

ACCOMPLISHMENTS REPORT
Southeast Regional Biomass Research Center
October, 2015 – December, 2017
Submitted by: Bill Anderson, Coordinator

Summary:

The coordinators of the USDA Biomass Research Centers developed a series of review papers based on the accomplishments of the centers over the past 5 plus years. They were published in a special issue of BioEnergy Research in 2016. The SERBRC has continued to work on various aspects of renewable products over the past 15 months since the last report.

Locations Reporting

Auburn, AL
Houma, LA
Florence, SC
Temple TX
Tifton, GA

I. Feedstock Development:

Identified a major dominant gene for resistance to root-knot nematodes from sweet sorghum. Southern root-knot nematodes (*Meloidogyne incognita*) are a pest on many economically important crop and vegetable species. Control of root-knot nematodes relies on chemicals, plant resistance, and cultural practices such as crop rotation. Little was known about the inheritance of resistance to the southern root-knot nematodes or the genomic regions associated with resistance in sorghum. In this study, resistant lines were identified, segregating populations were created, progeny were phenotyped for 7 traits, and genotyping-by-sequencing was employed. Scientists with USDA/ARS Tifton, GA., released a collection of tightly linked markers to the major dominant resistance gene which allows the resistance gene to be moved to any fertile sorghum line. This work allows sorghum that is resistant to root knot nematodes to be grown in a cropping system so that the next susceptible crop (ex. cotton, sugar beet, bell pepper, watermelon, and soybean) will have reduced nematode problems. The resistance gene from ‘Honey Drip’ is currently being utilized by the sorghum team at the USDA Plant Stress and Germplasm Development Research Unit (Lubbock, TX) so that their trait of increased number of sorghum grains (msd) can be stacked with the root-knot nematode resistance gene. Resistance gene from ‘Honey Drip’ have been moved into several susceptible lines to see if these plants become resistant.

Citation: Harris-Shultz, K.R., Davis, R., Knoll, J.E., Anderson, W., and Wang, H. Inheritance and identification of a major quantitative trait locus (QTL) that confers resistance to

Meloidogyne incognita and a novel QTL for plant height in sweet sorghum. *Phytopathology* 105(12):1522-1528. 2015.

Genetic diversity of the sugarcane aphid (Homoptera: Aphididae) and its primary symbiont in the United States.

Since 2013, the sugarcane aphid (*Melanaphis sacchari*) on sorghum has been rapidly spreading from state to state in the southern United States and in 2016 reached 19 states. These aphids become so abundant in numbers that most sorghum fails to develop the seed heads and often, plant death occurs. There is uncertainty if there are multiple biotypes in the U.S. or if all aphids are one biotype. Scientists with USDA/ARS Tifton, GA conducted high throughput sequencing for the sugarcane aphid and 1.44 Gb of nucleotides were generated. Genotyping of samples from 17 locations across 7 states and one U.S. territory revealed that all samples were one biotype with the exception of a single sample collected from Sinton, TX which has the predominant biotype as well as another biotype. Thus the invasive sugarcane aphid is spreading in the U.S. as primarily one asexual clone. This information is important as plant resistance as well as insecticide efficacy can be biotype specific.

Citation: Harris-Shultz, K., Ni X., Wadl, P., Wang, X., Wang, H., Huang, F. et al. Microsatellite markers reveal a predominant sugarcane aphid (Homoptera: Aphididae) clone is found on sorghum in seven states and one territory of the United States. *Crop Science* 57: 2064–2072. 2017.

Loci *Bm2* and *Blmc* that affect epicuticular wax deposition in sorghum are allelic.

Epicuticular wax (EW) covers the epidermis of the aboveground portion of plants and protects the tissue from abiotic and biotic stresses, especially from water loss. Previously, mutants in the sorghum *Bm2* gene, *bm2-1* to *bm2-6*, were discovered to have very low levels of EW as well as intracuticular waxes. A new mutation, bloom cuticle (*blmc*), was discovered that lacks visible EW and has reduced culm and leaf cuticle. Scientists with USDA/ARS Tifton, GA., developed a study to understand the number and identity of genes involved in EW deposition and whether or not the *blmc* is an allele of the *Bm2* locus. An allelism test was performed, which revealed that *blmc* is an allele of the *Bm2* locus, and was designated as *bm2-7*. Thus a large amount of the data that was generated separately for each locus can now be merged and the identity of a major gene that controls epicuticular wax can be pursued.

Citation: Punnuri, S., Harris-Shultz, K., Knoll, J., Ni, X., and Wang, H. The genes *Bm2* and *Blmc* that affect epicuticular wax deposition in sorghum are allelic. *Crop Science* 57:1552–1556. 2017.

Identification of potential bioenergy grasses that were good hosts for the invasive sugarcane aphid.

The sugarcane aphid (*Melanaphis sacchari*) since 2013 has been rapidly spreading from state to state in the southern United States on sorghum. The aphids rapidly reproduce on sorghum and grow to such numbers that many sorghum fails to produce a main head or plant death occurs if the infestation starts at the seedling stage. Since sorghum is an annual crop other grasses serve as hosts when sorghum is not grown. Scientists with USDA/ARS Tifton, GA., sought to identify whether the bioenergy grasses recommended to be planted in the southern United States can serve as potential hosts for the sugarcane aphid. A multigenerational study was conducted and Johnsongrass, energycane (*Saccharum* spp.), and giant miscanthus sustained multiple generations of sugarcane aphids. Poor hosts included the napiergrass cultivar Merkeron, giant reed and switchgrass. Thus, if widespread planting of bioenergy grasses were to occur in the United States, the plantings of napiergrass, giant reed, and switchgrass are likely to prevent the further increase of the sugarcane aphid population. This information will be important to county agents and farmers when making choices for the planting of bioenergy grasses in the Southeast.

Citation: Harris-Shultz, K., Ni, X., Wang H., Knoll, J. and Anderson, W. Evaluation of perennial bioenergy grasses as potential hosts of the sugarcane aphid (Hemiptera: Aphididae). Journal of Economic Entomology. Submitted.

Demonstration of combining ability in hybrid sweet sorghum

Sweet sorghum should be an ideal biofuel crop for the Southeast, but the current cultivars are all pure lines, which limits the quantity of seed that can be produced, and this seed cannot be mechanically harvested. Hybrid seed can be easily produced on short-statured plants, but less is known about other advantages of hybrid sweet sorghum over inbred cultivars. Heterosis in this crop has not been extensively studied in this region. Scientists with USDA/ARS Tifton, GA., crossed three female lines and 19 male lines in a factorial mating design (Design II) experiment. All hybrids and their parents were planted in the field in a randomized complete block experiment in 2012 and again in 2014. The yields of individual components (leaves, panicles, bagasse, and juice) were calculated based on their proportions of total biomass yields. Sugar yields were estimated from juice soluble solids concentration (Brix). Late-flowering lines, including Brandes, M 81E, Mer 76-3, and Top76-6, had favorable general combining ability (GCA) effects for sugar yields, and among females, N109A had favorable GCA for reduced lodging percentage. Heterosis for grain yield was observed for many hybrids, but sugar yields were usually similar between inbred male lines and their respective hybrids. Hybrids usually flowered earlier than inbreds, thus producing similar sugar yields in less time. Hybrid sweet sorghum appears to offer a modest yield advantage over the current inbred cultivars.

Citation: Knoll, J. E., and W. F. Anderson. 2016. Yield Components in Hybrid versus Inbred Sweet Sorghum. Crop Sci. 56:2638-2646.

II. Feedstock Production:

A NIFA AFRI Foundation grant was awarded to a team of scientists from ARS, the University of Georgia, the University of Florida and Fort Valley University. The project will assess the use of lupin and other winter crops as biomass sources and how their production affects the yield and quality of subsequent summer row crops (peanut and cotton in rotation) and soil health. An ARS scientist at Tifton is the project director and includes ARS scientists in Dawson, GA as well. In a second large grant, ARS scientists at Tifton, GA; Auburn, AL; Florence, SC; and Dawson, GA will perform work in a NIFA AFRI CAP grant led by the University of Florida on variety assessment, and management production practices for *Brassica carinata* as a feedstock for aviation fuel.

Simulating diverse native C4 perennial grasses with varying rainfall.

Rainfall is recognized as a major factor affecting the rate of plant growth development. The impact of changes in amount and variability of rainfall on growth and production of different forage grasses needs to be quantified to determine how climate change can impact rangelands. Comparative studies to evaluate the growth of several perennial forage species at different rainfall rates will provide useful information by identifying forage management strategies under various rainfall scenarios. The combination of rainfall changes and soil types on the plant growth of 10 perennial forage species was investigated by USDA/ARS scientists at Temple, TX. Both experimental methods, using rainout shelters, and numerical methods were used to simulate the plant growth with the simulation model, ALMANAC. Overall, most species significantly increased basal diameter and height as rainfall increased. Like measured volume, simulated yields for all species generally increased as rainfall increased. But, large volume and yield increases were only observed between 350 and 850 mm/yr. Simulating all species growing together competing agrees relatively well with observed plant volumes at low rainfall treatment, while simulating all species growing separately was slightly biased towards overestimation on low rainfall effect. Both simulations agree relatively well with observed plant volume at high rainfall treatment.

Citation: Kim, S., Williams, A.S., Kiniry, J.R., Hawkes, C.V. Youkhana, A.H., Nakahata, M.H., Littlejohn, K. Simulating diverse native C4 perennial grasses with varying rainfall. *Journal of Arid Environments*. 134:97-103. 2016.

Field-based estimates of global warming potential in bioenergy systems of Hawaii: Crop choice and deficit irrigation

Replacing fossil fuel with biofuel is environmentally viable from a climate change perspective only if the net greenhouse gas (GHG) footprint of the system is reduced. The effects of replacing annual arable crops with perennial bioenergy feedstocks on net GHG production and soil carbon (C) stock are critical to the system-level balance. USDA/ARS scientists at Temple, TX compared GHG flux, crop yield, root biomass, and soil C stock under two potential tropical, perennial grass biofuel feedstocks: conventional sugarcane and ratoon-harvested, zero-tillage napiergrass in Hawaii. Evaluations were conducted at two irrigation levels, 100% of plantation application and

at a 50% deficit. Peaks and troughs of GHG emission followed agronomic events such as ratoon harvest of napiergrass and fertilization. Yet, net GHG flux was dominated by carbon dioxide (CO₂), as methane was oxidized and nitrous oxide (N₂O) emission was very low even following fertilization. High N₂O fluxes that frequently negate other greenhouse gas benefits that come from replacing fossil fuels with agronomic forms of bioenergy were mitigated by efficient water and fertilizer management, including direct injection of fertilizer into buried irrigation lines. From soil intensively cultivated for a century in sugarcane, soil C stock and root biomass increased rapidly following cultivation in grasses selected for robust root systems and drought tolerance. The net soil C increase over the two-year crop cycle was three-fold greater than the annualized soil surface CO₂ flux. Deficit irrigation reduced yield, but increased soil C accumulation as proportionately more photosynthetic resources were allocated belowground. In the first two years of cultivation napiergrass did not increase net greenhouse warming potential (GWP) compared to sugarcane, and has the advantage of multiple ratoon harvests per year and less negative effects of deficit irrigation to yield.

Citation: Pawlowski, M.N., Crow, S.E., Meki, M.N., Kiniry, J.R., Taylor, A.D., Ogoshi, R., Youkhana, A., Nakahata, M.. PLoS One. 12(1):e0168510. DOI:01.1371/journal.pone/0168510. 2017.

Adaptation of C4 bioenergy crop species to various environments within the Southern Great Plains of U.S.

As highly productive grasses are evaluated for biofuel, a major consideration is how stable are grass yields across years and across sites. In this study, two experiments were conducted to examine some components of this for two biofuel species: switchgrass (*Panicum virgatum* L.) and Miscanthus x giganteus (Mxg). The potential yields of these two grasses were evaluated by scientists from USDA/ARS Temple, TX under various environmental conditions across Southern Great Plains, and including some soils with low soil fertility. In the first experiment, yields of four switchgrass ecotypes and Mxg varied among locations. Overall, plants showed the optimal growth performance in study sites close to where they originated. Using a computer simulation model, simulated yields of lowland switchgrasses and Mxg showed reasonable agreement with the measured yields across all study locations, while the simulated yields of upland switchgrasses were overestimated in northern locations. In the second experiment, different nitrogen fertilizer rates were utilized to investigate their effect on biomass yields. Switchgrass yields significantly increased over the range of three N rates, while Mxg only showed yield increases between the low and medium N rates. The results of this study will improve crop management of two biofuel species as well as the ability of computer models, which are critical to develop bioenergy market systems in Southern Great Plains.

Citation: Kim, S., Kiniry, J.R., Williams, A.S., Meki, M.N., Gaston, L.A., Brakie, M., Shadow, A., Fritschi, F.B., Wu, Y. Sustainability. 9:89. DOI:10.3390/su9010089. 2017.

Evaluation of high biomass sorghums lines at biomass feedstocks in Hawaii. Since the 1970s the state of Hawaii (HI) has been aggressively seeking alternative and renewable energy resources to reduce its overdependence on imported oil. Of the available alternatives, fuels produced from biological raw materials are viewed favorably due to the tropical year-round growing season for the production of fast-growing biofuel feedstocks. Although biomass sorghum [*Sorghum bicolor* (L.) Moench] has been identified as a high yielding bioenergy feedstock crop on the continental USA, there is lack of conclusive data on its performance in HI. USDA/ARS scientists at Temple, TX performed studies to (i) determine the adaptability and productivity of two biomass sorghum varieties, and (ii) identify the associated crop parameter attributes and environmental factors for high biomass yields. Two parallel trials were conducted on Maui, HI and in Temple, TX. At Temple, the sorghum varieties responded as expected, growing to heights in excess of 3 m and producing average biomass yields of 37.4 Mg ha⁻¹. The biomass sorghum varieties also had large leaf surface areas that captured more solar radiation which resulted in a faster plant growth rate. In Maui, and in sharp contrast to the results obtained at Temple both biomass sorghum varieties behaved like grain sorghums, flowering in approximately 90 days after planting. The varieties did not grow as tall as the ones in Texas and yields were drastically reduced. The study underscored the importance of not only choosing the right bioenergy crop species, but also the suitability of target environments, planting season and management practices.

Citation: Meki, M.N., Ogoshi, R.M., Kiniry, J.R., Crow, S.E., *Industrial Crops and Products*. 103:257-266. 2017.

Degree days to 50% flowering for 12 cultivars of spring canola-like mustard

Previous projects using computer simulations for canola have been based on the plant growth numbers established in the Northern Great Plains. With recent advances in canola breeding, establishing growth numbers for newly developed varieties is essential for computer modeling applications. USDA/ARS scientists at Temple, TX focused their research on the temperatures from each location from planting to the date of 50% flowering and calculated summed degree days (SDD). It appears that the SDD for each of these mustard varieties is relatively stable and similar to the potential heat units previously established for Polish canola in an earlier study.

Citation: Hunter, K.M., Archer, D.W., Gesch, R.W., Vigil, M.F., Hatfield, J.L., Allen, B.L., Jabro, J.D., Kim, S., Meki, M.N., Kiniry, J.R.. *Journal of Agriculture and Ecology Research International*. 11(4):1-8. 2017.

Allometric models for predicting aboveground biomass and carbon stock of tropical perennial C4 grasses in Hawaii.

Biomass is a promising renewable energy option that provides a more environmentally sustainable alternative to fossil resources by reducing the net flux of greenhouse gasses to the atmosphere. Yet, allometric models that allow the prediction of aboveground biomass (AGB), biomass carbon (C) stock

non-destructively have not yet been developed for tropical perennial C₄ grasses currently under consideration as potential bioenergy feedstock in Hawaii and other subtropical and tropical locations. The objectives of a study performed by USDA/ARS scientists at Temple, TX were to develop optimal allometric relationships and site-specific models to predict AGB, biomass C stock of napiergrass, energycane, and sugarcane under cultivation practices for renewable energy and validate these site-specific models against independent data sets generated from sites with widely different environments. Several allometric models were developed for each species from data at a low elevation field on the island of Maui, Hawaii. A simple power model with stalk diameter (D) was best related to AGB and biomass C stock for napiergrass, energycane, and sugarcane, ($R^2 = 0.98, 0.96, \text{ and } 0.97$, respectively). The models were then tested against data collected from independent fields across an environmental gradient. For all crops, the models over-predicted AGB in plants with lower stalk D, but AGB was under-predicted in plants with higher stalk D. The models using stalk D were better for biomass prediction compared to dewlap H (Height from the base cut to most recently exposed leaf dewlap) models, which showed weak validation performance. Although stalk D model performed better, however, the mean square error (MSE)-systematic was ranged from 23 to 43 % of MSE for all crops. A strong relationship between model coefficient and rainfall was existed, although these were irrigated systems; suggesting a simple site-specific coefficient modulator for rainfall to reduce systematic errors in water-limited areas. These allometric equations provide a tool for farmers in the tropics to estimate perennial C₄ grass biomass and C stock during decision-making for land management and as an environmental sustainability indicator within a renewable energy system.

Citation: Youkhana, A.H., Ogoshi, R.M., Kiniry, J.R., Meki, N.M., Nakahata, M.H., Crow, S.E. *Frontiers in Plant Science*. 8:650. DOI: 10.3389/fpls.2017.00650. 2017.

Corn stover fractions identified as an important feedstock for bioenergy and bio-product production.

Corn stover has long been recognized as a potential feedstock for bioenergy production, but nutrient removal, carbohydrate composition, and theoretical ethanol yield (TEY) for various corn stover fractions have not been previously determined. ARS Researchers in Florence, South Carolina, Auburn, Alabama, and Ames, Iowa determined that distribution of carbohydrates, nutrients, and TEY varied significantly among corn stover fractions and locations. This result indicates that site-specific sampling and analysis should be used to optimize bioenergy and bio-product utilization of corn stover. However, above-ear stover fractions were most desirable for cellulosic ethanol production across locations, while nutrient removal was reduced 24 to 61% by harvesting only above-ear stover fractions compared to harvesting all stover biomass. Reducing nutrient removal while enhancing ethanol production indicates select harvest of cellulosic biomass fractions has potential as a component in a sustainable farming system.

Citation: Mourtzinis, S., Cantrell, K.B., Arriaga, F.J., Balkcom, K.S., Novak, J.M., Frederick, J.R., Karlen, D.L. 2015. Carbohydrate and nutrient composition of corn stover from three Southeastern USA locations. *Biomass and Bioenergy*. 85:153-158.

Best management practices to increase cold tolerance for energycane production in non-traditional cane growing areas of Louisiana. Sugarcane is typically grown in the tropics between 23.5 degrees N and south; but, a future energy crop industry should push crops into non-traditional growing areas to marginalize competition between food and fiber. Therefore, field plots were established by USDA-ARS Sugarcane Research Unit in 2012 in Winnsboro, Louisiana to test cold tolerance cultural practices for the production of energycane, north of the sugar growing parishes of the state. Seed cane was cut in Houma and transported north about 350 km to Winnsboro. The recently commercially released variety Ho 02-113 was planted in replicated plots in 2012 and 2013 that were covered with increasing amounts of packed soil to serve as insulation against a winter freeze. Crop production practices including planting, pest management, and cultivation followed a very minimal input strategy. The second cold tolerance cultural practice tested was crop residue management. The thick residue layer acts as an insulator through winter months, but is detrimental to yields the following spring unless removed, preferably by burning. None of the residue treatments affected energycane yield most likely due to the lack of a hard, sustained winter freeze below 0°C. Energycane yields averaged across 2013 and 2014 were statistically similar ($p>0.05$) for each depth of cover treatment and averaged 55 Mg/ha of as-is biomass or 21 Mg/ha of dry matter.

Sugarcane biomass available over extended harvest times. Most sugarcane biomass is produced from June to August each year. But, a biomass bioenergy industry would require a dependable, year-round feedstock from which to produce biofuels. The USDA-ARS Sugarcane Research Unit in Houma, LA, planted ten high-yielding energycane varieties, Ho 72-114, L 79-1002, Ho 00-961, Ho 01-07, Ho 02-144, Ho 02-147, Ho 02-113, Ho 06-9001, Ho 06-9002, and Ho 08-9076, and two sugarcane check varieties, HoCP 96-540, and HoCP 04-838, in replicated plots ($n=4$) near Houma in 2012 and 2014. Beginning in August and ending in March, ten stalk bundles were removed from each plot and taken to the USDA Ardoyne Farm for processing. Stalks were weighed, chopped into billets, and fed into the prebreaker to shred the cane pieces. A portion of this shredded cane was put into the press and the juice was removed by pressure. The juice was analyzed for Brix and Pol, and the remaining fiber cake was dried at 65°C until dry and stored. The product of cane stalk weights and field stand counts is simulated cane yield. Preliminary results indicate that both cane variety, and date of harvest impacted yields, with a range of 77 to 164 Mg/ha and 89 to 147 Mg/ha, respectively. Dry matter yield (Brix + Fiber) averages were 36 to 40% of the as-is yields across all sample points.

Elucidating the risks of complete biomass removal for a bioenergy cane harvest on sustainable yields. The high value of sugar, an ephemeral bioenergy industry, and advances in lignocellulosic fuel production limit the production of sugarcane solely for use as a bioenergy feedstock in the U.S. However, current sugarcane harvesting technology allows testing of the

risks of feedstock production on soil health. Green-cane harvesting produces substantial crop residue (5-6 Mg dry residue ha⁻¹ y⁻¹) that is returned to fields by an extractor fan usually operated to maximize residue removal without losing cane billets. Under a feedstock harvesting scenario, most of the residue would be retained during harvest and deposited in trailers for transport to a processing center. Field plots were established at the USDA-ARS Sugarcane Research Unit's Ardoyne in Schriever, LA to evaluate variable residue returns observed by altering the harvester extractor fan speed (fans off, fans operated at 350 rpm, fans operated at 750 rpm). Both plant-cane and ratoon yields exhibited a biomass yield in the range of 58 to 90 Mg ha⁻¹. A recent publication discusses the loss of nutrients possible with a complete residue removal. The citation is below. Average nitrogen, phosphorus, and potassium leaf nutrient yields that would not be returned to the soil were estimated to be 74.0, 8.6, and 83.0 kg ha⁻¹ y⁻¹.

Citation: White, Jr., P.M., Viator, R.P., Webber, III, C.L., Eggleston, G. 2017. Potential losses of soil nutrients and energy content on the complete removal of sugarcane leaf material as a biomass feedstock. Sugar Tech. DOI 10.1007/s12355-017-0523-9. Published online 5-2017.

Economic assessment of a perennial biomass crop compared to row crop production for the Southeast. The Energy Independence Security Act (EISA) of 2007 mandated an increase advance biofuels to 21 billion gallons by 2022. As a result, numerous perennial warm-season grasses have been introduced and management practices evaluated to determine their suitability as biofuel feedstocks. While most of this production was intended for marginal cropland, understanding the farm level profitability of the feedstock production relative to traditional cropping systems is an important decision criteria for producers. USDA/ARS scientists from Tifton and Dawson, GA established and harvested 'Merkeron' napiergrass (*Pennisetum purpureum*) plots during crop years 2011 through 2015 adjacent to an on-going peanut (*Arachis hypogaea* L.), corn (*Zea mays* L.), and cotton (*Gossypium hirsutum* L.) cropping systems study in Shellman, GA. The WholeFarm farm planning system (USDA/ARS) was utilized to compare the economic competitiveness of Napier with the traditional peanut, corn, cotton cropping system. Variable cost for producing Napier ranged from \$61 to \$70 Mg⁻¹. Since no price observations exist for Napier, an alternate approach was included by estimating the breakeven Napier price relative to corn, cotton, and peanut (at average 5yr prices) required so that the net returns were equal. Comparative breakeven Napier prices non-irrigated, 50% irrigation rate and full irrigated were \$99, \$117, and \$112 Mg⁻¹, respectively. The required breakeven Napier price relative to the traditional cropping system along with the Napier cost of production implies that Napier will not compete economically against traditional cropping systems but depending on bioenergy feed stock prices could offer economic opportunities in riparian buffer zones or non-cropped areas.

Citation: Economic Competitiveness of Napier in Irrigated and Non-irrigated Georgia coastal plain cropping systems. Bioenergy research (submitted)

III. Conversion and Co-product Utilization

Biochar Research

Florence, SC

A biochars impact on soil quality and crop yields across multi-ARS locations. Over the past 10 years, scientists at numerous USDA-ARS locations have evaluated biochars potential to improve soil quality characteristics with anticipation of improving soil properties and increasing crop yields. These studies were conducted using biochars produced from different feedstocks and especially under different crop and tillage management scenarios. This leads to uncertainty in the predicative capability of biochars to improve soil properties and crop yields. Therefore, a field study was designed and conducted at six USDA-ARS locations to determine if a consistent response pattern could be established through standardizing the biochar type, amount applied, and conducting the experiment under similar soil/crop management practices. The biochar used in this experiment was a produced through fast pyrolysis of hardwood wastes products at temperatures between 500 and 600°C. The biochar was small-grained, did not contain appreciable amounts of nutrients, and was mostly composed of poly-condensed aromatic sheets. Figure 1 shows an image of the hardwood biochar taken using a scanning electron microscope (SEM). The SEM image shows that pieces of this hardwood biochar are < 200 µm in size.

The treatments were similar at all six locations and consisted of a control (no biochar), manure alone, biochar alone, and biochar + manure. Corn was grown in the treatments over three or four crop growth cycles. Both crop yields and above ground biomass (minus grain) were collected. Topsoil samples were collected before the experiment commenced and at termination. The soil samples were analyzed for basic plant nutrients and soil organic carbon (SOC) contents.

Analysis of pooled crop biomass from the six locations showed a significant location effect, but treatment effects were not significant. Only one location had a significant improvement in corn grain yield. At five of the six locations, there was a significant improvement in soil organic carbon levels of almost 50% relative to the controls. This hardwood biochar was not particularly effective at improving crop yields at the majority of ARS locations, but also did not depress corn yields. This hardwood biochar did increase topsoil SOC contents indicating that it has a benefit for soil quality enhancement.

Citation: Laird, D.A., J.M. Novak, H.P. Collins, J.A. Ippolito, D.L. Karlen, R.D. Lentz, K.R. Sistani, K. A. Spokas, and R.S. Van Pelt. 2017. Multi-year and multi-location soil quality and crop biomass yield response to hardwood fast pyrolysis biochar. *Geoderma* 289:46-53. DOI.10.1016/j.geoderma.2016.11.025.

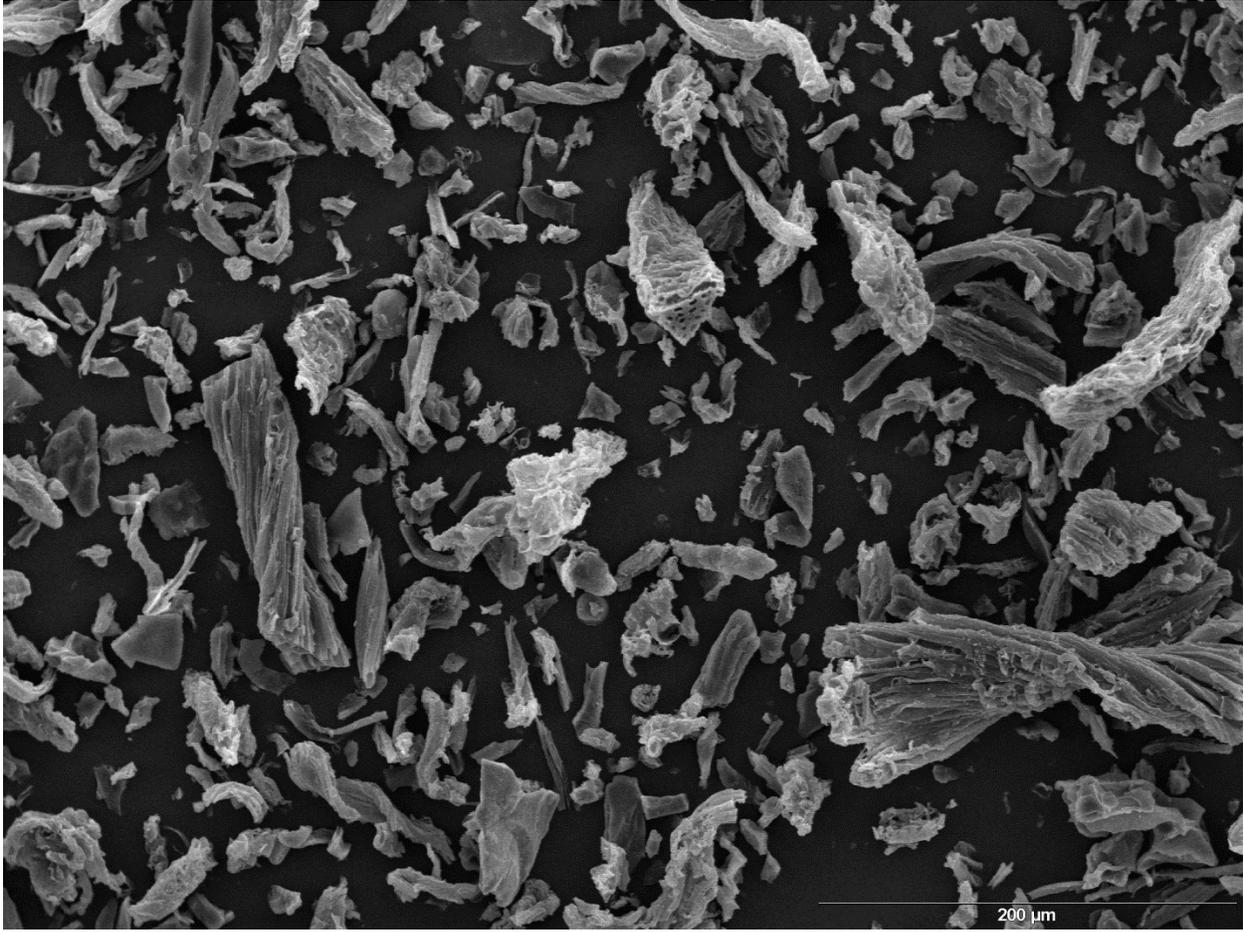


Figure. 1. The hardwood biochar employed in the multi-location study.

Biochar research activities; a meta-analysis at the global scale. Developing agricultural technologies to double food supply by 2030 and simultaneously reducing greenhouse gas emissions will be challenging. Biochar applied as a soil amendment could contribute to achieving these goals, but further research is required to ensure their optimal use. Previous research has shown that biochar applied to weathered soils improves soil physicochemical properties. Consequently, biochar may improve crop yields on nutrient-deprived soils insuring that crop production can be increased. This systematic metadata analyses revealed that global biochar research published between 2010 and 2014 was driven by the countries' human development and environmental quality. Biochar research in less developed countries generally assessed biochar production technologies and biochars' impact on chemical soil properties and plant productivity. Among the countries considering biochars use as a soil amendment, China dominates biochar research activities with a heavy focus on biochar production technologies and on use of biochar as sorbent for organic and inorganic compounds. Less developed tropical countries in which agricultural productivity is limited due to large areas of unfertile weathered soils could benefit from biochar research in highly developed countries. However, this will require that biochar research is intensified by *i*) enhancing knowledge transfer and capacity building, *ii*) increasing research investments and technical cooperation, and *iii*) encouraging synergies across scientific disciplines to improve understanding of the complex interactions between biochar, soil and plants.

Citation: Mehmood, K., E.C. Garcia, M. Schirrmann, B. Ladd, C. Kammann, N. Wrage-Mönnig, C. Siebe, J.M. Estavillo, T. Fuertes-Mendizabal, M. Cayuela, G. Sigua, K. Spokas, A.L. Cowie, J. Novak and J.A. Ippolito. 2017. Biochar research activities and their relation to development and environmental quality. A meta-analysis. *Agron. Sustain. Dev.* 37:22. DOI 10.1007/s13593-0430-1.

Biochars impact on greenhouse gas production. Agriculture and land use change has significantly increased atmospheric emissions of greenhouse gasses (GHG) such as nitrous oxide (N₂O) and methane (CH₄). Since human nutritional and bioenergy needs continue to increase, at a shrinking global land area for production, novel land management strategies are required that reduce the GHG footprint per unit of yield. Here we review the potential of biochar to reduce

N₂O and CH₄ emissions from agricultural practices including potential mechanisms behind observed effects. After a decade of intense biochar research, it has become clear that biochar as a soil amendment can reduce GHG emissions such as N₂O and CH₄ emissions. However, great uncertainty still exists with respect to biochar use and its GHG reducing effect as associated with different biochars, soil types/conditions, and in animal production. This is due to the lack of understanding of mechanisms for how biochar influences soil conditions like pH, nitrogen (N) availability to soil microbial communities, influence on microbial denitrifier gene expression, or by N capture in biochar particles. It is likely that these mechanisms work in concert under field conditions. Other potential biochar characteristics that can influence CH₄ emission reductions are the stimulation of soil methanotrophic bacterial communities as well as the electron shuttling and redox activity of biochars in ruminant guts. Biochar use in animal production offers a potential route to reduce GHG emissions, but research on it is lacking. Additionally, biochar use in composting as a method to reduce GHG production is understudied. We conclude that the use of biochar in agriculture systems provides a unique opportunity to reduce N₂O and CO₂ emissions, yet future research is required to maximize its benefits under different conditions.

Kammann, C., J. Ippolito, N. Hagemann, N. Borchard, M.L. Cayuela, J.M. Estavillo, T. Fuertes-Mendizabal, S. Jeffery, J. Kern, J. Novak, D. Rasse, S. Saarnio, H.P. Schmidt, K. Spokas, and N. Wrage-Mönnig. 2017. Biochar as a tool to reduce the agricultural greenhouse-gas burden – knowns, unknowns and future research needs. *J. Environ. Eng. Land. Manage.* 25:114-139. DOI:10.3846/16486897.2017.1319375.