 'Szarvasi 1' tall wg 6' row spacing
5) 'Largo' 12" rows
6) 'Jose' 12" rows
7) 'Alkar' 12" rows
8) 'Szarvasi 1' 12" rows

***Note**: Plant Materials Centers located at Bridger, Montana; Aberdeen, Idaho, Lockeford, California; Meeker, Colorado; and Fallon, Nevada are participating in the initial screening of the same tall wheatgrass biotypes.*

Emergence was observed in all treatments two weeks later. Stands counts and leaf stages were tabulated on Sept 26, 2007. All treatments had acceptable stands and leaf stages of 1.25 – 2.5.

Affiliated Project – Wheat Straw Genomics

A genomics approach to understand and manipulate genes controlling composition of wheat straw affecting ethanol production

Project PIs: Kulvinder Gill, Bill Pan, and Scot Hulbert

What is known

- Wheat straw is a valuable resource for soil protection, stabilization, nutrient cycling and organic matter buildup.
- Excess straw can be problematic in carryover of weeds and other crop pests. It can also interfere with planting of the next crop. This has compelled growers to burn their excess wheat straw, an environmental issue.
- Several million tons of wheat straw are produced annually in WA State.
- Wheat straw is mainly composed of cellulose, hemicelluloses, lignin and ash minerals, making it a potential source of biomass for cellulosic ethanol and other bioproducts such as paper products.
- Other than breeding efforts in the 1960's to introduce semidwarf wheat, wheat breeding efforts have totally focused on improving grain traits rather than straw traits.

What is not known

- Can we identify, characterize and manipulate genes/QTLs controlling wheat straw composition specifically targeting characteristics that influence ethanol yield?

Current research and preliminary observations:

Research objectives are to:

1. Use association mapping to study variation for the composition of wheat straw of cultivated wheats of the world and identify the composition that results in the highest ethanol yields
2. Identify genes/QTLs that regulate straw composition especially that controls ethanol yields
3. Develop user-friendly DNA markers for the genes/QTLs controlling ethanol yields from wheat straw. Chromosome 3A of wheat is known to harbor many hormone signaling genes and grain yield related traits, therefore Gill tested and confirmed that the genes controlling plant biomass are present on chromosome 3A.

Funding This preliminary research has been supported by the Vogel Endowed Research Fund.

Affiliated Project – Manipulating Stature in Biofuel Crops

Using genetic information from *Arabidopsis* to increase yield in biofuel crops

Project PI: Michael Neff

Our lab uses genetic and biochemical approaches to explore the interactions between multiple pathways that modulate plant size, stature and development. One area of research focuses on how plants regulate steroid hormone levels to modulate their size and stature. This work has the potential to dramatically increase yields in a variety of crop plants, including those used for creation of biofuels. One of our long-term goals is to understand the biology of how particular enzymes regulate levels of growth-promoting hormones in crop plants to manipulate their size and stature and increase yields.

We use *Arabidopsis*, an easy-to-grow plant with a fully sequenced genome, to better understand how plants use light as a source of information and how the signaling pathways activated by light interact with plant hormone pathways to influence a plant's height. With regard to the brassinosteroid hormones, we know that elevating levels of these hormones in *Arabidopsis* leads to larger plants with larger fruits. Reducing levels of these hormones in rice generates semi-dwarf plants with increased seed yields, possibly by changing the leaf angle and reducing lodging. We have identified enzymes in *Arabidopsis* and rice that can be manipulated to increase or decrease levels of these hormones. However, we have not yet identified similar genes in wheat, barley and *Camelina*, the first two being targets for cellulosic ethanol feed stock and the latter a potential source of biodiesel.

We have identified candidate genes from wheat and barley. These will be over-expressed in *Arabidopsis* to identify those which are involved in modulating levels of brassinosteroid hormones, an approach that we successfully used to identify the brassinosteroid-inactivating enzyme from rice. The identification of such brassinosteroid-inactivating or biosynthesis enzymes from wheat and barley will ultimately lead to targets for breeding approaches to alter stature and yield via the manipulation of the endogenous levels of these growth-promoting hormones.

For example, we may be able to generate plants with elevated levels of brassinosteroids by identifying varieties or mutants that have enhanced activity of key brassinosteroid biosynthesis enzymes and/or reduced activity of enzymes involved in brassinosteroid inactivation. If the plant architectural modifications caused by the elevated levels of brassinosteroids in wheat and barley are similar to those in *Arabidopsis*, it is anticipated that these wheat varieties would be larger with increased straw yield for cellulosic ethanol.

In contrast, we may be able to generate semi-dwarf plants with reduced levels of brassinosteroids by identifying varieties or mutants that have reduced activity of key brassinosteroid biosynthesis enzymes and/or enhanced activity of enzymes involved in brassinosteroid inactivation. If the plant architectural modifications caused by the reduced levels of brassinosteroids in wheat and barley are similar to those in rice, it is anticipated that these varieties would have increased grain size and yield.

Camelina is a close relative of *Arabidopsis* and is easily transformed with *Arabidopsis* DNA. Therefore, we may be able to directly manipulate brassinosteroid levels and stature in *Camelina* by over-expressing key biosynthesis or inactivating enzymes from *Arabidopsis*. With increased knowledge of the *Camelina* genome, we may ultimately be able to identify similar genes in this oil seed crop. *Camelina* plants with increased seed yield will be the goal of these studies.

Appendix A

Biofuels Cropping Systems Overview

Crop	Region 1 Eastern WA	Region 2 Eastern WA	Region 3 Central WA	Region 4 Western WA
Winter Canola	variety trials soil pathogen study planting methods winter survival herbicide performance	variety trials soil pathogen study planting date/rate winter survival herbicide performance	variety trials crop nutrient/water use planting date/rate herbicide performance	variety trials organic production herbicide performance
Spring Canola	nutrient management herbicide performance	nutrient management herbicide performance	nutrient management herbicide performance	variety trials herbicide performance
Winter Camelina	variety trials soil pathogen study winter survival planting date	variety trials cropping systems winter survival	variety trials	
Spring Camelina	variety trials soil pathogen study planting date herbicide performance	variety trials herbicide performance	herbicide performance	variety trials herbicide performance
Safflower	variety trials	variety trials	water use efficiency cropping systems nutrient/water req'ts	variety trials
Sunflower	variety trials	variety trials		variety trials
Flax	variety trials	variety trials		variety trials
Yellow Mustard	soil pathogen study herbicide performance	herbicide performance	herbicide performance	herbicide performance
Switchgrass			variety trials winter survival seeding date	
Soybean*			variety trials planting date	
Arundo donax*			water, fertilizer use feral control	
Wheatgrass*	variety trials			
Wheatstraw*	genomics			

*affiliated project

Appendix B

Biofuels Cropping Systems Project

Research locations & personnel

	Region 1 **Eastern WA**	**Region 2** **Eastern WA**	**Region 3** **Central WA**	**Region 4** **Western WA**
Research locations	Cook Agronomy Farm Palouse Conservation Farm Station Greenhouse/laboratory Plant Materials Center	Reardon Davenport Okanogan Ralston Lind Ritzville	Prosser Paterson Othello	Puyallup Mt. Vernon
PI's	Bill Pan Dave Huggins Ian Burke Joe Yenish Rich Koenig Scot Hulbert Chad Kruger Kulvinder Gill* Mark Stannard*	Scot Hulbert Frank Young Bill Schillinger Aaron Esser Joe Yenish Ian Burke Chad Kruger	Hal Collins Joan Davenport An Hang Bob Stevens Joe Yenish Ian Burke Chad Kruger Fran Pierce*	Craig Cogger Tim Miller Ian Burke Chad Kruger
Collaborators	Pat Fuerst Scot Hulbert Hans Kok Kate Painter Tim Paulitz Dennis Roe Dan Skinner Karen Sowers	Pat Fuerst Scot Hulbert Hans Kok Kate Painter Tim Paulitz Dennis Roe Karen Sowers	Pat Fuerst Scot Hulbert Hans Kok Kate Painter Tim Paulitz Dennis Roe Karen Sowers	Andy Bary Scot Hulbert Hans Kok Carl Libbey Kate Painter Karen Sowers
Technicians	Ron Bolton Ron Sloot John Rumph Shawn Wetterau	Ron Bolton Ron Sloot John Rumph Shawn Wetterau	Kelly Whitley	
Graduate Students	Ashley Hammac Ju Qiu Dusty Walsh Ebrahiem Babiken		Jason Streubel*	

*affiliated project