The Potential for Biochar to Deliver Greater Sustainability for Maize Cultivation and Processing: A White Paper

Written by:

Kathleen Draper, Ithaka Institute for Carbon Intelligence

July 2018

Generous financial support for the creation of this white paper was provided to the International Biochar Initiative from the Biochar for Sustainable Soils Project.

For further information please contact: draper@ithaka-institut.org

TABLE OF CONTENTS

The authors thank the following for their support in the creation of this paper: *Dominic Woolf who wrote the summary on yield impact, Phil Blom, JR Bollinger, Tom Miles, Christa Roth, Cecilia Sundberg, Michael Shafer and reviewers*

EXECUTIVE SUMMARY

Maize, also referred to as corn in many parts of the world, has been cultivated by humans for millenia. By weight more maize is grown globally than any other grain. In some parts of the world corn is one of the most important crops grown for human consumption. It can be eaten raw or cooked, roasted, ground, popped, fermented, soaked, boiled or converted into liquid form (e.g. whiskey). Maize is found in countless foods, and is also converted into oils, syrup, starches and more.

Yet in some of the largest corn growing regions of the world the amount of maize grown for human consumption represents a small fraction of the overall production. The vast majority is grown to feed livestock or to produce ethanol. Increasingly even in the developing world small holder farmers are being paid as contract farmers to grow maize for livestock on marginal soils unable to grow higher value crops. All manner of livestock and pets eat maize, either kernels only or as silage. Silage makes use of all parts of the plant by shredded, compressing and fermenting. Ethanol, a gasoline additive that, according to some, reduces pollution and dependence on fossil fuels, also makes use of the whole plant.

While debates about the environmental impacts of using massive amounts of arable land to grow food for livestock or fuel are on-going, maize is an enormously important crop both in the developed and developing world. As with many other crops, it future is threatened by warming temperatures, increasing droughts and other recurring threats brought on by climate change.

This paper reviews some ways that biochar, a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment, is being incorporated into maize production and processing systems to improve overall economic and environmental impacts. Given the wide variety of end uses and residual plant material that results from the different

Environmental benefits of producing and using biochar within the context of growing and processing maize accrue not only to soils, but to air, water and climate as well. These impacts, when viewed through the lens of the United Nations Sustainable Development Goals (SDGs) support progress towards achieving Food Security, Health and Wellness, Renewable Energy, Economic Development, Responsible Consumption and climate change mitigation and adaptation.

The methodology used in this paper combines a review of recent, relevant peer-reviewed literature with a survey of selected maize and biochar demonstration projects. Although extensive research has been done in academic settings related to using biochar with maize, particularly in the developing world, few long-term and large-scale demonstration projects have been conducted, particularly in the larger maize producing countries.

Recommendations for future research are detailed in the *Next Steps* section. As with many high volume, low value crops it is vital to understand the value proposition for using biochar in order for its use to broadly adopted. While low tech biochar producing stoves utilize the substantial amount of heat produced during carbonization, larger scale production heat could be used in different maize processing scenarios such as ethanol production or drying. A robust comparison of the life cycle assessment of growing and processing maize with and without biochar would also be of benefit is a world focusing on carbon reduction practices. Finally as with most crops, more real world biochar demonstration projects are needed so that optimized application rates and techniques can be determined for different soils used for maize production.

THE MAIZE GROWING CHALLENGE

Maize is one of the most ubiquitous crops grown on the planet. Global production for 2017/2018 was estimated at 1.034 B metric tons. The top three producers; U.S., China and Brazil account for 64.9% of global production. (USDA) Land dedicated to growing maize totals more than 183 million hectares. Yields per hectare vary enormously (see figure X). The U.S. leads at 11.08 t/ha while Zimbabwe has the lowest at 1.15 t/ha.

2017/2018 Corn Yield	
Country/Region	**Yield (M/t ha)**
World	5.63
United States	11.08
China	6.09
Latin America	
Brazil	4.97
Argentina	6.47
Bolivia	2.5
Mexico	3.71
European Union	7.42
Africa	
South Africa	5.21
Nigeria	1.69
Ethiopia	3.14
Egypt	8
Tanzania	1.27
Malawi	2.04
Zambia	2.54
Kenya	1.4
Uganda	2.55
Zimbabwe	1.15
Former Soviet Union	
Ukraine	5.44
Russia	4.9
South Asia	
India	2.92
Pakistan	4.69
Nepal	2.84
Southeast Asia	
Indonesia	3.3
Philippines	3.09
Vietnam	4.65
Thailand	4.45
Canada	10.04
Turkey	10
Others	2.54

With such variability it is difficult to generalize about the challenges maize farmers face. Yield is obviously not a concern in the U.S. in most years. But the painfully low yield and heavy reliance on maize in countries with growing populations in Africa and Asia leaves large numbers of people vulnerable to food insecurity. Drought, flooding, pests or just exhausted soils can lead to mass emigration if yields are lower than normal. India dedicates more than 9M ha to growing maize, yet produces only 24.12 M t/y, just 26% of the U.S. average yield. Clearly then, there is much that can be done to increase yield in many parts of the world.

Corn is a thirsty crop compared to others and less frequent rains has negatively impacted yields around the globe but is felt most in dryer parts of the world. Aquifers are being drained to irrigate corn to maintain and boost yield, an unsustainable practice if the aquifers are not being recharged. In the U.S. alone 5.6 cubic miles of irrigation water is withdrawn each year to keep yields high. In an increasing water constrained world, water usage needs to be carefully managed.

On the other hand, too much water can also be problematic for maize growers. The increase in heavy rains brought on by climate change can lead to flooded fields which can delay planting, reduce quality and/or quantity of yield and lead to increased disease pressure requiring yet more chemicals to fend of bugs, bacteria and fungi.

Fertilizer usage for maize production is rampant, costly and damaging to the environment. More than 5.6M tons of chemical nitrogen and nearly another million in organic N in the form of manure is spread, sprayed, injected or otherwise applied to maize fields in the U.S. every year. (Foley 2013) Often that N is washed away after heavy rains leading to increasingly severe eutrophication in local and not so local waterways. As one example, the Gulf of Mexico has been hard hit by excessive N used by corn farmers in the mid-west. It has also been found to leach into groundwater supplies leading to potential health issues. (Garcia et al 2017)

While many profess the best solution is specially engineered seed that grow maize that can withstand multiple biotic and abiotic threats (e.g. drought, waterlogging, increased heat and various diseases), a better solution may lie in restoring the underlying soils that are in many cases are exhausted resulting in low fertility and poor nutrient management capabilities. These factors often lead farmers to use ever more chemical fertilizers which are costly and environmentally damaging. Some farmers are coming to the realization that this is downward spiral and are instead seeking out ways to increase soil fertility and resiliency using more natural methods. Biochar represents one of the ways that farmers can begin to restore soils, but it offers several other potential benefits as well which are discussed below.

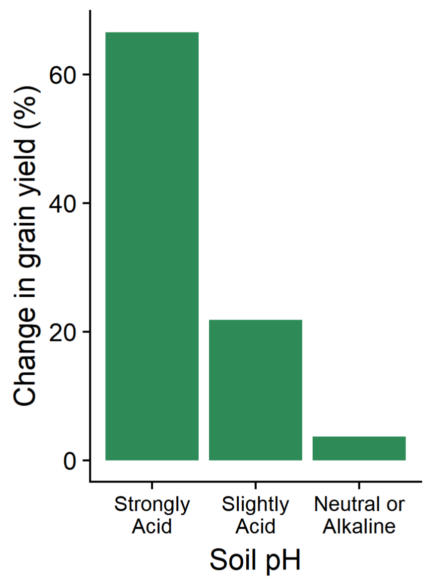
BENEFITS OF CARBONIZATION & BIOCHAR FOR MAIZE PRODUCTION

Given the importance of maize around the world, there has been significant attention paid by the biochar research community to understanding whether, why, when and where biochar can improve yield from a soil fertility perspective. More recently the ability of biochar to improve disease resistance of crops has seen increased interest as this also has a significant impact on yield and ultimately food security, which is one of the United Nations Sustainable Development goals (SDGs).

Continuing to use the lens of the United Nations SDGs, there are many other benefits that biochar provides to maize growers and processors as well as to their neighboring communities and consumers. Human health and wellness (SDG #3) benefits accrue to wide swaths of neighboring communities when crop residues are not burned in situ as happens far too frequently in some areas. Similarly preventing groundwater contamination from excess N, herbicides and other toxins goes beyond helping just growers. Renewable energy (SDG #7) can be produced at both small and large scale from maize residues. Biochar can facilitate economic growth (SDG #8) by increasing yields, decreasing the amount of off-farm purchases (e.g. fertilizers) and in some cases providing a new revenue stream for rural workers. Responsible consumption (SDG #12) includes optimizing organics management; carbonization provides one of the most sustainable options for managing maize residues. Last but not least are the wide variety of beneficial impacts biochar can provide to reduce the GHG emissions that typically result from growing and processing maize as well as the various climate change adaptation strategies it can offer (SDG #13).

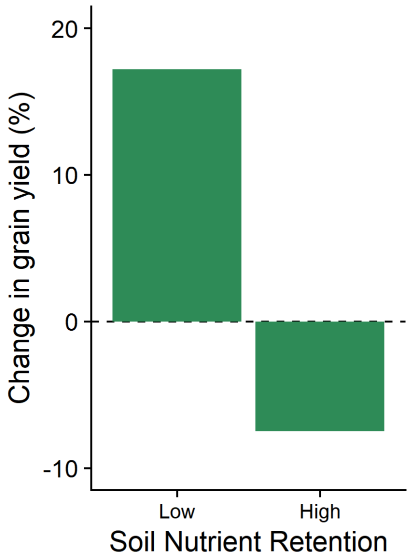
FOOD SECURITY: WILL BIOCHAR INCREASE CORN YIELD?

For many farmers, the key question underlying the decision of whether to invest in biochar is whether it will increase their yield. The answer to this depends on a number of factors, most important of which is the soil. Published scientific studies[i] on the effect of biochar on maize yield show that the most important soil qualities to consider in this regard are the soils acidity ("pH") and its ability to retain plant nutrients ("cation exchange capacity", or CEC for short).



When biochar was added to highly acid soils, maize yields increased by over 60% on average. On slightly acid soils, this number fell to 20%. Whereas, on neutral or alkaline soils no average improvement in yield was seen. Of course, it should be born in mind that the impressive yield increases from raising the pH of acid soils could also be achieved by using other materials (agricultural lime) to counter the acidity, often at lower cost.

The second soil property that has a significant impact on how well biochar improves yield is its CEC. CEC determines how effectively a soil can hold onto plant nutrients such ammonium (nitrogen), phosphorus, and potassium until they are required and taken up by the crop. A higher CEC means a more fertile soil. Fertile soils with a high CEC and thus high nutrient retention capacity showed an average *reduction* in maize yield of 7% following biochar application. Whereas, on less fertile soils with a low CEC, biochar increased maize yield by 17% on average.



There are some important aspects of biochar's ability to improve nutrient retention in less-fertile soils that are worth highlighting. First, this improvement can be expected to last for the long term. Indeed, the CEC of biochar is known to actually *increase* over time. Second, especially on tropical soils CEC is extremely challenging to increase by other types of fertility management. The primary method for increasing CEC is to build up the organic matter content of the soil. But, in tropical soils organic matter decomposes so quickly that building it up substantially is difficult, making biochar a more attractive proposition in these environments.

So what does this all mean? In a nutshell, farmers who want to grow maize on less fertile or acidic soils should definitely consider biochar as a potentially useful tool in their fertility management. Not only can biochar increase yields in these circumstances, but it can also make otherwise marginal fields sufficiently productive to become economically viable for maize production. On the other hand, farmers with already fertile soils, or access to other types of amendments that can address excess acidity are unlikely to see any increase in yield, and could potentially rather see a decrease under some conditions.

The published data on maize trials used here consisted of 293 experimental treatments in 27 publications. A comprehensive list of recent publications on biochar crop trials can be found in Simon Jeffery et al. Environmental Research Letters 12 (2017) 053001, and in Andrew Crane-Droesch et al. Environmental Research Letters 8.4 (2013): 044049.

Food Security: Disease Resistance

Disease pressure on farmers of all types is a constant concern. Maize growers face a plethora of diseases that include varieties of blight, mildew, rots, rust, spots and streaks. In many parts of the world the cost of fighting off these threats with chemicals is not affordable to small farmers which may be a contributor to low yields. Biochar use in soils is showing promise as a means to not only boost fertility but to also increase disease resistance in plants. It has been known to reduce the severity of powdery mildew as well as certain pest infestations. (Kummar et al 2017) Some are proposing using biochar as a more sustainable carrier for bacterial innoculants to increase plant resistance to various diseases. (Egamberdieva et al 2018)

Health & Wellness: Reduced Air Pollution

Although increasingly regulated, open burning of crop residues is still common practice in many places. Though this low-cost slash and burn method of clearing land for the next seasons crop has been practiced for millennia, it is sends vast amounts of CO2, dioxins, volatile organic compounds (VOCs) and PAHs into the atmosphere. (Oanh et al 2018, Sirithian et al 2018) Slash and burn is a leading cause of air pollution, which can have profound effects on human health.

Carbonizing maize residues using low tech, mobile kilns can significantly reduce particulate matter, toxins and GHGs that result from open burning. While there may be certain challenges in hilly terrains various options for lighter weight kilns have been explored. Another challenge for in-field biochar productions in dry regions is lack of water access for quenching after carbonization. In these areas, in lieu of quenching, various 'snuffing' options are been trialed including the use of soil, manures, sealing lids and in some cases fire resistant blankets.

Health & Wellness: Reduced Ground Water & Soil Pollution

Many farmers feel they are at war with weeds, insects, fungi, and anything else that has the potential to destroy their crop. To fed off these adversaries they use herbicides, pesticides, insecticides, fungicides and other chemical toxins that will leave there crops and kill off most other flora or fauna competing for water or nutrients. It is not uncommon for these chemicals to become mobile and contaminate groundwater and drinking supplies. Biochar has been shown to help to significantly slow movement of alachlor, an herbicide banned in Europe as it is a suspected carcinogen. (Mendes et al 2017) They found that high application rates of woody biochar performed best, but all types of tested biochars inhibited movement far more than other proposed strategies such as no tillage.

Researchers have also found that biochar can mitigate pesticide leaching. Cheng et al (2017) found that leaching of simazine, the second most commonly detected pesticide in surface water and groundwater in the United States, Europe, and Australia, can be significantly reduced with the use of biochar. It should be noted that there is an on-going discussion as well as research to understand biochar's overall impact on the efficacy of pesticides. Some have argued that less pesticides can be used as biochar will prevent leaching, while others are concerned that more pesticides will be needed if they are prevented from working effectively when biochar is in the soil. However, from a human health perspective, reducing toxins leaching into groundwater can have a profound impact on local communities.

Herbicides and pesticides are not the only contaminants lurking in agricultural soils. In many parts of the word soils contain heavy metals which find their way into plants and then enter the food chain. In China where up to X% of farm land has heavy metal concentrations that exceed safe limits, there is a significant focus on using biochar to immobilize different metals. Biochar has demonstrated the capacity to both immobilize certain metals while enhancing plant growth. (Ahmad et al. 2017)

RENEWABLE ENERGY

Maize residues have long been used to produce energy in the form of heat and more recently in the form of fuel ethanol. Abundant supplies at low cost make it an attractive material for renewable energy production even if the there is still debate on the overall net benefit to the environment of using maize for fuel. The USDA estimates that more than 100 million metric tons of stover can be harvested and delivered for less than USD$41/t to regional biomass energy plants located within the corn belt in the US. It should be noted that most bioenergy plants to date are solely focused on energy production using combustion which produces few, if any, other beneficial co-products.

Maize residues generally have relatively low moisture content making them a good fit for pyrolysis or gasification. Cobs have an advantage over other maize residues in that they need little pre-processing prior to using them to produce energy, while stalks, leaves and husks may need to be shredded or otherwise handled.

Heat produced from pyrolysis or gasification of corn cobs is used for cooking in various developing world countries, particularly in Africa. Efforts are under way to create low cost mechanisms for harvesting heat for farmers in the developing world to use to dry corn to prevent spoilage. Drying corn can be challenging for farmers especially in wet conditions

Cooking with corn cobs in Malawi reduces the need for

ECONOMIC GROWTH

The FAO estimates that 3 billion people live on smallholder farmers of 2 hectares or smaller. Often what they sow from the soil represents not only what food they have to eat, but the income they have to live on. As mentioned previously biochar can, in some cases, enable higher yields and in some scenarios, it can enable crop survival or at least minimize losses in the face of challenging weather precipitated by climate change. Through improved nutrient management it can also reduce, and in some cases eliminate the need for off-farm purchases of chemical fertilizers which can represent a significant cost to smallholder farmers. Research in Nepal showed that using 1/3 the recommended about of fertilizer and 2% biochar provided higher nutrient availability to maize than using 100% of the recommended fertilizer. (Pandit et al 2018) This translated into a yield increase of 231%. Even in highly arid soils maize residue biochar increased available P and increased maize yield by up to 75%. (Ahmed et al 2018) Reduced fertilizer purchases could represent a significant savings to farmers, especially if they are able to produce their own biochar from maize residues. Increased revenues can also improve their economic situation.

Another key aspect of UN SDG #8 is the decoupling of economic growth and environmental degradation. As we have been describing, the use of biochar has a beneficial impact on the environment including improved air, water, soil and climate change.

Responsible Consumption: Maize Residue Management

Maize is one of the top three crops in terms of residue production, accounting for more than 20% of globally produced crop residues (Cherubin et al 2018). Depending both on the end use of the maize and the kind of harvesting equipment used, the amount of unused residues can vary substantially. When only the grain is used, the ratio of residues to crop can be as high as 1.5:1. (Jain et al 2014)

Maize grown for grain, either for human or animal consumption, only utilizes the kernels leaving the stalk, husks, leaves and cobs to be managed. In richer countries where combine harvesters are used, the entire stalk is harvested. Once the stalks are cut, shucked and shelled, the cob, husks, stalk and leaves are shredded and left on the field either scattered to add organic matter and nitrogen to the soil, or in rows to be bailed for other uses. In the developing world much of the plant is not typically harvested beyond the cob. In many places around the world the residues are burned in the field as the lowest cost option to prepare fields for the next crop. This happens even in places where regulations prohibit burning. Farmers may see the fines as less costly compared to manually clearing residues or may not fear enforcement of burn bans.

Maize grown for livestock consumption can be in one of two forms: kernels or silage. Silage includes almost all parts of the corn with the exception of a small portion of the stalk and roots which are left in the field.

Corn ethanol also uses the entire stalk but after the fermentation process a residue called dried distillers grain (DDG) remains. DDG is often sold to cattle farmers either wet or dry as a feed additive, though this faces seasonal demand with summer being a low demand period as livestock is generally pastured to avoid additional feed costs.

Due to its plentiful nature, lack of alternative uses and low moisture content, many researchers have carbonized and characterized all manner of maize residues (Intani et al 2018, Liu et al 2018) in an effort to understand potential applications for them . A brief discussion of some corn residues and their resulting biochar follows.

Stover

Stover refers to a blend of maize stalks, leaves, cobs and husk left after harvest and/or processing for grain. Morrisette et al (2011) estimated a typical stover blend by dry weight to be approximately: 50% stalk, 22% leaves, 15% cobs, and 13% husk.

Shen et al (2015) found corn stover biochar to contain high ash and high potassium (K). They hypothesized and showed that these qualities contribute to improved adsorbency and eliminates the need to further activate the carbon with KOH as is sometimes done with activated carbon. They showed that corn stover biochar can be successfully used as an additive within a digester processing sludge to increase methane quality and quantity.

Cobs

Maize cobs account for roughly 17% of total maize biomass (Li et al 2018). Few markets or alternative uses for this material exist making it an ideal feedstock for biochar, particularly at processing locations where maize is dekerneled. When carbonized they produce the highest carbon content of all maize residues, varying from 72.5%, 83.8% and 86.9% when produced at temperatures of 300C, 450C and 600C respectively.
In addition to uses in soil, researchers have found that cob biochar is a low cost, renewable replacement for platinum, a precious metal, when used in microbial fuel cells (Li et al 2018). Other researchers have proposed using cob biochar in direct carbon fuel cells. (Yu et al 2014)

Distillers Grain

Ethanol plants generate a large amount of distillers grain with solubles (DGS), a co-product that in most cases is marketed as a feed for livestock. However, some have raised concerns about antibiotics in DGS – antibiotics are used in the ethanol production process to reduce the development of bacteria. Other concerns with feeding livestock DGS are focused on mycotoxins, E.coli and high sulfur.

While selling DGS is an important revenue stream for ethanol producers, there are limits to the amount of DGS livestock can consume which has prompted USDA researchers to look at alternative uses for DGS including as a feedstock for pyrolysis. Their proposal diverts a portion of DGS to be pyrolyzed and used as a soil amendment for growers. The syngas and bio-oil generated could be utilized in the ethanol production process, replacing the need for costly fossil fuels, thereby making the process more economical and sustainable. (Spokas et al 2012)

More recently researchers in Oklahoma have shown that certain types of biochar, though not yet those derived from corn residues, can enhance ethanol production, in some cases up to 90%. (Sun et al 2018) They surmised that biochar's functional groups, pH buffering capacity and cation exchange capacity (CEC) could be what boost production of ethanol and butanol

High temperature biochar made from distillers grain has been investigated for use in high performance supercapacitor electrode materials with some success. (Jin et al 2014)

Climate

The production and use of biochar within the maize supply chain can mitigate climate change through a variety of mechanism. Reduced fertilizer usage, carbon sequestration, reduced GHG from burning residues and offsetting fossil fuel usage for energy by utilizing heat and/or electricity from carbonizing maize residues are all ways mitigation strategies.

Farmers understand that the climate is already changing with rising temperatures, decreasing rainfall and more intense weather events. All of this is forcing them to adapt to these new weather realities in various ways. New or different varieties may help farmers cope, as can a change in planting schedules. Planting less densely lowers the need for water, but also the potential yields.

Biochar can provide some types of adaptation assistance to maize growers as well. Incorporating biochar into soil can improve water management which is helpful both during times or drought and flooding. One way biochar may help maize to survive better during droughts is by enhancing the surface area in root systems and increasing the amount of fine hairs that can reach water in lower areas. (Abiven et al 2015) Biochar's ability to improve soil-plant water interaction may be what enables improved plant growth and nutrient management. (Haider et al 2015)

Soil erosion and degradation has been occurring at an increased rate since the dawn of agriculture but is happening ever more rapidly in the face of climate change. Some estates claim the planet has lost half of the topsoil in the past 150 years. Rebuilding lost soil and particularly soil carbon is critical to farmers and to a growing population. Combining biochar with manures or compost can help rebuild both labile and recalcitrant carbon. Indeed, applying a combination of compost and biochar can even lead to reduced soil loss of up to 25%. (Lee et al 2018)

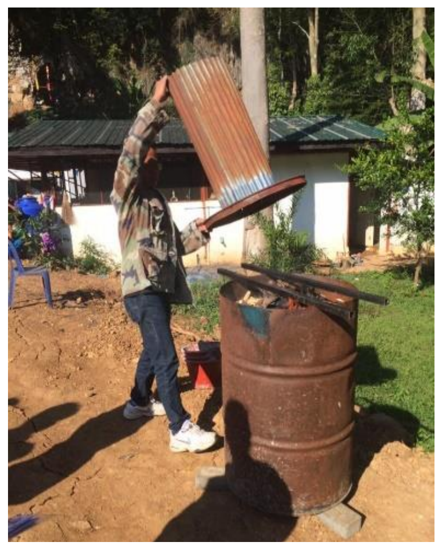
BIOCHAR PRODUCTION TECHNOLOGIES

Small scale cookstoves

Micro-gasification cookstoves have been used around the world for more than a decade. Dry material such as corn cobs can be used in these cookstoves as shown in Figure X. In areas with limited forest cover, these stoves can reduce deforestation. They can also reduce the amount of time women and girls spend collecting firewood. In cultures where the traditional three-stone fire cooking method is used, biochar-producing stoves can have the added benefit of significantly improved indoor air quality while generating a by-product that can be used to increase soil resilience and food security.

Farm Scale Kilns

Biochar production technologies such as the Top Lit Updraft (TLUD) kiln provide low-cost batch processing options to create larger amounts of biochar. TLUDs are closed kilns often built using 200 liter metal barrels. TLUDs can produce approximately 25% yield per batch per hour, e.g., for every 100 kg of feedstock, 25 kg of biochar could be produced. While these units can be built inexpensively (<USD$100), certain low-cost models need to be replaced with some frequency as the metal tends to buckle from the contained heat. Efforts to harvest heat generated during carbonization for use in drying corn are underway.



Warm Hearts Thailand TLUD stove


Warm Heart Trough Carbonizer

Another recent development in low cost kilns is the Warm Heart's trough created by innovators from the Warm Hearts organization in Thailand. These scalable flame cap carbonizers work well with long feedstock such as corn stalks, bamboo, and tree trimmings requiring far less pre-handling (i.e. shredding or chipping) than other types of carbonization equipment.

While the heat generated during carbonization is not generally harvested, this represents a significant step forward over in situ burning which is still common in many parts of the developing world.

The Kon-Tiki kiln is also a flame cap kiln which can be built in various sizes. The most basic Kon-Tiki kilns can be created with only a shovel. Cone shaped soil pit kilns with metal shields or stones placed around the cone pit have been utilized around the globe to create biochar from many different feedstocks.


Carbonizing corn cobs in a Kon-Tiki kiln

These technologies require basic training to ensure safety, proper biochar production and to ensure that particulate matter and GHG emissions are minimized.

Mid-Scale Pyrolysis

Mid-scale pyrolysis or gasification technologies customized to produce biochar are often referred to as Combined Heat and Biochar (CHAB), and are available in a range of sizes. Given the economic realities in most countries where coffee is cultivated, the high cost of large scale CHAB equipment currently available in the developed world does not make these systems economically viable even when the thermal energy is factored into the equation. Medium scale equipment (<USD$50,000) applicable for milling stations is being tested or awaiting funding for use at a few coffee and biochar projects. In addition to mitigating the various waste disposal issues previously described, many of these machines can provide energy either in the form of heat or electricity. Larger scale pyrolysis equipment (>USD $500,000) may be more appropriate for large coffee roasting operations in the developed world. These can reduce residue management costs while producing valuable by-products in the form of heat and electricity which can be used within the roasting operation.

MAIZE AND BIOCHAR DEMONSTRATION PROJECTS

The authors identified a number of projects which involve biochar as a component of maize cultivation and processing activities. These projects have been completed, are on-going, or are in the planning stages and are located in Africa, Asia, and the United States. The drivers for the projects include economic, environmental, and social factors such as:

- Ability to improve waste (residue) management
- Improved outdoor air quality
- Reduced dependence on chemical fertilizers
- Potential to utilize heat from carbonization to dry corn
- Increased economic development; employment for rural villagers to produce biochar,

Profiles for a few of the maize and biochar project developers interviewed are outlined below. Note that these projects encompass a range of implementation stages, testing protocols, and experiences; some have more details on crop effects than others.

ETHIOPIA: JIMMA UNIVERSITY & B4SS

Jimma University worked with the B4SS project to demonstrate to farmers how to make biochar from available crop residues, blend it with compost and apply to a variety of crops including maize, soybean, cabbage, peppers and perennial crops such as coffee and avocado. Farmers were taught how to make biochar on a small scale with stoves or using a larger soil pit Kon-Tiki kiln. Not only have farmer incomes risen due to increase crop yield and diversity, but fewer chemical inputs need to be purchased each season.

Ethiopian farmers carbonize unwanted biomass residues to improve livelihoods. Photo Credit: Bio Char

Kenya: Biochar for long-term food security in smallholder farms

A long-term collaboration between the Center for International Forestry Research (CIFOR) and researchers from Sweden started biochar trial in 2006 and monitored results over 20 growing seasons (10 years). The focus was on understanding the long-term impact of biochar at high application rates (10 kg m^{-2}) on fields where farmers grow alternately maize and soybean. Researchers found that on average biochar treated fields produced 1 tonne per ha more than unfertilized fields. They believe this persistent yield increase may be attributed to improvements in water holding capacity, pH and nutrient management.

More recently the team wanted to assess more realistic application rates based on available residues in the area. They worked with more than 150 smallholder farmers to test lower application rates (0.1, 0.5, and 1.0 kg m^{-2}). These rates correspond to typically available and unused biomass from maize and other organic waste. They found that significant maize residues (stover and cobs) were available at more than half of the farms in quantities of up to 500 kg per ha. Smaller application rates also led to persistent yield increases of 2.9, 5.0 and 6.4 times higher than yields in unfertilized fields.

Malawi: 'aMaizing cooking'

With private sector funding from Alliance One and Christa Roth, clean burning cookstoves have been developed and deployed that are capable of cooking with alternatives to wood. Corn cob residues, an abundant and underutilized resource, are being put to good use in micro-gasification cookstoves at farms in Kasunga, Malawi. With only 10 kg of dry maize cobs these stoves run for 40 minutes without refueling, which is sufficient time to cook a pot porridge. The resulting biochar is being used at plant nurseries.

Thailand: Warm Hearts International

Warm Heats International is a grassroots organization focused on empowering rural villagers in Thailand. They have extensive experience converting maize residues into biochar as a means of waste management, valorization of residues, improved air quality and economic development.

They have collaborated with rural corn processers to convert the massive amounts of leftover corn residues into biochar using low cost TLUDS. Biochar production becomes a village wide event after the harvest. The Warm Heart Environmental Team is working on harvesting the heat generated during biochar production for use in drying corn kernels which will save the operators significant cost, gas can cost up to $120USD per day, while also reducing GHG emissions.


TLUDs stand ready to carbonize a mountain of corn residues.

The organization has also been working with small farmers in Thailand to promote biochar production as a better alternative, both environmentally and economically, to burning corn stalks in situ. They have clearly demonstrated to farmers the reduction in air pollution and a mechanism for creating no or low-cost soil amendments that can make their soils more productive and resilient.

Using pairs, local laborers can cut 6 tons of corn stalks in 6 days which converts to 1.5 tons of biochar. Laborers are paid 2 – 4 Thai baht per kilo ($60 - $120USD/t) which compares favorably to the rural minimum wage of 300 baht per person per day ($9USD). Troughs are dug into the soil at the bottom of hills to be used for carbonizing stalks. As water is not nearby quenching is difficult. In lieu of quenching a metal lid, fashioned from a flattoned 55 gallon barrel is used to snuff the flames. Once cooled, the biochar is placed in bags and stomped on to reduce particle size. Larger farms in the region prefer to purchase pure biochar versus soil amendments, but efforts are being made to market a blended soil amendment to smaller farmers that do not compost.

Educating rural farmers about the benefits of revitalizing soils characterized as clayey, acidic and relatively sterile using biochar based soil amendments has proved challenging as most are still convinced that adding chemical fertilizers is the best way to farm. While the markets for biochar as a soil amendment or other carbon sequestering uses are slowly being created, Warm Hearts has found a booming demand for 'green charcoal' made from corn stalk biochar. During carbonization much of the volatiles are burned off producing a briquette that burns hotter, longer and cleaner than locally available charcoal make using old-fashioned, inefficient and sometimes highly polluting beehive kilns.

USA: JR Bollinger

Forth generation Missouri farmer JR Bollinger raises corn, soybeans, wheat, sorghum and millo on 1,000 acres. He realized the soil on the family farm lacked on of the most fundamental signs of health; worms. After years of chemical fertilizer an herbicide usage he shifted towards carbon-smart, biological farming to restore life to the soil.

A combination of biochar, microbes, minerals and other ingredients is ‘strip-tilled’ into a 6” band, directly where seeds are planted. Soil from the other 80% of the field is left undisturbed. In subsequent years the strip till location will move such that within 5 years the entire field will be covered.

In the first year after applying the biochar blend, corn in the strip till field was 16” taller than corn in the neighboring fields. It had thicker, longer leaves and finished 2 weeks earlier. Ears had on average 2 extra rows. Weed pressure was diminished, possibly because the corn grew so fast. Corn yields were up 30%. Yields in the sorghum fields, both irrigated and non-irrigated, were the highest in the entire state of Missouri.

In addition to increased revenues from additional yield and larger ears of corn, fertilizer costs were down nearly $100 per acre. Herbicide use was eliminated.

DISCUSSION AND FUTURE RESEARCH

Based on the authors’ research, there are a number of areas which could benefit from additional attention and funding in order to further clarify and quantify the benefits of using biochar in maize growing and processing. As biochar use is still relatively low, many of these recommendations apply to many other perennial and annual crops.

VALUE PROPOSITION FOR BIOCHAR USE IN MAIZE PRODUCTION

Unlike many perennial crops with higher value, corn tends to be a high volume low value crop, at least in the major production countries. Revenues per acre from corn are generally less than $1KUSD. Thus the value proposition for using biochar can be challenging where the cost of biochar is high.

Farmers such as JF Bollinger have found creative solutions which optimize low application rates that yield improved harvest. For other large-scale farmers to follow his lead, they will need to be convinced that the use of biochar is economically advantageous. This requires a more detailed understanding of the cost of biochar and the cost of application technologies. A cost benefit assessment should also asses reduced costs and increased revenues.

The value proposition for the developing world is likely to be very different as yields tend to be much lower so the potential upside in revenue is greater. The cost of biochar is also likely to be lower due to lower labor costs. However, where residues are currently burned, the additional labor needed to harvest and carbonize residues may be a decisive factor in whether small farmers spend the time and energy on producing their own biochar. Other inputs such as fertilizer or pesticides are likely to be higher as a percentage of overall costs, so the ability to lower off-farm inputs will have a greater advantage.

Creating a template and examples from existing biochar projects would be very helpful in convincing others to begin biochar trials.

Harnessing heat for drying Maize

Unlike coffee residue carbonization, efforts to harness heat specifically for drying maize have not yet been commercialized, though research is under way. As spoilage can occur without proper drying and growers can find it challenging to sell maize that is not sufficiently dry, having a low cost, reliable method for drying would be very beneficial for both large and small farmers.

Heat and/or electricity from carbonizing maize residues in other maize processing scenarios should also be explored and piloted.

Life Cycle Assessment

To understand the impact biochar use could have on maize production and processing, it would be useful to compile a series of life cycle assessments (LCA) for growers with and without the use of biochar. In addition, it would be helpful to create LCAs for dekerneling centers or ethanol production sites where the heat and/or electricity could be generated from carbonizing residues could be utilized within the system. While the use of biochar is currently not an accepted carbon offset product, the later scenario may be eligible for carbon credits in certain areas. These offsets could be useful in financing carbonization equipment.

Additional demonstration projects

Given the global importance of maize and the depth of promising academic research that has been done related to maize and biochar, the lack of large-scale, long term biochar and maize trials is somewhat surprising. It is likely that this is due in the developed world to the relatively high cost of biochar ($600 - $2,000USD per ton). In the developed world, where small scale farmers can be shown how to produce biochar using low tech methods, the hurdle is more likely lack of education on the production and use of biochar. Where rural farmers have been shown how to make, mix and use biochar properly, results have demonstrated value and farmers have generally been supportive and interested in continuing and even educating others. [B4SS Peru project]

It is critical to partner with local or regional agricultural cooperatives or extension organizations that are in direct contact with growers. Providing biochar education to these types of groups can have a cascading effect. Targeting lead farmers during initial demonstrations projects is also important as these individuals can further help disseminate information about lessons learned, best practices and methods.

Demonstration projects should be pragmatic in terms of application rates. Much of the early research on biochar was done using high rates of application which may not be sustainable or affordable. Basing trials on application rates that can be generated using available residues from a small holder's land is important for trials in the developing world. In the developed world it is important to use economically viable application rates.

As yield is often not the main constraint for maize production, a key focus of trials should be to understand optimal reduction of off-farm inputs (e.g. fertilizer, herbicides) and compare resistance to common maize pests and pathogens. It would also be helpful to compare nutrient quality and metal toxicity (where corn may be grown in contaminated soils) of crops grown with and without biochar.

Trial Design Optimization

With relatively few long-term real-world examples of biochar use in maize production, it is still difficult to provide specific recommendations for optimal application rates, blending materials and application methods. Academic research provides a broad spectrum of promising scenarios for the use of biochar in growing maize, but these are not regionally adapted. It is also helpful that the biochar classification system is based on the fertilizer needs of an average maize crop. (Camps et al 2015) Creating a customizable trial design format which farmers can use to understand how much corn residue biochar should be applied given their current soil nutrient content, would be helpful. This should include other widely available blending materials (e.g. manures) which are often co-composted with biochar in the developing world.

CONCLUSION

Although there exists a substantial amount of academic research on the benefits to yield of using biochar in maize cultivation, much work remains to be done to translate these benefits into real world demonstrations in different growing conditions. Given the myriad benefits to carbonizing maize residues and utilizing maize biochar, one might expect much more in-field experimentation and adoption than has occurred to date.   It is vital to articulate these benefits broadly to those focused on assisting rural farmers as biochar represents a low-cost way for farmer to increase food security while minimizing threats to health from air and soil pollution. In the right scenario it can improve farmer livelihoods and serve to provide new local economic opportunities. Importantly it also can convert a waste residue into a carbon sequestration tool to help rebalance atmospheric carbon.

THE AUTHOR

Kathleen Draper, draper@ithaka-institut.org, is the US Director of the Ithaka Institute. The *Ithaka Institute for Carbon Intelligence,* which was founded in Valais, Switzerland, with its American branch in an office in Rochester, NY, is dedicated to research, education, and consulting related to closed loop biochar solutions which can be implemented in both the developing and developed world. They are the editors of the Biochar Journal and the developers of the Kon-Tiki Kiln, biochar plasters, and sustainable packaging made from biochar. She is also a Board Member of both the International Biochar Initiative and the U.S. Biochar Initiative.

REFERENCES

Abiven, Samuel, Andreas Hund, Vegard Martinsen, and Gerard Cornelissen. "Biochar amendment increases maize root surface areas and branching: a shovelomics study in Zambia." *Plant and soil* 395, no. 1-2 (2015): 45-55.

Ahmad, Munir, Adel RA Usman, Abdullah S. Al-Faraj, Mahtab Ahmad, Abdelazeem Sallam, and Mohammad I. Al-Wabel. "Phosphorus-loaded biochar changes soil heavy metals availability and uptake potential of maize (Zea mays L.) plants." *Chemosphere* 194 (2018): 327-339.

Amin, Abu El-Eyuoon Abu Zied. "Phosphorus dynamics and corn growth under applications of corn stalks biochar in a clay soil." *Arabian Journal of Geosciences* 11, no. 14 (2018): 379.

Cheng, Hongguang, Davey L. Jones, Paul Hill, and Mohd Saufi Bastami. "Biochar concomitantly increases simazine sorption in sandy loam soil and lowers its dissipation." *Archives of Agronomy and Soil Science* 63, no. 8 (2017): 1082-1092.

Cherubin, Maurício Roberto, Dener Márcio da Silva Oliveira, Brigitte Josefine Feigl, Laisa Gouveia Pimentel, Izaias Pinheiro Lisboa, Maria Regina Gmach, Letícia Leal Varanda et al. "Crop residue harvest for bioenergy production and its implications on soil functioning and plant growth: A review." *Scientia Agricola* 75, no. 3 (2018): 255-272.

Egamberdieva, Dilfuza, Ma Hua, Moritz Reckling, Stephan Wirth, and Sonoko Dorothea Bellingrath-Kimura. "Potential effects of biochar-based microbial inoculants in agriculture." *Environmental Sustainability* (2018): 1-6.

Eng, Monica. "American livestock get extra dose of antibiotics from spent ethanol grain, report says." Chicago Tribune, May 14, 2012. http://www.chicagotribune.com/dining/chi-ethanol-distillers-grain-may-contain-antibiotic-residues-20120514-story.html#

Foley, Jonathan. "It's Time to Rethink America's Corn System." Scientific American, March, 5, 2013. https://www.scientificamerican.com/article/time-to-rethink-corn/

Gallegher, Paul, Baumes, Harry. "Biomass Supply From Corn Residues:
Estimates and Critical Review of Procedures." USDA Agricultural Economic Report Number 847. 2012 https://www.usda.gov/oce/reports/energy/Biomass%20Supply%20From%20Corn%20Residues-Nov-2012.pdf

Garcia, Valerie, Ellen Cooter, James Crooks, Brian Hinckley, Mark Murphy, and Xiangnan Xing. "Examining the impacts of increased corn production on groundwater quality using a coupled modeling system." *Science of The Total Environment* 586 (2017): 16-24.

Haider, Ghulam, Hans-Werner Koyro, Farooqe Azam, Diedrich Steffens, Christoph Müller, and Claudia Kammann. "Biochar but not humic acid product amendment affected maize yields via improving plant-soil moisture relations." *Plant and soil* 395, no. 1-2 (2015): 141-157.

Intani, Kiatkamjon, Sajid Latif, Zebin Cao, and Joachim Müller. "Characterisation of biochar from maize residues produced in a self-purging pyrolysis reactor." *Bioresource technology* (2018).

Jain, Niveta, Arti Bhatia, and Himanshu Pathak. "Emission of air pollutants from crop residue burning in India." *Aerosol and Air Quality Research* 14, no. 1 (2014): 422-430.

Jin, Hong, Xiaomin Wang, Zhengrong Gu, Gary Anderson, and K. Muthukumarappan. "Distillers dried grains with soluble (DDGS) bio-char based activated carbon for supercapacitors with organic electrolyte tetraethylammonium tetrafluoroborate." *Journal of Environmental Chemical Engineering* 2, no. 3 (2014): 1404-1409.

Kumar, Abhay, Yigal Elad, Ludmila Tsechansky, Vikas Abrol, Beni Lew, Rivka Offenbach, and Ellen R. Graber. "Biochar potential in intensive cultivation of Capsicum annuum L.(sweet pepper): crop yield and plant protection." *Journal of the Science of Food and Agriculture* 98, no. 2 (2018): 495-503.

Lee, Chia-Hsing, Chung-Chi Wang, Huan-Hsuan Lin, Sang Soo Lee, Daniel CW Tsang, Shih-Hao Jien, and Yong Sik Ok. "In-situ biochar application conserves nutrients while simultaneously mitigating runoff and erosion of an Fe-oxide-enriched tropical soil." *Science of the Total Environment* 619 (2018): 665-671.

Li, Meng, Hongguo Zhang, Tangfu Xiao, Shengdan Wang, Bopeng Zhang, Diyun Chen, Minhua Su, and Jingfeng Tang. "Low-cost biochar derived from corncob as oxygen reduction catalyst in air cathode microbial fuel cells." *Electrochimica Acta* (2018).

Liu, Zhaoxia, Wenjuan Niu, Heying Chu, Tan Zhou, and Zhiyou Niu. "Effect of the Carbonization Temperature on the Properties of Biochar Produced from the Pyrolysis of Crop Residues." *BioResources* 13, no. 2 (2018): 3429-3446.

Mendes, Kassio F., Kathleen E. Hall, Kurt A. Spokas, William C. Koskinen, and Valdemar L. Tornisielo. "Evaluating agricultural management effects on alachlor availability: tillage, green manure, and biochar." *Agronomy* 7, no. 4 (2017): 64.

Morissette, René, Philippe Savoie, and Joey Villeneuve. "Combustion of corn stover bales in a small 146-kW boiler." *Energies* 4, no. 7 (2011): 1102-1111.

Oanh, Nguyen Thi Kim, Didin Agustian Permadi, Philip Hopke, Kirk Smith, Nguyen Phan Dong, and Anh Nguyet Dang. "Annual emissions of air toxics emitted from crop residue open burning in Southeast Asia over the period of 2010–2015." *Atmospheric Environment* (2018).

Pandit, Naba Raj, Jan Mulder, Sarah Elizabeth Hale, Vegard Martinsen, Hans Peter Schmidt, and Gerard Cornelissen. "Biochar improves maize growth by alleviation of nutrient stress in a moderately acidic low-input Nepalese soil." *Science of the Total Environment* 625 (2018): 1380-1389.

Shen, Yanwen, Jessica L. Linville, Meltem Urgun-Demirtas, Robin P. Schoene, and Seth W. Snyder. "Producing pipeline-quality biomethane via anaerobic digestion of sludge amended with corn stover biochar with in-situ CO 2 removal." *Applied energy* 158 (2015): 300-309.

Spokas, Kurt, Ruan, Roger, Morrison, Bob. “Adding Value to Ethanol Production by-products through production of biochar and bio-oil.” Final technical report for Minnesota Corn Growers. 2012. https://www.ars.usda.gov/ARSUserFiles/41695/MNCornGrowersProject/FinalReport_Sept24.pdf

Sirithian, Duanpen, Sarawut Thepanondh, Melanie L. Sattler, and Wanna Laowagul. "Emissions of volatile organic compounds from maize residue open burning in the northern region of Thailand." *Atmospheric Environment* 176 (2018): 179-187.

Sun, Xiao, Hasan K. Atiyeh, Ajay Kumar, Hailin Zhang, and Ralph S. Tanner. "Biochar Enhanced Ethanol and Butanol Production by Clostridium carboxidivorans from Syngas." *Bioresource technology* (2018).

U.S. Department of Agriculture. “World Agricultural Production.” July 2018
https://apps.fas.usda.gov/psdonline/circulars/production.pdf

Yu, Jinshuai, Yicheng Zhao, and Yongdan Li. "Utilization of corn cob biochar in a direct carbon fuel cell." *Journal of Power Sources* 270 (2014): 312-317.

DDG - https://www.youtube.com/watch?v=NiW5a95Z8XU

Prices for corn, distillers grain, ethanolhttps://www.ams.usda.gov/mnreports/lsdethanol.pdf