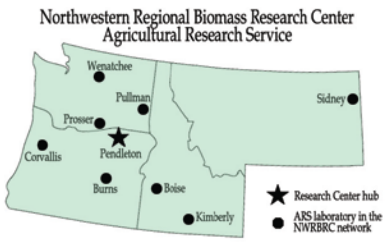

Accomplishments Report (2010-2014)
Northwestern Regional Biomass Research Center

U.S. Department of Agriculture
Agricultural Research Service

This report summarizes the accomplishments of the Agricultural Research Service's Northwestern Regional Biomass Research Center (NWRBRC) focusing on feedstock development, feedstock production, and conversion and co-product utilization. A key purpose of the report is to provide information for an external assessment of the NWRBRC's performance over the past four years (2010-2014).

Overview

In 2010, five regional USDA Biomass Research Centers were established to coordinate USDA-ARS intramural research to help accelerate the establishment of commercial biofuel supply chains based on agricultural feedstocks. The NWRBRC is a network of existing ARS facilities and scientists located in Washington, Oregon, Idaho, and Montana. Northwestern ARS locations include: Boise, ID; Burns, OR; Corvallis, OR; Kimberly, ID; Pendleton, OR; Prosser, WA; Pullman, WA; Sidney, MT; and Wenatchee, WA. Regional coordination is the responsibility of Dan Long (Pendleton, OR) who reports NWRBRC accomplishments to the Agency Leadership Team. The Agency Leadership Team is then expected to report the accomplishments directly to the USDA Office of the Secretary and Office of the Chief Scientist.

Research Units Reporting

Northwest Watershed Management Research Unit – Boise, ID
Range and Meadow Forage Management Research Unit – Burns, OR
Forage Seed and Cereal Research Unit – Corvallis, OR
Northwest Irrigation and Soils Research Unit – Kimberly, ID
Soil and Water Conservation Research Unit – Pendleton, OR
Vegetable and Forage Crop Research Unit – Prosser, WA
Land Management and Water Conservation Research Unit – Pullman, WA
Agricultural Systems Research Unit – Sidney, MT
Physiology and Pathology of Tree Fruits Research Unit – Wenatchee, WA

Accomplishments

Feedstock Development

Juniper encroachment into shrub steppe rangelands in the Great Basin reduces understory vegetation, promotes extensive bare ground, and substantially increases runoff and erosion across spatial scales. ARS scientists at Boise, ID evaluated the hydrologic impacts of juniper encroachment and tree removal, which would provide a feedstock for producing biofuel. Tree cutting has favorable runoff and erosion responses over time. Tree mastication improves infiltration where tree debris is well-distributed throughout the inter-canopy. Burning increases runoff and erosion in the immediate post-fire period, but may improve inter-canopy hydrologic function in the years following fire. Experimental field data have been used to develop and apply the Rangeland Hydrology and Erosion Model (RHEM) for quantification of environmental benefits and targeted application of rangeland conservation practices. The above described research has increased understanding of the hydrologic impacts of juniper encroachment and tree removal, and has led to development of tools for predicting and targeting the juniper removal practices (Pierson et al. 2010, 2011, 2013, 2014; Williams et al. 2014a, 2014b; and Al-Hamdan et al. 2014). CRIS Project 5362-13610-011-00

Rangelands in eastern Oregon are experiencing a rapid expansion of juniper due to reduced fire return intervals and indirect effects of livestock grazing. ARS researchers at Burns, OR documented the environmental benefits of juniper removal, which can also serve as a potential feedstock for biofuel production. Juniper expansion has negative ecological impacts on understory vegetation, which provides both forage for livestock and habitat for wildlife. Expansion also increases bare ground and cooperative research with ARS scientists at Boise, ID demonstrated the degree of water loss and soil movement when bare ground is exposed as a result of juniper competing with understory vegetation. This research has led to effective methods of juniper removal and ways of restoring native plant communities once the juniper has been removed (Davies et al., 2014; Bates et al., 2013; Bates et al 2011; Madsen et al., 2011). CRIS Project 5360-21630-001-00

Switchgrass and other warm-season grasses are fast growing and can be made into a fuel for cars. However, long-term removal of biomass of this crop might deplete organic matter in the soil. Scientists in Pendleton, OR evaluated how the soil would change when switchgrass was grown instead of winter wheat. Changing to switchgrass increased the ratio of carbon to nitrogen in the soil and increased the rate at which CO2 was lost from the soil. In addition, the nitrogen mineralization rate under switchgrass was greater than that under winter wheat. A perennial crop such as switchgrass can produce major changes in soil likely because of its large network of stems and roots (Chatterjee et al., 2013). USDA-CSREES Project: Soil ecosystem changes in C and N budgets induced by a shift to biofuels production.

Crop biomass is available for conversion to bioenergy, but a certain amount must remain on the land for soil protection. Scientists in Pendleton, OR used the computer model CQESTR to predict impacts of stover removal on the soil organic carbon (SOC) of a sandy soil near Florence, SC. After 23 years, CQESTR predicted a reduction in SOC (0-5 cm depth) by 21% under disk tillage and by 30% under conservation tillage with 66% residue harvest. Residue removal from loamy sand soils may well have an adverse impact on SOC stocks despite the method of tillage. The model will be valuable for predicting SOC resulting from various cultural practices and for management planning for C credits (Gollany et al., 2010). CRIS Project 5356-11120-002-00D

Rapid assessments of the potential long-term impact of harvesting crop residues for cellulosic biomass are needed. ARS scientists at Pendleton, OR, validated the CQESTR model successfully and predicted decreases in soil organic carbon (SOC) due to cultivation and crop residue removal when compared with measured SOC from long-term experiments across North

America, and simulated the potential of various agricultural management systems to maintain SOC. Manure or a cover crop/intensified crop rotation under no-tillage were options to mitigate loss of crop residue carbon from agricultural soils, as using fertilizer alone was insufficient to overcome residue removal impact on SOC. These results have important implications for farmers, crop advisors, scientists, and policy makers interested in carbon trading schemes or biofuels. Crop residues play a vital role in maintaining SOC, which is not only required for conserving soil, but also for ensuring the long-term production of biofuel feedstock (Gollany et al., 2011). CRIS Project 5356-11120-002-00D

The need for biofuel feedstocks to replace 30% of the United States petroleum needs by 2030 will require harvesting up to 50% of currently enrolled conservation reserve program (CRP) land. The material harvested from these lands will provide lignocellulosic feedstocks for ethanol production. Unlike CRP in the central and eastern United States, the predominate grasses grown in the Pacific Northwest are cool season grasses. Scientists from Oregon State University and ARS in Pendleton, OR determined the productivity of CRP in one major small grain producing county in northeastern Oregon and the suitability of that material as a lignocellulosic feedstock. Based on one year of sampling, aboveground productivity is greater than projected by the USDA Soil Survey. Despite differences in plant species, soils, and rainfall among sites, the biochemical composition of the samples was found to be similar in all but one of the sites. This material appears suitable for use in a single integrated process to produce bioethanol. These results support further exploration across the region to determine CRP productivity and confirm similar plant species composition (Juneja et al., 2011). CRIS Project 5356-21610-001-00D

A potential source of lignocellulosic ethanol feedstocks are conservation buffers established to reduce soil loss, improve water quality, and provide wildlife habitat. Unlike cropland, conservation buffers are not monocultures, but rather often a rich mix of many types of plants. A team of scientists with Oregon State University and ARS in Pendleton, OR analyzed nine plant species commonly found in the inland Pacific Northwest (USA) conservation buffers for their suitability as biofuel feedstocks. Because at harvest these plant species are mixed non-uniformly, their biochemical differences are likely to complicate and reduce the production potential of ethanol from conservation buffers in the Pacific Northwest. These composition variations could vary the processing efficiency in terms of sugar recovery and eventual ethanol production yield (Kumar et al., 2012). CRIS Project 5356-21610-001-00D

Perennial herbaceous bioenergy crops (e.g. switchgrass) have the potential to sequester soil C, supply a portion of U.S. energy needs and reduce atmospheric CO_2 enrichment when used as a fuel. Assessments of C sequestration are needed since the C contained in the above ground biomass will be removed from the field when processed as a bioenergy feedstock. In addition, assessments of the export of essential plant nutrients (N, P, K, and S) are needed to determine reductions in soil fertility that impact fertilizer recommendations. Aboveground biomass yields averaged 20.4 16.9 and 14.5 Mg dry matter $ha^{-1}y^{-1}$ for Kanlow, Shawnee, and Cave in Rock varieties, respectively, that would produce 7,500 L ethanol ha^{-1} for the highest yielding variety. The export of C, N, P, K and S from the field averaged 7.6 Mg C $ha^{-1}y^{-1}$, 214 kg N $ha^{-1}y^{-1}$, 52 kg P $ha^{-1}y^{-1}$, 426 kg K $ha^{-1}y^{-1}$ and 19 kg S $ha^{-1}y^{-1}$ among varieties, with 2.6 Mg of soil C ha^{-1} derived from switchgrass in the surface 30 cm of soil after three years of production. Each variety required 1kg of N to produce 83 kg of biomass. Bioenergy crop producers can use this information to adjust fertilization rates to meet their feedstock production goals. In addition, these data would also be useful in the development of secondary markets, such as C-credit trading or by ethanol producers interested in nutrient recovery for production of fertilizer or animal feed supplements (Collins et al., 2010; Kimura et al., 2014). CRIS Project 5354-21660-002-00D

As crop and non-crop lands are increasingly becoming converted to biofuel feedstock production, it is of interest to identify potential impacts of annual and perennial feedstocks on soil ecosystem services. Soil samples obtained from 6 regional sets of switchgrass (*Panicum virgatum* L.) and 3 regional sets of sorghum (*Sorghum bicolor* L.) crop and nearby non-crop grassland locations were analyzed for chemical characteristics, microbial gene diversity and abundance, active microbial biomass and nematode diversity. Sorghum crop and non-crop sites differed significantly from switchgrass sites with regard to soil chemistry; i.e., sorghum crop soils had significantly higher NO_3-N, NH_4-N, SO_4-S, and Cu levels than non-crop soils. Using GeoChip 4.0 functional gene arrays (FGA) to analyze soil DNA, microbial gene diversity was significantly lower in sorghum crop soils than in non-crop soils. Microbial gene diversity at switchgrass sites varied between geographic locations, but not with land use type. No significant differences in microbial gene abundance were observed between sorghum crop and non-crop soil samples. However, microbial gene abundance in switchgrass crop soil samples was significantly lower than in non-crop soils. Gene diversity at sorghum locations was significantly correlated with pH, NO_3-N, NH_4-N and % silt in the majority of 15 FGA categories. Gene abundance at switchgrass locations was correlated with pH, Cu, Mn, Fe, % soil moisture, % sand, % silt, % clay and active bacterial biomass. Our results suggest that cultivation of a perennial biofuel crop such as switchgrass influences soil ecosystem services less than cultivation of an annual biofuel crop such as sorghum (Watrud et al., 2012). CRIS Project 5354-21660-002-00D

The United States has established a goal of producing 36 billion gallons of biofuel by 2022. This demand will in part be met by growing oilseed feedstock. Little is known about the impact of growing oilseed crops on wind erosion in the Inland Pacific Northwest United States where poor air quality is a major environmental concern. We found that emission of windblown dust (including PM10 or particles less than 10 microns in diameter regulated by the US EPA) was as much as 250% higher from oilseed crop rotations than conventional wheat rotations. To maintain good air quality, farmers must be vigilant in protecting the soil from wind erosion when growing oilseeds on western dryland agricultural lands (Sharratt and Schillinger, 2014). CRIS Project 5348-11000-006-00D

Cereal residues are considered an important feedstock for future biofuel production. Harvesting cereal residues, however, could lead to substantial soil degradation. Our objective was to evaluate trade-offs associated with harvesting straw including impacts on soil erosion and quality, soil organic C (SOC) and nutrient removal. We used cropping systems data from 369 georeferenced points on the 37-ha Washington State University Cook Agronomy Farm to develop straw harvest scenarios that included conventional tillage (CT) and no-tillage (NT) and both two- and three-year crop rotations. Site-specific field estimates of annual lingo-cellulosic ethanol production scenarios ranged from 681 to 1541 L/ha and indicated that both crop rotation and site-specific targeting of residue harvest are important factors. Harvesting straw reduced average residue C inputs by 46% and to field levels below that required to maintain SOC under

CT. This occurred as a function of both straw harvest and the inclusion of low residue producing crops in rotation with cereals. Harvesting straw under CT was predicted to reduce soil quality as Soil Conditioning Indices (SCI) were negative throughout the field. In contrast, SCI's under NT were positive throughout the field despite straw harvest. Estimated replacement value of nutrients (N, P, K, S) removed in harvested straw was $14.59/Mg dry straw with field variation that ranged from $12.27 to $69.74/ha for the continuous cereal rotation. We concluded that substantial trade-offs exist in harvesting straw for biofuel, that trade-offs should be evaluated on a site-specific basis, and that support practices such as crop rotation, reduced tillage and site-specific nutrient management need to be considered if straw harvest is to be a sustainable option (Huggins et al., 2014; Karlen and Huggins, 2014). CRIS Project 5348-11000-006-00D

Grass seed production systems of the Pacific Northwest, in particular, have considerable potential for providing residue feedstocks for biofuel systems. Critical to moving in this direction, and in making long-term soil management decisions supporting farm sustainability, is understanding the impact residue management decisions on soil quality and, in particular soil C dynamics. ARS scientists at Corvallis studied the effects of a 6-yr rotation and residue management (high vs. low residue) on soil quality were investigated at three locations in Oregon. Each location contrasted in soil drainage classification. Tillage (till vs. direct seeded) and crop rotation were also studied. Crop rotations consisted of continuous perennial grass seed production, grass/legume seed production, and grass/legume/cereal seed production. The grass species grown at each location were different and represented those most commonly produced in each environment; perennial ryegrass (*Lolium perenne* L.), tall fescue [*Schedonorus phoenix* (Scop.) Holub], and creeping red fescue (*Festuca rubra* L.). All three grass seed crop rotations and residue methods maintained high soil quality in conventional or direct seeded soils, but under some situations, soil quality was higher with continuous grass rotation and high residue. It was found that straw removal for value-added use, like bioenergy production, could be accomplished in the Pacific Northwest western valleys without appreciably affecting soil C. Furthermore, grass seed cropping systems play an important role in soil C storage and enhancement, a valuable ecosystem service in this region where grass seed is produced on land that is not suitable for production of conventional crops that require better-drained soil. By nature, perennial grass seed crops promote high soil fertility and enriched soil C pools and consequently contribute to the tolerance of these systems to the use of less conservation-oriented crop management methods at times when crop loss could be potentially high. This attribute provides producers greater latitude in selecting soil and crop management options to address issues of soil fertility, pest, weed, or seed certification to minimize economic crop yield losses (Griffith et al., 2011). CRIS Project 5358-21410-003-00D

Differences in the suitability of straws from four forage and turf grasses, nine native grasses, six populations of switchgrass, and twenty four varieties of wheat, grown at multiple locations under contrasting environmental conditions for thermochemical conversion to bioenergy were demonstrated by ARS scientists at Corvallis. The amounts of silicon, chloride, and other nutrients that affect the formation of slag in gasification reactors, along with macronutrients like nitrogen, phosphorus, potassium, and carbon were quantified and compared among the respective groups of straw. This is important new knowledge that is critical in developing bioenergy crops that are suitable for technologies to convert straws and other agricultural residues into energy. This development enabled the selection of appropriate genetic strains of these straw-producing crops by breeding programs to utilize for improving traits that are critical to bioenergy production. This information is also useful where restoration and conservation planting efforts are designed to permit dual use of these grasses as both conservation aids, and as potential biomass feedstock (El-Nashaar et al., 2010, 2011). CRIS Project 5358-21410-003-00D

Feedstock Production

Degraded riparian areas on agricultural land in eastern Oregon and Washington have been identified as having potential for producing perennial grasses and other dedicated biofuel crops. Scientists in Pendleton, OR compared the cellulosic ethanol production potential of tall wheatgrass with that of alfalfa, barley, and wheat in low, intermediate, and high rainfall zones. Tall wheatgrass and its mixtures had superior ethanol yield to alfalfa, barley, or wheat as a result of high biomass and high cellulose, particularly in the intermediate and high rainfall zones. Though biomass production compared favorably with feedstocks grown in the upper mid-western and eastern US, regional ethanol production potential was low because stream buffers make up only 1.1% of acreage in this region. Weed management is a primary concern if degraded land is to be considered for biofuel production. CRIS Project 5356-21610-001-00D

Scientists in Pendleton, Oregon adapted a technology to measure crop height and aboveground biomass of wheat using an inexpensive Light Detection and Ranging (LiDAR) instrument mounted to a combine harvester. Based on field results, LiDAR measurements of crop height can determine straw productivity with about 85% accuracy. Maps of straw yield can be derived from LiDAR when it is coupled to a GPS receiver. Maps of harvestable straw can be computed by subtracting the amount of straw required to maintain soil carbon from a map of total straw. These findings are important in soil conservation programs where accurate information is needed on how much straw is available for commercial use and soil protection (Long et al., 2013). CRIS Project 5356-21610-001-00D

Natural variation in the seed oil concentration of oilseed crops sent to a crushing plant can impair recovery of oil from the seed. Scientists in Pendleton, Oregon, demonstrated that the in-line NIRS technology can determine seed oil concentration in a grain stream to within an error of 0.73%. This result is sufficiently promising to suggest that in-line NIRS could be used to evaluate the performance of the extraction process in a crushing plant so that the expeller can be adjusted to maximize oil extraction and minimize residual oil levels in the finished meal. Ability of crushing plants to monitor extraction efficiency would also enhance profitability and help ensure maximum efficiency of the harvested acres of oilseed crops (Long et al., 2012). CRIS Project 5356-21610-001-00D

Special equipment is needed for harvesting high energy forage crops in small plots. Scientists in Pendleton, OR constructed a flail-type harvester implement to be powered by an 85 hp narrow specialty tractor. Mounted to the front of the tractor, the harvester was successfully used to harvest up to 9 ton per acre in 8.8-m plots before its collection box was filled. Under normal conditions, three people can harvest 12 plots (20 m long) within 1 hour including weighing the biomass, emptying the harvester, and bagging samples. The harvester can be attached to a tractor and made ready for harvesting, or removed to make the tractor available for other purposes, in about 1.5 hour. Cost of materials for the harvester was <$10,000 (Long et al., 2011). CRIS Project 5356-21610-001-00D

Switchgrass (*Panicum virgatum*) is a warm-season perennial grass that has been grown for seed for more than 30 years in the Columbia Basin. Switchgrass and other selected perennial warm-season grasses (WSG) can be successfully grown in the hotter and irrigated regions of the Pacific Northwest (PNW) as feedstock for cellulosic biofuel or forage for livestock. Research studies were first established with switchgrass and other WSG at WSU-Prosser in 2002 and the USDA-ARS Integrated Cropping Systems field station near Paterson, WA in 2004. More than a decade later, these initial plantings of switchgrass remain productive. The fields or trials have been harvested twice per season, maintaining relatively dense stands (specific to the species and variety) and are now "sustainable". But to accomplish the goal of long-term sustainable biomass feedstock or forage the crop must be established, properly, which is the focus of this bulletin. Varietal differences for number of seeds per pound, optimum planting time, weed control practices, growth and development above- and below- ground and establishment year yields of switchgrass under irrigation in the PNW are compared. This bulletin encapsulates our experiences, research results and recommendations with pre- and post-seeding management and early switchgrass seedling development under irrigation. Guidelines are provided to growers and researchers to avoid critical errors when establishing switchgrass in the PNW (Fransen et al., 2014). CRIS Project 5354-21660-002-00D

Switchgrass has potential to become a major crop grown for ethanol production. Weeds present during switchgrass establishment reduce switchgrass stands, delay or prevent maximum switchgrass yields, and lower the quality of the switchgrass harvested. Grass weeds are particularly difficult to selectively control during switchgrass establishment and can cause stand failure and the need to replant. Scientists at Prosser, WA demonstrated that quinclorac and pendimethalin applied in the year of switchgrass establishment controlled both large crabgrass and green foxtail. Mesotrione controlled large crabgrass, but failed to control green foxtail during switchgrass establishment. Quinclorac was the only treatment that did not injure switchgrass excessively and has potential for use in managing grass weeds during switchgrass establishment. Identification of effective herbicides for grass weed control during switchgrass establishment provides producers with effective tools to improve success of switchgrass stand establishment, improve switchgrass yields and quality, and increase profitability of switchgrass production (Boydston et al., 2010). CRIS Project 5354-21660-002-00D

Since 2011, scientists at Prosser, WA have investigated biomass yield for bioenergy production within a hybrid poplar (*Populus* x *canadensis and P.* x *generosa*) – switchgrass (*Panicum virgatum*) intercrop system. This five year project has been quantifying biofuel energy biomass production potentials, C sequestration and greenhouse gas emissions within a switchgrass-hybrid poplar intercrop system. We have shown that intercropping provides increased biomass production as measured by the land equivalent ratio (LER). When LER is > 1 then crop synergy is positive; if < 1 then negative. After three production years LER remains above 1.5, validating the synergistic effect of intercropping, while producing an average of 8 dry tons switchgrass per acre which is available for biomass bioenergy conversion. Greenhouse gas and nitrous oxide fluxes increased following the application of manure or commercial fertilizers. Nitrous oxide fluxes were higher for commercial fertilizers than manure treatments due to the higher nitrification rates of fertilizers vs. manures and were higher at the second application of fertilizers, related to the increased application of irrigation later in the growing season. This approach of intercropping also reduces the need for utilizing prime farm lands for biofuel production and has been beneficial to both species. USDA-NIFA Project - Carbon Sequestration and Greenhouse Gas Emissions from the Sustainable Intercropping of Switchgrass and Hybrid Poplar for Bioenergy and CRIS Projects 5354-21660-002-00D and 5354-21660-003-00D

The production of oilseed crops represents a unique opportunity for PNW producers to provide a biodiesel feedstock for an emerging renewable biodiesel industry. The inclusion of oilseeds in rotation offers producers an alternative strategy to improve farm economies and gain additional benefits that improve soil and water conservation, reduce pest cycles, and diversify cropping systems. Safflower (*Carthamus tinctorius*) is considered a low input and drought tolerant crop, but responds well with irrigation and fertilizers. Scientists at Prosser, WA planted three safflower varieties S334, S345 and CW99OL in April 2008-2011 under center pivot irrigation. Standard irrigation and deficit irrigation were 28 and 22 inches, respectively. The difference in water applied between the deficit irrigated and the standard water treatment was 6 inches resulting in a treatment of 80% of ET in 2009 and 8 inches, 70% of ET in 2010 and 2011. Safflower oilseed yields averaged 3100 lbs ac^{-1} among years in for all treatments. Safflower oilseed yields were significantly higher under the 100 than 145 lb N $acre^{-1}$ fertilizer rate in 2008. Safflower oilseed yields were not significantly different between the full and 70% ET treatments, indicating a potential 5 to 7 inch water savings using a deficit irrigation strategy depending on year. Deficit irrigation (70% of ET) had a positive effect on WUE with an average increase of 23 lb seed yield $acre^{-1}$ $inch^{-1}$ of water applied. Oil contents of the seed were 1.5 – 2.2% higher under deficit irrigation than under full irrigation following the higher yields and greater water use efficiencies. CRIS Projects 5354-21660-002-00D and Washington State Dep. Agric. (WSDA) - WSU Joint Near-Term Research and Development Project “Developing viable biofuel cropping systems in Washington State”

The winter wheat, highly erosive, weed infested tillage-fallow crop production system has been practiced on 60% of the wheat growing region of the Pacific Northwest (PNW) for over a century. Winter canola has the potential to be integrated into this low-rainfall cropping system, however, producers are reluctant to grow winter canola because of lack of agronomic research for this crop and poor stand establishment when one or two producers have tried to grow it. From 2007 until 2011, scientists at Pullman, WA conducted experiments in north central WA in 10-inch rainfall zones to determine the optimum time and rate of winter canola planting. Using a modified deep-furrow, winter wheat drill, researchers found the optimum time of planting was from early to late August and air temperatures approximately 85°F for several days after planting. The cool temperatures are required to prevent the soil from getting too hot and killing the seedlings as they emerge through the soil. Optimum yields were not necessarily associated with high winter survival and high spring plant densities. Canola yields of 1500 lbs/acre to 1650 lbs/acre were realized with a 4 lb/acre seeding rate and an increased rate of 8 lb/acre did not increase yield because of intraspecific competition. Winter survival ranged from 56% to 83% with approximately 60% being average. The integration of winter canola into the winter wheat-fallow, low rainfall regions of the PNW would reduce weed and disease infestations of wheat, diversify growers production systems and markets, and improve soil quality (Young et al., 2014 in press). CRIS Project 5348-21610-001-00D

The winter wheat, highly erosive, weed infested tillage-fallow crop production system has been practiced on 60% of the wheat growing region of the Pacific Northwest (PNW) for over a century. Spring canola has the potential to be an alternative oilseed crop in this region either as an opportunity crop during periods of above-normal precipitation or as a replant crop if fall-planted canola has been winter killed. In 2009 and 2010, scientists at Pullman, WA and Pendleton, OR conducted a study in WA and OR to evaluate the effect of no-till planting methods on spring canola plant establishment, yield, and oil quantity. In our study, when crop residue was low (3 of 4 site-years), one of the best no-till planting methods for crop establishment and yield was with a conventional double disk opener, a drill that most growers of the region already own – thus reducing costs by not having to purchase a no-till drill. The use of expensive no-till openers did not improve establishment and yield compared with the double disk openers. Broadcasting spring canola seed, although popular in Canada and Great Britain did not perform well in the PNW in our environmental conditions. This treatment had consistently the lowest crop establishment and yield compared to seeding directly into the soil with all openers. No-till spring canola shows promise as a sustainable crop by reducing weed and disease infestations of wheat, diversifying growers' production systems and markets, and improving soil and air quality (Young et al., 2012). CRIS Project 5348-21610-001-00D

Identifying suitable cropping alternatives to fallow can increase acreage for crops that can be used as biodiesel and jet fuel feedstock. These potential cropping systems need to efficiently use water and nitrogen (N) fertilizer, which is a major input expenditure. USDA researchers at Sidney, MT investigated yield, weeds, insects, and water and N use of three oilseeds (camelina, crambe, and juncea canola) as replacement for fallow in 2-year durum rotations. Results from the five-yr study suggested that in semi-arid areas, juncea canola could be a suitable alternative to fallow in 2 year durum rotations. Researchers found that juncea canola had significantly superior seed and oil yield compared to the other oilseeds tested and appears to be a promising candidate for biofuel production in semi-arid areas of eastern Montana and western North Dakota. Furthermore, growing juncea canola in place of fallow did not affect the following year's durum yield meaning producers can expect to maintain existing profits from their wheat production while adding additional profit from a new cash crop. Because several million acres of fallowed fields are available in semi-arid regions, the nation could also benefit through an increased supply of oilseed feedstocks for biodiesel production which could help reduce our dependence on imported oil, without impacting existing food production (Lenssen et al., 2012; Allen et al., 2014a). CRIS Project 5436-13210-006-00

Dryland corn acreage in the northern Great Plains has increased about ten-fold over the past decade with the introduction of more drought tolerant hybrids and a strong market for corn in the food, feed, and bioenergy sectors. However, dryland corn yields are highly variable due to relatively little and inconsistent precipitation during the growing season. Two management strategies that improved corn yield in dry years (about 10 inches of growing season precipitation) were lowered seeding rates and planting in a skip-row configuration (plant 2 rows skip 1 row). When planting rates exceeded 15,000 seeds per acre, corn utilized the limited available soil moisture early in the growing season to produce vegetative growth at the expense of grain fill. Conversely, when corn was planted at rates as low as 10,000 seeds per acre, there was greater soil water available during the reproductive stages resulting in both greater corn grain yield and a greater proportion of total biomass as grain. Planting corn in a skip-row configuration had little impact on grain yield, though biomass yield was often greater than when corn is planted in every row. Lowering seeding rates and altering row configurations in dryland corn production during dry years can increase grain and biomass yield, improve water productivity, and reduce input costs in a semi-arid environment (Allen, 2012). CRIS Project 5436-13210-006-00

Camelina offers a new cropping alternative to fallow in the northern Great Plains. However, little agronomic information is available for this non-food oilseed feedstock intended for jet fuel or biodiesel markets. Consistent and timely establishment of very small seeded crops, like camelina, is critical for stand density, evenness of emergence and ripening, and to suppress weed competition. Consequently, ARS researchers in Sidney, MT determined that seeding camelina to a depth deeper than ¼ inch decreased plant density and crop competiveness with weeds. Also, researchers found that camelina emerged at temperatures below 0°C, suggesting that early planting in the spring would probably be limited by field access due to wet soil rather than the base temperature requirement. Uneven emergence and ripening of camelina was a persistent problem in various USDA-ARS trials conducted near Sidney, MT in spite of efforts to modify seeding depths, rates, and species selection, suggesting a need for further crop development and breeding selection (Allen et al., 2014b). CRIS Project 5436-13210-006-00

Lack of cropping diversity and limited soil water availability constrain spring wheat production in the northern Great Plains. To improve cropping system performance, ARS researchers in Sidney, MT conducted a 9-yr experiment to compare productivity, soil water and N use, and soil C and N pools, in four crop rotations with increasing levels of diversity (continuous spring wheat (SW); pea-SW; barley hay-pea-SW; barley hay-corn-pea-SW), two tillage systems (no-till and minimum till), and two management systems (Conventional management included standard seed rates and plant spacing, early planting date, broadcast N fertilizer, and short stubble height; Ecological management included variable seed rates and plant spacing, delayed planting date, banded N fertilizer, and tall stubble height). Spring wheat in diversified rotations (including those with bioenergy crops) had greater yield and water use efficiency than continuous wheat. Including bioenergy crops in diversified rotations not only offset the demand for nonrenewable resources, but also improved the productivity of subsequent rotational crops as well as the production potential of the overall cropping system. No-tillage with conventional management increased surface residue, soil C and N storage, and microbial biomass and activity, while minimum till with conventional management increased soil N availability (Lenssen et al., 2014; Sainju et al., 2011; Sainju et al., 2012a; Sainju et al., 2012b). CRIS Project 5436-13210-006-00 and USDA-NIFA Project: Carbon sequestration and nitrogen cycling for greenhouse gas mitigation by southeastern US annual and perennial energy crops

Conversion and Co-product Utilization

Pyrolysis of biomass produces renewable energy and biochar, which when stored in soil can move atmospheric carbon dioxide to soil carbon. ARS researchers at Kimberly, ID evaluated the effects of hardwood-derived biochar on irrigated calcareous soil. Compared to untreated soil, biochar produced a consistent increase in soil carbon, but had little effect on other soil nutrients, other than causing an initial, temporary increase in the availability of soil manganese. The biochar had few effects on corn silage nutrient concentrations and silage yields until the second growing season, when it reduced nitrogen and sulfur concentrations in silage and reduced yield relative to untreated soil. This research provides important guidance to farmers growing crops on biochar-amended soils (Ippolito et al., 2014). CRIS Project 5368-12000-010-00

In Washington, 1.3 million tonnes of distiller's grains and 78.5 million tonnes of oilseed meals are expected to be produced in the upcoming years as byproducts of the biofuel industry. These byproducts contain plant nutrients, similar to other byproducts such as manures and composts. Transformations of N from poultry litter (PL), dairy manure compost (DMC), anaerobically digested fiber (ADF), Perfect Blend 7-2-2^{TM} (PB), a compost/litter mixture (C/L), dried distillers grains (DG), and mustard meal (MM) applied to a Quincy fine sand were investigated by scientists at Prosser, WA in an incubation experiment over 210 days. Amendments were applied at a rate of 200 mg total N kg^{-1} and the incubation temperature was adjusted biweekly to represent the soil temperature in the Pacific Northwest (PNW) region of the U.S. The soil was sampled regularly to measure the concentration of ammonium and nitrate extractable in 2 M KCl. Mineralization of organic nitrogen was rapid from PL and PB, while relatively slow from MM and DG. The cumulative release of available N for 210 days accounted for 61 and 56 percent of total N in MM and DG, respectively, in contrast to 44 percent for PL. With application of MM and DG, NH_4-N accumulated in the soil with very little nitrification, due to possible inhibition of nitrification due to the compounds present in these amendments. Nitrogen mineralization was negligible from DMC, thus suggesting that this amendment may be least effective as a source of plant available N for most annual crops growing period (Moore et al., 2010). CRIS Project 5354-21660-002-00D

Mustard (*Sinapis alba*) varieties vary in glucosinolate content, which may affect weed growth suppression properties of the seed meal. Oilseed meals are valuable co-products of biodiesel production. Researchers at Prosser, WA discovered that *Sinapis alba* seed meal produced from seed containing high and low levels of glucosinolate differed in their ability to suppress weed growth. The dose response of *Sinapis alba* seed meals differing in glucosinolate content on two weed species was determined. Low glucosinolate seed meal (0.17 mg sinalbin/g dry weight) failed to suppress weeds at lower doses compared to seed meal containing high glucosinolate content (17 mg sinalbin/g dry weight). These results helped identify the active compounds in mustard meal and refine the use patterns of mustard meal for weed suppression. Use of mustard seed meal may be useful to producers of organic crops for weed suppression and help reduce excessive costs of hand weeding (Boydston et al., 2011). CRIS Project 5354-21660-002-00D

The thermo-chemical conversion (pyrolysis) of plant biomass is being studied in the US for its potential to produce second generation liquid biofuels and the co-product biochar, which can be used as a soil amendment. The recent focus on biochar as a soil amendment for improving soil physical-chemical properties and C sequestration has revealed knowledge gaps in the research covering different feedstocks in various soil types. Scientists at Prosser, WA evaluated biochars made from four feedstocks (wood pellets, softwood bark, switchgrass straw, and animal digested fiber) produced by pyrolysis for pH, CEC, water holding capacity, elemental content, and C and N mineralization potentials in five soils. Biochar was found to improve soil pH, water holding capacity and soil C pools. In irrigated systems, appropriate choice of biochar feedstock could increase soil WHC and thus reduce either the frequency or amount of irrigation. The recalcitrant nature of the biochars investigated can also improve C sequestration in agricultural soils because the proportion of total C in biochar that is recalcitrant leads to SOM stability (Smith et al., 2010;

Streubel et al., 2011). CRIS Project 5354-21660-002-00D and Washington State Dep. Agric. (WSDA) – Use of bio-char from the pyrolysis of waste organic material as a soil amendment

Biochar has been promoted recently as a soil amendment to sequester carbon, increase crop production and for retention of phosphorus and nitrogen. However, when used in high quantities, biochar may impact the activity and bioavailability of herbicides. Scientists at Prosser, WA demonstrated that biochar added to two soils reduced the bioavailability of both atrazine and metribuzin. The addition of 10 ton/acre biochar greatly reduced herbicidal activity of atrazine and metribuzin on a Quincy sand soil increasing the amount of atrazine required to obtain 90% oat injury from 0.035 lb ai/a (without biochar) to 0.38 lb ai/a (with biochar) and the amount of metribuzin from 0.02 lb ai/a (without biochar) to 0.09 lb ai/a (with biochar). On a Warden sandy loam soil, biochar had little effect on atrazine activity but increased the amount of metribuzin required to obtain 90% oat injury from 0.09 lb ai/a to 0.3 lb ai/a. Reduction in herbicidal activity was the result of increased sorption of both herbicides by biochar. This information can be utilized by producers to modify herbicide rates and prevent weed control failures when utilizing biochar as a soil amendment. CRIS Project 5354-21660-002-00D

Sorption of nutrients by biochar from dairy storage lagoons and used as a supplemental fertilizer off site is a beneficial strategy to reduce nutrient contamination around dairies while producing bioenergy from pyrolysis and anaerobic digestion technologies. In addition, the sale of the nutrient enriched biochar off-farm as a fertilizer will increase dairy revenues. Scientists at Prosser, WA found biochar amended with dairy effluent applied at a 6 T ha^{-1} supplied adequate soluble P levels in Ranger and Umatilla potato petioles through 60 days after emergence, although P levels were 50% greater using a commercial MAP fertilizer at 280 kg P ha^{-1} rate the availability of P was similar. This study showed that P sequestered from dairy lagoons by biochar can be used as a P fertilizer supplement. Since dairies typically maintain a small land base and apply an excess of P to soils (135 - 500 kg P ha^{-1}) this strategy to remove nutrients from the farm that could be sold as a fertilizer supplement would increase dairy revenues and decrease environmental impacts (Collins et al., 2013). CRIS Project 5354-21660-002-00D and Washington State Dep. Agric. (WSDA): Use of bio-char from the pyrolysis of waste organic material as a soil amendment

Dairy production in the Pacific Northwest has grown steadily over the past decade. This increase has been accompanied by management challenges associated with production of large concentrations of dairy animal wastes that are implicated in the decline in surface and subsurface water quality as well as an increase in the production of greenhouse gases when used as a soil amendment in vegetable production. Anaerobic digested dairy effluent (ADE) has been shown to be a viable feedstock for bioenergy conversion to liquid fuels. Scientists at Prosser, WA conduced field studies to characterize greenhouse gas emissions from a silt loam soil amended with urea fertilizer, liquid dairy manure (DLM), anaerobic digested dairy effluent, anaerobic digested fiber, unfertilized and treatments cropped to silage corn and left fallow. Short duration CO_2-C increases were observed after mid-season applications of liquid manure slurries. Methane (CH_4-C) emissions were similar among treatments during the periods of measurement except for the several days following application of the ADE and DLM slurries. Emission rates of greenhouse gases (GHG) were significantly less (<60%) than the emissions coefficient standard proposed by the International Panel on Climate Change (IPCC) indicating that Climate

Models overestimate the contribution of GHG's from AD dairy manure applications in our region. Additional study is needed to determine GHG fluxes from ADE dairy storage lagoons. (Collins et al., 2011). CRIS Project 5354-21660-002-00D and Washington State Dep. Agric. (WSDA): WSU Joint Near-Term Research and Development Project "Developing viable biofuel cropping systems in Washington State"

Researchers at Wenatchee, WA evaluated the efficacy of brassicaceae seed meals for the control of apple replant disease and the effects of such treatments on the causal pathogen complex, tree growth and fruit yield were examined over a five year period in conventional production systems. When applied independently, all pre-plant seed meal treatments or a post-plant mefenoxam failed to enhance tree growth or control disease to the level attained in response to soil fumigation. Postplant mefenoxam treatments revealed that failure of seed meal amendments to enhance tree growth and yield when used independently was due, primarily, to increased apple root infection by *Pythium* spp. in *Brassica napus* and *Sinapis alba* seed meal–amended soils, and by *Phytophthora cambivora* in *Brassica juncea*–amended soil. When used in conjunction with a postplant application of mefenoxam, *B. juncea* and *S. alba* seed meal pre-plant soil amendments were as effective as preplant 1,3-dichloropropene-chloropicrin soil fumigation in terms of disease control, vegetative tree growth, and five-year fruit yields of Gala/M26 apple. As these trials utilized the highly susceptible rootstock M26, the results demonstrate that this integrated strategy is a viable alternative to soil fumigation for the control of apple replant disease in conventional production systems (Mazzola et al., 2012; Weerakoon et al., 2012). USDA Integrated Organic Grants Program. Project Title: Use of Resident Biological Resources for the Management of Soilborne Diseases in Organic Tree Fruit Production Systems

Effective non-chemical strategies for long-term control of plant parasitic nematodes are desired within the tree fruit producer community due to an absence of nematicides available for post-plant application. Researchers at Wenatchee, WA examined pre-plant application of Brassicaceae seed meal formulations used in conjunction with a virtually impermeable film for control of apple replant disease and suppression of lesion nematode in two organic orchard systems. Seed meal formulations provided multi-year suppression of the lesion nematode densities in apple roots to levels significantly below the no treatment control, and although soil fumigation significantly suppressed densities of this nematode during the initial growing season, extensive re-infestation of fumigated soil by the nematode was observed during the two growing season to densities dramatically higher than the control or seed meal treated soils. Nematode suppression in the seed meal treated soil was associated with significant changes in soil biology including increased densities of nematode parasites and predators. This research indicates that a biologically viable alternative to chemical nematicides or soil fumigants can provide extended long-term suppression of plant parasitic nematodes in orchard production systems (Reardon et al. 2013). USDA-CSREES Integrated Organic Grants Program. Project Title: Predictive management of soil microbial communities using defined amendments to enhance production in organic cropping systems

Scientists at Wenatchee, WA developed Brassica seed meal formulations which enabled control of apple replant disease without the need for a post-plant mefenoxam soil drench. Disease control obtained was equivalent or superior to pre-plant soil fumigation irrespective of apple rootstock. In addition, pre-plant *Brassica juncea/Sinapis alba* seed meal amendment resulted in growth and fruit yields that were significantly greater than that attained in response to soil fumigation at two organic orchard sites. The seed meal formulation provides an effective alternative to soil fumigation for control of apple replant disease in both conventional and organic production systems. Superior tree growth in seed meal treated soils was correlated with prolonged suppression of plant parasitic nematodes and root infecting fungal/oomycete pathogens relative to that attained in fumigated soil. Resilience of the seed meal soil system, and susceptibility of the fumigated soil, to re-infestation by replant pathogens was associated with differential structure of the rhizosphere microbial community (microbiome). After two years, the rhizosphere microbiome in fumigated soils was indistinguishable from that of the no-treatment control, while trees established in seed meal treated soil possessed unique rhizosphere bacterial and fungal profiles. Overall diversity of the rhizosphere microbiome was demonstrably reduced in the seed meal treatment compared to control or fumigation treatments, suggesting that enhanced biodiversity was not instrumental in achieving enhanced system resilience and/or pathogen suppression (Mazzola and Strauss, 2013; Mazzola and Brown, 2010; Mazzola and Zhao, 2010). USDA-CSREES Integrated Organic Grants Program. Project Title: Predictive management of soil microbial communities using defined amendments to enhance production in organic cropping systems

Year-to-year variation in crops grown and yields achieved will impact the availability of straw for biofuel conversion plants of varying capacities. ARS scientists at Corvallis, OR developed procedures for sequentially optimizing the location of new biofuel conversion plants across the PNW based on available straw density and location and capacity of previous built plants. Multi-year average straw density was superior to single-year data in optimizing the location of plants with capacities from 1 to 10 million kg straw per year, with 100 million kg plants being less sensitive to yearly differences in production. The information on localized straw density and the optimized plant locations based on capacity will be valuable to entrepreneurs designing and building cellulosic biofuel conversion plants. CRIS Project 5358-21410-003-00D

ARS Corvallis scientists, along with private partners, developed an integrated system for on-farm energy production from agricultural residues generated during grass seed production and evaluated the economic and environmental feasibility of utilizing this system to produce bioenergy at the farm-scale. ARS Corvallis successfully gasified seed screenings resulting from the seed cleaning process and used syngas from the gasification to produce approximately 35 kW of electricity at a feed rate of 180 pounds of screenings per hour. Although electricity generation provides added value to the farm, by itself it does not justify the expense of a gasification system. CRIS Project 5358-21410-003-00D

The effects of biochar, produced from gasification of Kentucky bluegrass (*Poa pratensis* L.) (KB) seed screenings, as a soil amendment in wheat crops grown under dryland acid soil conditions has not been determined. Researchers in Corvallis, OR have demonstrated that KB biochar improves soil texture, soil water holding capacity, and raises soil pH resulting in improved wheat growth and development over untreated soil. In 2013, dryland wheat plots amended with KB biochar yielded 67 bu/ac wheat compared to lime amended, 44 bu/ac, and untreated plots, 26 bu/ac. Biochar treated plots increased saturated hydraulic conductivity over untreated plots from 24.2 to 34.1 cm/h. At wheat harvest in August 2013, biochar treated plots had nearly 20% more soil water than untreated or lime amended plots. Other data showed that biochar treated soil increased soil, reduced the uptake of aluminum by wheat plants. Chemical analyses of the biochar also demonstrated that returning biochar to the production field sequestered significant quantities of carbon and returned potassium and phosphate to the soil. Biochar from KB could provide dryland wheat farmers additional confidence of a successful wheat crop where soil moisture and acid soil conditions routinely have adverse effects on crop establishment and economic yield, especially with changing climatic events that result in crop stress. This research has now expanded to acid mine soils and their remediation with biochar. ARS scientists have recently demonstrated the use of KB and wood gasified biochar in the remediation of acid mine soils with native grasses that if left untreated will not support plant life. This research demonstrates that biochar produced with an on-farm gasification system has economic and agronomic value as a soil amendment and will enhance the economic feasibility of on-farm gasification of agricultural residues (Griffith et al., 2013). CRIS Project 5358-21410-003-00D

Publications

Al-Hamdan, O.Z., M. Hernandez, F.B. Pierson, M.A. Nearing, C.J. Williams, J.J. Stone, J. Boll, and M.A. Weltz. 2014. Rangeland hydrology and erosion model (RHEM) enhancements for applications on disturbed rangelands. Hydrological Processes DOI: 10.1002/hyp.10167.

Allen, B.L. 2012. Dryland corn yield affected by row configuration and seeding rate in the northern Great Plains. J. Soil Water Conserv. 67:32-41.

Allen, B.L., A.W. Lenssen, U.M. Sainju, T. Caesar-TonThat, and R.G. Evans. 2014a. Nitrogen use in durum and selected Brassicaceae oilseeds in two-year rotations. Agron. J. 106:821-830.

Allen, B.L., M.F. Vigil, and J.D. Jabro. 2014b. Camelina growing degree hour and base temperature requirements. Agron. J. 106:940-944.

Bates J.D., K.W. Davies, and R.N. Sharp. 2011. Shrub-Steppe early succession following invasive juniper cutting and prescribed fire. Environmental Management **47**, 468–481. doi:10.1007/S00267-011-9629-0

Bates, J.D., R.N. Sharp, and K.W. Davies. 2013. Sagebrush steppe recovery after fire varies by development phase of Juniperus occidentalis woodland. International Journal of Wildland Fire http://dx.doi.org/10.1071/WF12206

Boydston, R. A., H. P. Collins, and S. Fransen. 2010. Response of three switchgrass (*Panicum virgatum*) cultivars to mesotrione, quinclorac, and pendimethalin.Weed Technol. 24:336-341.

Boydston, R. A., M. Morra, V. Borek, L. Clayton, and S. F. Vaughn. 2011. Onion and weed response to mustard (*Sinapis alba*) seed meal. Weed Sci. 59:546-552.

Chatterjee, A., D.S. Long, and F.J. Pierce. 2013. Switchgrass influences soil biogeochemical processes in dryland region of the Pacific Northwest. Communications in Soil Science and Plant Analysis. 44:2314-2326.

Collins, H.P., J. Smith, A.K. Alva, C. Kruger, and D. Granatstein. 2010. Carbon Sequestration under Irrigated Switchgrass (Panicum virgatum) Production. Soil Sci. Soc. Am. J. 74:2049-2058.

Collins, H.P., A.K. Alva, J D. Streubel, S F. Fransen, C. Frear, S. Chen, C. Kruger and D. Granatstein. 2011. Greenhouse Gas Emissions from an Irrigated Silt Loam Soil Amended with Anaerobic Digested Dairy Manure. Soil Sci. Soc. Am. J. 75:2206-2216.

Collins, H.P., J. Streubel, L. Porter, A.K. Alva and B. Chavez-Cordoba. 2013. Phosphorous uptake by Ranger and Umatilla potato cultivars from biochar coated with anaerobic digested dairy manure effluent. Agron. J. 105:989–998.

Davies, K.W., J.D. Bates, M.D. Madsen, and A.M. Nafus. 2014. Restoration of Mountain Big Sagebrush Steppe Following Prescribed Burning to Control Western Juniper Environmental Management 53:1015–1022.

El-Nashaar, H.M., G.M.Banowetz, C.J. Peterson, and S.M. Griffith. 2010. Genetic variability of elemental composition in winter wheat straw. Energy & Fuels 24:2020-2027.

El Nashaar, H.M., G.M. Banowetz, C.J. Peterson, and S.M. Griffith. 2011. Elemental concentrations in Triticale straw, a potential bioenergy feedstock. Energy and Fuels. 25:1200-1205.

Fransen, S.C., H.P. Collins and RA Boydston. 2014. Establishment and Management of Switchgrass for Forage and Biofuel under Irrigation. WSU Extension Bulletin. In Press.

Gollany, H.T., J.M. Novak, Y. Liang, S.L. Albrecht, R.W. Rickman, R.F. Follett, W.W. Wilhelm, and P.G. Hunt. 2010. Simulating soil organic carbon dynamics with residue removal using the CQESTR Model. Soil Science Society of America Journal. 74:372-383

Gollany, H.T., R.W.Rickman, Y. Liang, S. Albrecht, S. Machado, and S. Kang. 2011. Predicting agricultural management influence on long-term soil organic carbon dynamics: Implications for biofuel production. Agronomy Journal 103:234-246.

Griffith, S.M., G.M. Banowetz, R.P. Dick, G.W. Mueller Warrant, and G.W. Whittaker. 2011. Western Oregon Grass Seed Crop Rotation and Straw Residue Effects on Soil Quality. Agronomy Journal. 103:1124-1131.

Griffith, S.M., G.M. Banowetz, and D. Gady. 2013. Chemical characterization of chars developed from thermochemical treatment of Kentucky bluegrass seed screenings. Chemosphere 92: 1275-1279.

Huggins, D.R., C.E. Kruger, K.M. Painter, and D.P. Uberuaga. 2014. Site-specific trade-offs of harvesting cereal residues as biofuel feedstocks in dryland annual cropping systems of the Pacific Northwest, USA. Bioenerg. Res. 7:598-608.

Ippolito, J.A., M. Stromberger, R.D. Lentz, and R.S. Dungan. 2014. Hardwood biochar influences calcareous soil physicochemical and microbiological status. Journal of Environmental Quality. 43(2):681-689.

Juneja, A., D. Kumar, J.D. Williams, D.J. Wysocki, and G.S. Murthy. 2011. Potential for ethanol production from conservation reserve program lands in Oregon. Journal of Renewable and Sustainable Energy. 3(6). Available at http://dx.doi.org/10.1063/1.3658399 (verified 9 May 2014).

Karlen, D.L., and D.R. Huggins. 2014. Crop residues. Cellulosic energy systems. 1st ed. John Wiley and Sons, Ltd.

Kimura, E., S.C. Fransen, and H.P. Collins. 2014. Biomass Production and Nutrient Removal by Switchgrass (*Panicum virgatum*) under Irrigation. Agron. J. Submitted.

Kumar, D., A. Juneja, W. Hohenschuh, J.D. Williams, and G.S. Murthy. 2012. Chemical composition and bioethanol potential of different plant species found in Pacific Northwest conservation buffers. Journal of Renewable and Sustainable Energy. Available at http://dx.doi.org/10.1063/1.4766889 (verified 9 May 2014).

Lenssen A.W., W.M. Iversen, U.M. Sainju, T.C. Caesar-TonThat, S.L. Blodgett, B.L. Allen, and R.G. Evans. 2012. Yield, pests, and water use of durum and selected crucifer oilseeds in two-year rotations. Agron. J. 104:1295-1304.

Lenssen, A.W., U.M. Sainju, W.M. Iversen, B.L. Allen, and R.G. Evans. 2014. Crop diversification, tillage, and management influences on spring wheat yield and soil water use. Agron. J. (accepted 4/28/2014).

Long, D.S., P.A. Scharf, and F.J. Pierce. 2011. Narrow-width harvester for switchgrass and other bioenergy crops in experimental plots. Agronomy Journal. 103:780-785.

Long, D.S., J.D. McCallum, F.L. Young, and A. Lenssen. 2012. In-stream measurement of canola (Brassica napus L.) seed oil concentration using in-line near infrared reflectance spectroscopy. Journal of Near Infrared Spectroscopy. 20(3):387-395.

Long, D.S., and J.D. McCallum. 2013. Mapping straw yield using on-combine light detection and ranging (lidar). International Journal of Remote Sensing. 34:6124-6134.

Madsen, M.D., D.L. Zvirzdin, B.D. Davis, S.L. Petersen, and B.A. Roundy. 2011. Feature extraction techniques for measuring pinon and juniper tree cover and density, and comparison with field-based management surveys. Environmental Management 47:766–776

Mazzola, M. and J. Brown. 2010. Efficacy of brassicaceous seed meal formulations for the control of apple replant disease in organic and conventional orchard production systems. Plant Dis. 94:835-842.

Mazzola, M. and X. Zhao. 2010. *Brassica juncea* seed meal particle size influences chemistry but not soil biology-based suppression of individual agents inciting apple replant disease. Plant Soil 337:313-324.

Mazzola, M., C.L. Reardon, and J. Brown. 2012. Initial species composition and brassicaceae seed meal type influence extent of *Pythium*-induced plant growth suppression. Soil Biology & Biochemistry 48:20-27.

Mazzola, M., and S.L. Strauss. 2013. Resilience of orchard replant soils to pathogen re-infestation in response to Brassicaceae seed meal amendment. Aspects of Applied Biology 119:69-77.

Moore, A.D., A.L. Alva, H.P. Collins, and R.A. Boydston. Mineralization of nitrogen from biofuel byproducts and animal manures amended to a sandy soil. Communications in Soil Science and Plant Analysis. Volume 41:1315-1326. 2010.

Pierson, F.B., C.J. Williams, P.R. Kormos, S.P. Hardegree, P.E. Clark, and B.M. Rau. 2010. Hydrologic vulnerability of sagebrush steppe following pinyon and juniper encroachment. Rangeland Ecology and Management 63:614-629.

Pierson, F.B., C.J. Williams, S.P. Hardegree, P.E. Clark, P.R. Kormos, and O.Z. Al-Hamdan. 2013. Hydrologic and erosion responses of sagebrush steppe following juniper encroachment, wildfire, and tree cutting. Rangeland Ecology and Management 66:274-289.

Pierson, F.B., C.J. Williams, P.R. Kormos, and O.Z. Al-Hamdan. 2014. Short-term effects of tree removal on infiltration, runoff, and erosion in woodland-encroached sagebrush steppe. Rangeland Ecology and Management DOI: http://dx.doi.org/10.2111/REM-D-13-00033.1

Reardon, C. L., S.L. Strauss, and M. Mazzola. 2013. Effect of brassicaceae seed meal amendments on nitrogen cycling and nematode populations in orchard soils. Soil Biol. Biochem. 57:22-29.

Sainju, U.M., A.W. Lenssen, T. Caesar, J.D. Jabro, R.T. Lartey, R.G. Evans, and B.L. Allen. 2012a. Dryland soil nitrogen cycling influenced by tillage, crop rotation, and cultural practice. Nut. Cycl. Agroecosystems 93:309-322.

Sainju, U.M., A.W. Lenssen, T. Caesar-TonThat, R.T. Lartey, R.G. Evans, B.L. Allen, and J.D. Jabro. 2012b. Tillage, crop rotation, and cultural practice effects on dryland soil carbon fractions. Open J. Soil Sci. 2:242-255.

Sainju, U.M**.,** A.W. Lenssen, T. Caesar-TonThat, J.D. Jabro, R. T. Lartey, R.G. Evans, and B. L. Allen. 2011. Dryland residue and soil organic matter as influenced by tillage, crop rotation, and cultural practice. Plant and Soil. 338:27-41.

Sharratt, B. and W. Schillinger. 2014. Windblown dust potential from oilseed cropping systems in the Pacific Northwest United States. Agron. J. 106:1147-1152.

Smith, J.L., H.P. Collins, and V.L. Bailey. 2010. The effect of young biochar on soil respiration. Soil Biol. Biochem. 42:2345-2347.

Spokas, K.., K.B. Cantrell, J.M. Novak, D.W. Archer, J.A. Ippolito, H.P. Collins, A.A. Boateng, I.M. Lima, M.C. Lamb, A.J. McAloon, R.D. Lentz and K.A. Nichols. 2012. Biochar: A synthesis of its agronomic impact beyond carbon sequestration. J. Environ. Qual. 41:973-989.

Streubel, J.D., H.P. Collins, M. Garcia-Perez, J. Tarara, D, Granatstein and C.E. Kruger. 2011. Influence of contrasting biochar types on five soils at increasing rates of application. Soil Sci. Soc. Am. J. 75:1402-1413.

Streubel, J.D., H.P. Collins, J. Tarara and R.L. Cochran. 2012. Biochar produced from anaerobically-digested fiber reduces phosphorus in dairy lagoons. J. Environ. Qual. 41:1166-1174.

Watrud, L.S., J.R. Reichman, M.A. Bollman, B.M. Smith, E.H. Lee, J.D. Jastrow, M.D. Casler, H.P. Collins, S. Fransen, K.P. Vogel, V.N. Owens, B. Bean, W.L. Rooney, D.D. Tyler, and G.A. King. 2013. Chemistry and microbial functional diversity of biofuel crop and non-crop soils. Bioenergy Research. 6:601-619.

Weerakoon, D.M.N., C.L. Reardon, T.C. Paulitz, A.D. Izzo, and M. Mazzola. 2012. Long-term suppression of *Pythium abappressorium* induced by *Brassica juncea* seed meal amendment is biologically mediated. Soil Biology & Biochemistry 51:44-52.

Williams, C.J., F.B. Pierson, O.Z. Al-Hamdan, O.Z., Kormos, P.R., Hardegree, S.P., Clark, P.E. 2014a. Can wildfire serve as an ecohydrologic threshold-reversal mechanism on juniper-encroached shrublands? Ecohydrology 7:453-477.

Williams, C.J., F.B. Pierson, P.R. Robichaud, and J. Boll. 2014b. Hydrologic and erosion responses to wildfire along the rangeland-xeric forest continuum in the western US: A review and model of hydrologic vulnerability. International Journal of Wildland Fire 23:155-172.

Young, F. L., D.S. Long, and J.R. Alldredge. 2012. Effect of planting methods on spring canola (Brassica napus L.) establishment and yield in the low-rainfall region of the Pacific Northwest. Online. Crop Management doi:10.1094/CM-2012-0321-01-RS.

Young, F., D. Whaley, D. Roe, and J.R. Alldrege 2014. Introducing Winter Canola to the Winter Wheat-Fallow Region of the Pacific Northwest. Crop Management (in press)