# Checking in With CenUSA

## *Sustainable Production and Distribution of Bioenergy for the Central US*

CenUSA Bioenergy is a multidisciplinary project funded by the U.S. Department of Agriculture-National Institute of Food and Agriculture (USDA-NIFA). The goal of the project is to research the production and use of perennial grasses on marginal lands for use as alternative biofuels and bioproducts. Learn more about CenUSA at www.cenusa.iastate.edu

David Laird[1], a professor in the Iowa State University agronomy department, spoke about his work and experience as a CenUSA a co-project director with a focus in soil research and biochar. In December 2018, Laird spoke with CenUSA Communications Intern Tyler Worsham about how in his role as co-project director, he helped develop the original proposal and worked on developing sustainable bioenergy management systems in order to accrue environmental benefits that will mitigate climate change. [2]

**How did you initially get involved in CenUSA?**

"I was a part of the team that initially developed the proposal that went to the USDA (U.S. Department of Agriculture). I worked with the project director, Ken Moore, and the rest of the team and helped develop the proposal. I was in it from the beginning."

**What made you the ideal candidate for your leadership position?**

"Understand that CenUSA is a rather large group. About 20 scientists were involved in one capacity or another. They covered a diverse range of research topics that centered around the development of feedstocks and sustainable bioenergy systems. I am a soil scientist, so my interest is in sustainable production of bioenergy feedstocks and how agronomic systems impact soil quality and soil carbon sequestration.

Soil contains a lot of organic carbon. Roughly four times as much carbon is in the soils on planet earth as is in the atmosphere or in the plant biomes that surround the planet. Soil is a huge reservoir of carbon, and if we manage our land in such a way that we degrade our soils, it will result in carbon leaving the soil and entering the atmosphere. This will exacerbate global warming.

Biochar impacts on crop productivity needed to be integrated into the economic models so that the economists could predict the effect on market forces, production systems and land use on a global scale. *David Laird*

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[1] Learn more about David Laird at https://www.agron.iastate.edu/people/david-laird.

[2] All of the words and ideas expressed in this interview fairly and accurately represent the speaker. Some quotes may be paraphrased for brevity and clarity. The opinions expressed in herein do not necessarily reflect those of Iowa State University, USDA-NIFA, Purdue University, Ohio State University, USDA-ARS, the University of Minnesota, the University of Nebraska, Lincoln, the University of Vermont, or the University of Wisconsin.

On the other hand, if we can manage the land in such a way that we can pull carbon dioxide out of the atmosphere, turn that carbon into plant material and turn that plant material into soil organic carbon, then we will be pulling greenhouse gasses out of the atmosphere to help mitigate or reduce the threat of climate change. My research and my contribution to the CenUSA leadership revolved around how we develop sustainable bioenergy management systems that are carbon net-negative, pull carbon out of the atmosphere and build soil organic carbon."

**We just touched on it, but what specifically did you do in your work in feedstock production systems?**

"We ran a series of test plots on which we were growing some of the bioenergy feedstocks. Switchgrass, prairie polycultures and corn stover were the three main crops we were comparing. We were also investigating the use of a material called biochar as a soil amendment.

A part of the vision of CenUSA was to take all of this biomass and process it into bioenergy products via a biochemical platform known as pyrolysis. Pyrolysis is like heating. You can take any kind of organic matter −corn stalks, switchgrass or any organic compound, and put it in an oven. If you keep the oxygen out of the oven, the biomass won't burn. Instead, the biomass (organic matter) thermally decomposes, producing a gaseous product, a liquid product, and a solid product. That solid product is char, or biochar. The liquid product is bio-oil which we envision refining to produce liquid transportation fuels and other products, and the gaseous product is called syngas. It's a combustible low-energy density gas, so you can get some heat out of it, and you can potentially use that to drive the whole process forward.

Only two products are leaving the pyrolysis plant, oil and char. The oil goes to a refinery and is turned into liquid transportation fuels and other products. The char, the solid residue from this process, goes back to the cornfield or the switchgrass field from which you harvested the original biomass feedstock. There's value in this for multiple reasons.

One of those reasons is that a lot of nutrients such as potassium, phosphorus, calcium and magnesium tare extracted from the soil when you grow a plant. The plant takes these nutrients up into its roots, and they get incorporated into its biomass. If you harvest the biomass, the nutrients are removed from the soil system and typically have to be replaced by adding fertilizer or soil quality will degrade, but when you pyrolyze the biomass, those nutrient ions are concentrated into the biochar. Therefore, if you later return the biochar to the soil from which you harvested the biomass, you are recycling the nutrients.

One of the unique features of biochar is that it is a highly stable form of carbon. That is, it is only slowly decomposed by soil micro-organisms. Most of the soil organic matter present in soils comes from roots, leaves and other plant tissue that are deposited on the soil and are then slowly decomposed by those micro-organisms. Normally only a small amount of crop-residue carbon gets incorporated into the soil as hummus, the stuff that makes the soils dark in color. Most of the crop-residue carbon is quickly returned to the atmosphere as carbon dioxide.

Biochar is a component of soil humus, but it happens to be the most stable component. If you can imagine a leaf from a plant falling down onto the soil, the carbon that is in that leaf is going to be consumed by micro-organisms and returned to the atmosphere as carbon dioxide. The half-life of that carbon is only about six months, which means that after four or five years, 99 percent of the carbon in that leaf is back in the atmosphere. It's only temporarily stored in the soil.

The half-life of biochar carbon is hundreds, if not thousands of years, so you're taking a material such as the plant leaf that normally decomposes rapidly, and you are turning a portion of it into biochar. This means that you've changed the carbon dynamics so that you can start to increase soil-organic carbon levels by sequestering this very biologically recalcitrant form of carbon to the soil.

The third thing that biochar does is that it changes the physical and chemical properties of soil. Biochar is a low-density material, so when you add it to soil, it makes the soil less dense, increasing the soil porosity. This allows air, water and roots to penetrate the soil more easily. It increases the ability of soil to hold onto water and nutrients, and thereby reduces leaching loss of nutrients out of the bottom of the soil. This increases soil fertility and makes the soil more productive.

This is particularly true for poor quality soils, so by selectively applying biochar to degraded or poor quality soils, you can have a positive impact on agricultural productivity. So again, the three primary benefits of biochar are; 1) recycling of nutrients back to the soil that are otherwise taken away when the biomass is harvested, 2) building soil organic carbon levels by adding a highly recalcitrant form of carbon, the biochar, which helps to mitigate global climate change, and 3), improving soil quality, making soils more fertile and more productive.”

**How did you learn that biochar made for a good soil amendment?**

“This is a long and complicated story, but suffice it to say that there are soils down in the middle of the Amazon jungle that are human-made soils. Some of these anthropogenic soils date back thousands of years. The Amazon region naturally has very poor quality soils. But farmers discovered that by incorporating biochar, manure and other things into their soils, they were able to improve the fertility and productivity of these soils.

This practice in the Amazon goes back nearly 6,000 years. Other cultures − tropical Africa, Japan, France and others also have long histories of applying biochar to soil. I was aware of this history, but my interest in biochar really took off in the mid-2000swhen it dawned on me that the biochar co-product of pyrolysis bioenergy production systems could be used as a soil amendment. I realized that we had a way of making bioenergy and biochar at the same time. We could use the biochar to enhance the sustainability of biomass harvesting, thereby making the whole bioenergy production system more sustainable and carbon-negative.

This revelation occurred to me around 2004, and I've been pursuing sustainable bioenergy systems ever since. It's a really cool idea, and CenUSA greatly helped in advancing the research. With the support of CenUSA, we were able to do the research and write the papers that documented the viability of the concept that biochar can make bioenergy systems more sustainable and potentially even carbon-negative. It’s not ‘the solution’ by itself, but it can be integrated into complex biomass production systems and bioenergy conversion technology where you grow switchgrass, run it through a pyrolysis plant and turn it into energy products and biochar and then return the biochar to the soils. My contribution to CenUSA really focused on that piece of the story, how we can hopefully make the overall bioenergy production system more sustainable by sequestering carbon in the soil by recycling nutrients and enhancing soil quality and productivity.”

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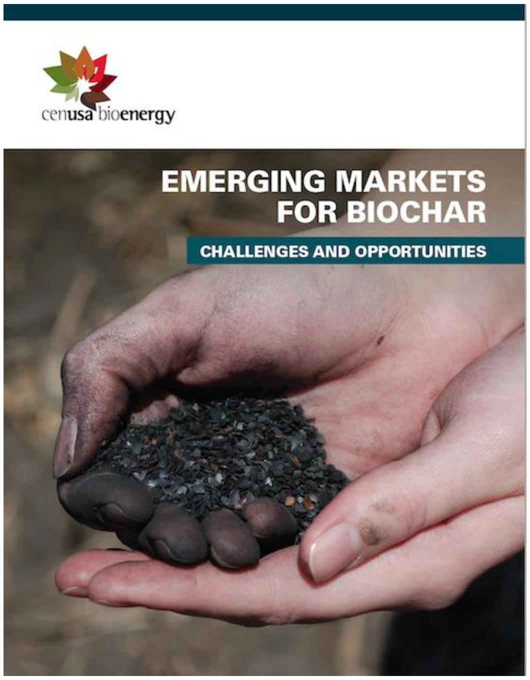
**I heard some of your presentations that were posted on the CenUSA YouTube channel ([https://www.youtube.com/user/CenusaBioenergy](https://www.youtube.com/user/CenusaBioenergy)), and you mentioned that biochar was used for bioproducts. How else can biochar be used other than as a soil amendment?**

“The reason it is called biochar rather than charcoal is because biochar is used for some environmental applications, primarily as a soil amendment, whereas charcoal is burned and used as a fuel. Otherwise, there is very little difference between charcoal and biochar.

The research on biochar is now focusing on a number of high-value applications. Biochar is not just one material, rather it is a huge family of materials that have different properties and characteristics. You want to use the right type of biochar for the right application. If you put the wrong biochar on the wrong soil, you could have a negative impact on crop productivity. If you put the right one on, you have a positive impact. You can also engineer chars for a number of different high-value environmental applications: cleaning environmental contaminants, removing phosphorus from ground water, improving conditions of urban brownfields and revegetating former mine lands.

A lot of work is going into using biochar to clean up a number of environmental contaminants. If you have groundwater that is contaminated with an organic solvent, we have engineered biochars that have a property which will actually remove chlorine ions from chlorinated solvents and clean up the contaminated groundwater. It's a cool application. Now imagine that you've got this plume of contaminated groundwater that is moving down grade. All you have to do is dig a trench deep enough to intercept the groundwater and back-fill the trench with the right kind of biochar. The contaminants will be removed as the groundwater moves through the biochar.



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Another application for biochar is the removal of phosphorous from groundwater. You've got bodies of water like the Chesapeake Bay that have eutrophication problems. You have algae blooms that then die and create toxic dead zones. The problem is that there is a lot of phosphorus in the soils, and that phosphorus is moving with the groundwater, ending up in the rivers and flowing to the Chesapeake Bay. There's been work showing that you can dig a trench parallel to the creek, back-fill it with a type of biochar and as the water moves through that biochar, the phosphorus is removed from the water before the creek water gets to the Chesapeake Bay. These kinds of high-value applications are being studied.

Another example would be urban brownfields. You have an industrial site in a city in which the soils are contaminated with heavy metals or other toxic compounds. If you incorporate the right type of biochar into those soils, you can sequester, trap or sometimes degrade the contaminants and allow those urban brownfields to become green and grow.

Another application that is being pursued is mine-land reclamation. Let's say that you've got an old coal mine There are mine tailings left over which can then be toxic and have other environmental problems associated with them, and nothing will grow on some of these mine tailings. Specific types of biochars are being developed that can be plowed into the tailings which will help remediate specific environmental problems and help to revegetate those areas.

These are some of the higher value applications that are being commercially developed with biochars right now. Those are the low hanging fruit because they generate higher profits for biochar companies than agriculture. CenUSA was primarily about developing sustainable bioenergy systems in which the biochar is applied to the soil off of which the biomass was harvested for bioenergy production. In that kind of a scenario, the biochar makes economic sense as a part of the system. Right now, biochar is a bit more economically challenging if you just want to apply it on agricultural fields.

The economics are a little weak because the only thing that counts is the increase in crop yields at the end of the day. If increased crop yields are the only value considered, the biochar isn't worth very much. Maybe it's $50 to $150 per ton, but if you start factoring in carbon sequestration and the increased sustainability of the system by putting the biochar in the ground, then the value of the biochar increases. With biochar, a farmer might be able to grow continuous corn and sustainably harvest both the grain and the corn stover. Without biochar, the long-term harvesting of both grain and stover leads to degradation of soil quality and eventually declining productivity. At a systems level, you can find more value in biochar applications."

**What kind of future do you see for the biochar industry and what innovations do you hope to see in the future?**

"Value-added products are an area of research and industry growth right now, and biochar is a promising technology for addressing climate change. I think a time will come when our society will realize that it is time to get serious about addressing climate change and will put a value on carbon sequestration. This could be through a carbon tax or some kind of cap-and-trade program. The biochar industry will really take off if or when that happens.

Quite frankly, the biochar system we are talking about, where it is a co-product of bioenergy production, is one of the low-hanging fruits for addressing climate change. I think the pyrolysis-biochar-bioenergy platform will be widely adopted when there is economic value associated with carbon sequestration. If you can find a political mechanism to pay farmers to put carbon in their soil, this could become a very effective piece to the solution of climate change. It's not 'the solution', but it is part of the solution.

Our best estimates right now are that the pyrolysis-biochar-bioenergy platform could be 15-to-25 percent of the whole solution, uniquely so, because it literally provides a means of removing carbon from the atmosphere while generating carbon-negative products that displace fossil fuel.

The pyrolysis-biochar-bioenergy platform is effective because, on the front end, fossil fuels are displaced by carbon-negative bioenergy products such as liquid biofuels. On the back end, when biochar is applied to soils atmospheric carbon is being sequestered for a very long time, hundreds or even thousands of years. The biochar is what makes the system 'carbon negative.'

The only problem with the pyrolysis-biochar-bioenergy system right now is that it has to compete with low-cost petroleum, and under the current paradigm, the environmental externalities associated with fossil fuels are discounted. When you put gas in your car, you're not paying for the environmental cost of that gasoline. Furthermore, when you put biofuels generated through the pyrolysis-biochar-bioenergy platform in your car, there is currently no credit going back to the biochar and the biofuel for the environmental benefits associated with it. The real problem is that environmental externalities are not currently factored into energy systems."

**In what ways did CenUSA challenge and broaden your professional knowledge and skill set?**

"I think one of the challenges that we all faced was learning to work together as a broad, interdisciplinary team. Through CenUSA, I was working with cropping system scientists, engineers, and economists. I was not working in the isolated silo of 'soil science.' When I work with other people from other disciplines, I have to know their interests and concerns and learn to 'speak a different language.' That's a real value that came to me professionally from the CenUSA project."

**Could you go into further detail on some of the other disciplines and ideas to which you were exposed?**

"I worked closely with the engineers. This includes Robert Brown and his team over in Mechanical Engineering at the Bioeconomy Institute. There were also people in biosystems engineering involved in the project, by the way. They were primarily working on how to develop fast pyrolysis plants, factories that can take biomass and can turn it into these liquid bioenergy products. Of course, they have a different language, priorities, and interests. We had to learn to compromise and figure out what will work as an engineer and what will work as an agronomist and soil scientist in order to make the whole system economically viable and agronomically sustainable.

Similarly, when collaborating with the economists, we worked on developing a biochar model. This is a computer model that can potentially be used to predict agronomic and environmental outcomes. All of these outcomes impact crop productivity, and when you throw biochar into that, it's only one of a long list of variables that can impact crop productivity. Our way of trying to predict the agronomic outcome, i.e. the impact on yield at the end of the growing season, was to try to develop a computer model. That model was then used in collaboration with the economists. The economists however, are interested in broader market impacts; they think in terms of a global trading system. All of these economic feedbacks have an impact on carbon sequestration. They not only impact the price of the crops, but it may mean that, for example, there's no economic incentive to cut down some piece of rainforest to grow more crops if the price of crops goes down. There might even be an economic incentive to abandon some marginal land that is currently being used for crops and let it grow back into forest.

As it grows back into forest, carbon is pulled out of the atmosphere. This is what's called an indirect land-use effect. Biochar impacts on crop productivity needed to be integrated into the economic models so that the economists could predict the effect on market forces, production systems and land use on a global scale."

**Have you worked on any projects as large or as well funded as CenUSA?**

"I worked on a NSF-EPSCoR project that was funded at a similar level. That project was focused on capacity building. My role involved mentoring junior faculty and building up technical and equipment capabilities.

I also worked on a project a number of years ago that was basically a soil-carbon sequestration project that was a multi-university, multi-institutional project. I've been in several large scale projects. I would say that of those, however, CenUSA was by far the most interdisciplinary project. We've had a lot of interesting features and collaborations across the board."

**More specifically, could you describe how CenUSA differed from these other projects?**

"Well, I think interdisciplinary collaboration was the key difference. As I said before, CenUSA was all about collaborations that involved economists, engineers, agricultural engineers, sociologists, the switchgrass breeders over in Nebraska and people from all of these different disciplines who were trying to work together on a common systems level vision. Other projects have been somewhat interdisciplinary, but not to the same extent that CenUSA was.

Extension was also a large part of CenUSA. You are doing Extension now because you are trying to communicate the outcomes, ideas and products of CenUSA to a broader audience. Most scientists are focused on communicating with other scientists by publishing in scientific journals. The Extension team helps us get the message out to the rest of the world. That outreach effort is a neat part of CenUSA."

**What were some unforeseen obstacles you encountered in your research?**

"Some of the challenges were that biochar evolves in soils over time. Therefore, the influence of biochar on soil's physical, chemical and biological properties also evolves with time. When you produce a mechanistic model like the model we worked on, you cannot possibly capture all of that complexity.

One of the real challenges is trying to figure out what the most important dynamics are and how they can be incorporated into a model. The model is by no means perfect. Of course, our goal in the modeling effort was to capture enough of the reality so that we can make a prediction about impacts and for the predictions to be right most of the time. We have no delusions in thinking that we can capture all of the complexity. Being able to produce and identify the critical processes and components are some of the challenges we faced.

Another challenge we faced was the reality of agriculture. We planted out switchgrass and our prairie crops in the spring of 2012. If you go back and check the history, you'll find that 2012 was a massive drought year in Iowa and much of the

Midwest. One of the setbacks we had was that the switchgrass that we planted in 2012 died! It wasn't able to survive the drought, so we had to replant the switchgrass in 2013. We had to face the agronomic reality that climate makes on crop."

**What were some of the most noteworthy discoveries and successes in your work of which you are proudest?**

"The system-level understanding that I described for you is probably the single most important piece overall. We proved that biochar is a critical part of the pyrolysis-biochar-bioenergy platform. The biochar supports the long-term sustainable production of the biomass feedstock for bioenergy production systems. By integrating biochar into the system, it is possible to make the whole pyrolysis-biochar-bioenergy platform carbon-negative. This is huge. We're talking about a system that is potentially 20 percent of the solution to global climate change. That's not trivial."

**How will you take your CenUSA experience and put it to use in other projects?**

"Again, what stands out is the ability to work in interdisciplinary teams. I think that's a real key value that comes out of CenUSA on a professional level. Having built a professional network of people with all of those contacts is certainly valuable for the next project that comes down the line."

**What is one core idea about your work that you would like to communicate to the average person in the generally interested public?**

"At a systems level, you can grow bioenergy crops, harvest biomass and produce liquid bioenergy products through the pyrolysis-biochar-bioenergy platform. The biochar recycles the nutrients, sequesters carbon, builds soil quality and enhances productivity. That whole systems-level idea, that this is something that has the potential contribution to the mitigation of climate change while generating economic value is the key message I would like people to understand. This is a sustainable system that has potential to be used to produce renewable liquid fuels that could replace fossil fuels while improving soil quality and enhancing productivity at a systems level."

## David Laird CenUSA Work Product

### Outreach and Extension

- ✓ Fact Sheet: CenUSA Biochar Research Efforts. **David Laird** & Jill Euken, Iowa State Univ. 2017. https://cenusa.iastate.edu/files/cenusa_2019_055.pdf

- ✓ Fact Sheet: Biochar: Prospects of Commercialization. **David Laird**, Iowa State Univ. & Pam Porter, Univ. of Wisconsin. 2014. https://cenusa.iastate.edu/files/cenusa_2019_018.pdf

- ✓ Research Summary: Biochar Can Improve the Sustainability of Stover Removal for Bioenergy. **David Laird**, Iowa State Univ. 2013. https://cenusa.iastate.edu/files/cenusa_2019_026.pdf

✓ Instructional Video: Biochar: Introduction to an Industry. **David Laird**, Iowa State Univ. (2014). (4:43). https://www.youtube.com/watch?v=Vccp-zcYvdg

✓ Webinar: Introduction to Biochar Commercialization Opportunities. **David Laird**, Iowa State Univ. 2014. (34:04). https://www.youtube.com/watch?v=iZRMvVhKotM

## Publications

✓ Aller, D., S. Bakshi & **D.A. Laird**. 2017. Modified method for proximate analysis of biochars. J. Analytical & Applied Pyrolysis. 124: 335-342. doi.org/10.1016/j.jaap.2017.01.012

✓ Aller, D., R. Mazur, K. Moore, R. Hintz, **D. Laird** & R. Horton. 2017. Biochar age and crop rotation impacts on soil quality. Soil Sci. Soc. Am. J. 81(5): 1157-1167. doi:10.2136/sssaj2017.01.0010

✓ Aller, D., S. Rathke, **D. Laird**, R. Cruse & J. Hatfield. 2017. Impacts of fresh and aged biochars on plant available water and water use efficiency. Geoderma 307: 114-121. https://doi.org/10.1016/j.geoderma.2017.08.007

✓ Aller, D., W. Sawadgo, K. Moore, D. Laird, W. Zhang & S. Archontoulis. 2018. Long term biochar effects on corn yield, soil quality and profitability in the US Midwest. Field Crops Res. 227 (1): 30-40. https://doi.org/10.1016/j.fcr.2018.07.012

✓ Archontoulis, S.V., I. Huber, F.E. Miguez, P.J. Thorburn & **D.A. Laird**. 2016. A model for mechanistic and system assessments of biochar effects on soils and crops and tradeoffs. GCB Bioenergy 8: 1028-1045. doi: 10.1111/gcbb.12314. http://onlinelibrary.wiley.com/doi/10.1111/gcbb.12314/full. (Open access)

✓ Bakshi, S., D.M. Aller & **D.A. Laird**. 2016. Comparison of the physical and chemical properties of laboratory- and field-aged biochars. J. Environ. Qual. 45(5): 1627-1634. doi: 10.2134/jeq2016.02.0062

✓ Bakshi, S., C. Banik & **D.A. Laird**. 2018. Quantification and characterization of chemically-and thermally labile and recalcitrant biochar fractions. Chemosphere 194: 247-255. doi.org/10.1016/j.chemosphere.2017.11.151

✓ Bakshi, S., C. Banik, S.J. Rathke & **D.A. Laird**. 2018. Arsenic sorption on zero-valent iron-biochar complexes. Water Research. 137: 153-163. doi.org/10.1016/j.watres.2018.03.021

✓ Banik, C., M. Lawrinenko, S. Bakshi & **D.A. Laird**. 2018. Impact of Pyrolysis Temperature and Feedstock on Surface Charge and Functional Group Chemistry of Biochars. J. Environ. Quality. 47(3): 452-461. doi:10.2134/jeq2017.11.0432

✓ Basso, A.S., F.E. Miguez, **D.A. Laird**, R. Horton & M. Westgate. 2013. Assessing potential of biochar for increasing water-holding capacity of sandy soils. GCB Bioenergy 5(2): 132–143

✓ Bonin, C.L., R.B. Fidel, C. Banik, **D.A. Laird**, R. Mitchell & E.A. Heaton. 2018. Perennial biomass crop establishment, community characteristics, and productivity in the upper US Midwest: Effects of cropping systems seed mixtures and biochar applications. Eur. J. Agron. 101: 121-128

- ✓ Chumki, B., M. Lawrinenko, S. Bakshi & **D.A. Laird**. Functional groups in relation to biochar surface charges. 2018 J. Environ. Quality 47(3). doi: 10.2134/jeq2017.11.0432

- ✓ Fidel, R., **D.A. Laird** & K. Spokas. 2018. Sorption of ammonium and nitrate to biochars is electrostatic and pH dependent. Scientific Reports 8: 17627

- ✓ Dokoohaki, H., F. Miguez, **D.A. Laird**, R. Horton & A. Basso. 2017. Assessing the biochar effects on selected physical properties of a sandy soil: An analytical approach. Commun. Soil Sci. Plant Anal. 48(12): 1387-1398 doi: 10.1080/00103624.2017.1358742

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- ✓ Fidel, R., S. Archontoulis, B. Babcock, R.C. Brown, H. Dokoohaki, D. Hayes, **D.A. Laird**, F. Miguez, & M. Mba Wright. 2017. Commentary on 'Current economic obstacles to biochar use in agriculture and climate change mitigation' regarding uncertainty, context-specificity and alternative value sources. Carbon Manage. 2: 215-217. doi. 10.1080/17583004.2017.1306408

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- ✓ Fidel, R.B., **D.A. Laird** & T.B. Parkin. 2017. Impact of six lignocellulosic biochars on C and N dynamics of two contrasting soils. GCB Bioenergy. doi. 10.1111/gcbb.12414. https://onlinelibrary.wiley.com/doi/pdf/10.1111/gcbb.12414. (Open access)

- ✓ Fidel, R. **D.A. Laird** & K. Spokas. 2018. Sorption of ammonium and nitrate to biochars is electrostatic and pH dependent. Scientific Reports 8: 17627

- ✓ Fidel, R.B., D.A. Laird & M.L. Thompson. 2013. Evaluation of Modified Boehm Titration Methods for Use with Biochars. J. Environ. Qual. 42: 1771-1778

- ✓ Fidel, R.B., **D.A. Laird**, M.L. Thompson & M. Lawrinenko. 2017. Characterization and quantification of biochar alkalinity. Chemosphere 167: 367-373

- ✓ Johnson, J.M.F., D.L. Karlen, G.L., Gresham, K.B. Cantrell, D.W. Archer, B.J. Wienhold, G.E. Varvel, **D.A. Laird**, J. Baker, T.E. Ochsner, J.M. Novak, A.D. Halvorson, F. Arriaga, D.T. Lightle, A. Hoover, R. Emerson & N.W. Barbour. 2014. Vertical distribution of structural components in corn stover. Agriculture 4: 274-287. doi:10.3390/agriculture4040274. http://www.mdpi.com/2077-0472/4/4/274. (Open access)

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