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SPREADING THE CHAR:

THE IMPORTANCE OF LOCAL COMPATIBILITY IN THE DIFFUSION OF BIOCHAR SYSTEMS TO THE SMALLHOLDER AGRICULTURE COMMUNITY CONTEXT

Laura Muñoz

Photo credit: Carbon Roots International: from their website.

In partial fulfillment of a Bachelor of Arts Degree in Environmental Analysis, 2013-14 academic year, Pomona College, Claremont, California

Readers:
Dr. Bowman Cutter
Dr. Richard Hazlett

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Foreward

It was my summer break, 2012, after my second year of college. But it was winter in Brazil's Mata Atlântica (Atlantic Coastal Forest), one of the world's most biodiverse regions of which only 7 percent still remains. After a day's work of forest and ecosystem monitoring in the fragmented remains of the forest, I would often sit on the porch of the cabin and gaze out at the lands before me. I watched the cows graze nonchalantly on the bare, eerily beautiful hills. I tried to imagine everything that was there when the forest still was.

Throughout my two-month experience in Brazil, I learned a lot about the area, its history, and the livelihoods of the local people. I experienced the magic of the little forest that remained. I learned why I saw mostly pasture, even though farmers had prospered from coffee farming only decades before. I learned why there were big, reddish erosion and landslide scars on some of the hillsides. I learned why the Muriqui woolly spider monkey was almost extinct.

I also heard stories of local community members illegally clearing protected forest for agriculture. After a period of resentment and misunderstanding, I thought to myself, "What would I do?" Of course I would choose to chop down some trees instead of letting my family starve.

The following four months, I studied ecology in Ecuador for a semester. I couldn't help but cringe when I watched the rich forests full of endemic creatures burning to the ground in exchange for a couple years worth of marginal cultivation. And then I would think to myself, "What would I do?"

Experiencing these emotions while watching the simultaneous suffering of people and the Earth is what eventually brought me to this thesis – to try to find ways to simultaneously and successfully address the social, economic and environmental issues that are so intertwined with the lives of poor smallholder farmers.

I was drawn to learning more about biochar and its possibilities because of its enthralling history, its capacity to address multiple issues, and its longevity.

Introduction

This thesis enters the context of smallholder agriculture communities in the developing world. It explores the potentials of biochar and what biochar systems could bring to the smallholder communities while simultaneously bringing environmental benefits. It then acknowledges the challenges of diffusion – the spreading of an unfamiliar innovation. It seeks to answer the question of what will make diffusion of biochar systems more successful in the smallholder context, fixating on the characteristic of compatibility as well as the role local community members can play in making a new biochar system more visible to the rest of the community.

What is biochar?

Biochar is charcoal that is produced and used with specific conditions and intentions. It is made from organic matter, or biomass, which is heated in a closed space with little access to oxygen.[1] While regular "charcoal" may be used for a variety of purposes – fuel, art, or filtering to name a few – "biochar" specifically refers to charred organic matter that is created with the intent to apply it to soils. The two main and widely recognized purposes of biochar application to soils are soil management (usually for agricultural purposes) and climate mitigation (through carbon sequestration). Biochar is shown in Figure 1.[2]

Figure 1. Biochar

The practice of soil remediation using charred material dates back thousands of years. Evidence of its historical use can still be found in different parts of the world today, most famously in the anthropogenically modified "terra preta" (translating to "black

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[1]Lehmann, Johannes and Stephen Joseph. "Ch. 1: Biochar for Environmental Management: An Introduction." *Biochar for Environmental Management: Science and Technology.* Ed. Johannes Lehmann and Steven Joseph. London: Earthscan, 2010. 1-9. Print.

[2] Photo source: http://spin-project.eu/

earth") soils of the Amazon Rainforest that sustained thriving civilizations before the arrival of the Spanish conquistadors.[3]

In the past few decades, there has been a surge in interest and activity surrounding biochar for two main reasons: First, it has been discovered that "biochar-type substances" can account for the sustained fertility and high organic carbon content in the aforementioned terra preta soils. Second, research has shown that biochar is more stable and long lasting than any other soil amendment and can provide a host of other benefits in soil such as improved structure and resource efficiency, which lead to other more specific benefits. Biochar is the best and only known soil amendment that enhances soil quality for such a long term, signifying its great potential as a significant tool for environmental management.[4]

The four main objectives that can motivate biochar applications for environmental management are soil improvement (via improved long-term productivity and reduced environmental costs), waste management, climate change mitigation, and energy production. Individually or in combination, these uses must have either a social or financial benefit (or both) to motivate application. Because of its diverse array of uses and effects, different biochar systems may emerge on different scales.[5] This study mainly discusses to small-scale biochar systems in order to remain within the scope of the smallholder context. Biochar is discussed in further detail and context in Chapters 1 and 2.

Rural Agriculture in the Developing World

In 2005, 1.4 billion people were living in "extreme poverty" – on less than US$1.25 per day.[6] About 70 percent of them lived in rural areas. In 2011, 55 percent of the entire developing world population was rural, and that percentage was continuing to grow. 60 percent of the total rural population in developing countries was living below US$2 per

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[3] Bates, Albert K. *The Biochar Solution: Carbon Farming and Climate Change.* Gabriola Island, B.C.: New Society, 2010. Print.
[4] Lehmann and Joseph. "Ch. 1: Biochar for Environmental Management: An Introduction."
[5] Lehmann and Joseph. "Ch. 1: Biochar for Environmental Management: An Introduction."
[6] "The Millennium Development Goals report." *The United Nations Website*. United Nations, 2010. Web.

day.[7] According to the World Bank, agriculture is the main source of income and employment for 70 percent of the world's rural poor.[8]

This study focuses on small-scale rural agriculture, also known as smallholder farming, in developing countries. According to the International Fund for Agricultural Development, around 2 billion people in developing countries live and work on smallholder farms for their livelihoods.[9] These smallholdings usually consist of a small plot of low-rental-valued land that supports one family through a mix of subsistence and cash crop farming. Family and fellow community members may do other sorts of work as well.[10]

Subsistence farming, for which the main goal is to grow enough food to feed the family, usually consists of plots with staple crops and vegetables. Although subsistence is the first priority for most smallholders, other plots, when available, are used to grow crops (often cash crops) for regional markets.[11]

One of the biggest challenges these people currently face are the depletion and degradation of land. Land degradation refers to induced changes in the land such as erosion, acidification, contamination, desertification, or salination.[12] These changes impair its capacity to function in its natural state and agriculturally. The U.N. Food and Agriculture Organization estimates that 24 percent of the earth's land surface area is degraded. Cropland accounts for 20 percent of the earth's degraded land even thought it only makes up about 12 percent of the earth's land surface.[13]

Land degradation makes it continually more difficult for rural smallholder farmers to produce enough nourishment and other agriculture-based products to sustain their own livelihoods, let alone meet the needs of urban populations,[14] because it results in the loss of productive capacity in the land. The land degradation issues faced by rural farmers are brought on by multiple factors, but one of the biggest contributors is the poor farming

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[7] "IFAD Rural Poverty Report 2011." *International Fund for Agricultural Development (IFAD).* Quintily, November 2010. Web.

[8] "Agriculture & Rural Development." *The World Bank Group.* World Bank, 2013. Web.

[9] Nwanze, Kanayo F. "Food prices: smallholder farmers can be part of the solution." *International Fund for Agricultural Development.* (IFAD). IFAD, Feb. 2011. Web.

[10] Bunnett, R. B. "Interactive Geography 4." SNP Pan Pacific Publishing, 2002. pp. 125, 315. Web.

[11] Gradl, Christina et al. "Promising Agribusiness."

[12] Johnson, D.L. et al. "Meanings of environmental terms." *Journal of Environmental Quality* 26: (1997) 581–589. Web.

[13] Block, Ben. "Land Degradation Worse Than Previously Reported." Worldwatch Institute. 2013. Web.

[14] "Agriculture & Rural Development." *World Bank.* The World Bank Group, 2013. Web.

practices that deplete soils and increase their vulnerability.[15] These issues are interconnected with many other social, economic and environmental issues. Their causes and their extent will be further discussed in Chapters 2 and 3.

Action must be taken

Around 40% of all agricultural land (which covers about 40% of earth's total land surface) is considered "seriously degraded,"[16] arable land is being lost at an annual rate of more than 38,640 square miles per year,[17] and these percentages are continuing to increase. Along with it increases threats to the livelihoods of smallholder farmers and other negative consequences. Land degradation is detrimental to the wealth and economic development of nations, it compromises food security, and it raises competition for diminishing resources, which can cause conflict or famine. In addition to these damaging social consequences, ongoing land degradation and the resulting deforestation are destroying invaluable natural ecosystems. It is imperative that action beyond current levels is taken to slow, stop and reverse land degradation for the sake of people living today and for generations to come.

Can we effectively address smallholder problems using biochar systems?

After discussing smallholder agriculture issues and the beneficial properties of biochar, this paper goes on to explore the possibility of using small-scale biochar systems to address the issues that smallholder communities and the natural environment face.

When examining the current knowledge of biochar's functions alongside rural developing world agricultural problems, biochar indeed holds promise as a potential remedy to certain aspects of the land degradation issue. Research and trials have demonstrated that using biochar as a soil remediation tool can increase water retention,

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[15] *European Conservation Agriculture Federation.* Web. 30 Sept. 2013.
[16] "Agriculture and the need for natural resource management." *European Conservation Agriculture Federation.*
[17] Guffanti, Rich. "Chapter 1: Science & the Environment." GeocitiesSites.com. 2013. Web.

nutrient availability, soil carbon, organic matter retention, soil microorganism activity and structural health for the long term.[18]

History has shown that ancient soils anthropogenically modified with biochar substances can remain fertile for thousands of years following their modification, especially compared to the surrounding unmodified Amazonian soils that are typically leeched of nutrients, organic matter, carbon content and productive agricultural capacity.

These premises suggest that the application of biochar [possibly in combination with other organic substances] could have a potential to ameliorate poor agricultural land and increase the long-term resilience of current soils that are headed on a path to degradation. It may also increase the yields of smallholder farmers, bringing immediate benefits to their livelihoods. If successful, these effects would also slow environmental harm such as deforestation by decreasing the need to clear new land for planting after just a couple years.

Chapter 4 demonstrates that there are multiple biochar technologies that can fit into the rural smallholder context, and the biochar systems have the potential to address multiple interconnected smallholder issues. The next question is if there are technologies for the smallholder context available, *what are the barriers to their adoption of biochar systems*?

Diffusion and the importance of compatibility and observability

Biochar systems may have the *potential* to bring great benefit to smallholder communities and feasible technologies do exist. However, can it actually happen effectively? Only in the past decade or so have people launched biochar system diffusion projects in the smallholder context. It is a very new field, and there are still many uncertainties about it.

This paper explores Everett M. Rogers' *diffusion of innovations* theory to examine how diffusion projects work (i.e. attempting to spread adoption of a biochar system within a community) and what they must take into account. A few diffusion theory-based

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[18] Lehmann, Johannes and Joseph, Stephen. *Biochar for Environmental Management: Science and Technology.* London: Earthscan, 2010. Print.

hypotheses are analyzed by examining three case studies of (attempted) biochar system diffusion to smallholder community contexts. I examine the role of perceived compatibility and the role of key community members in observability of a biochar system.

The exploration of diffusion strategies is vital. Even if biochar systems have great potential to bring benefit to smallholder communities, it does not mean that they *will*. Examining and analyzing real-life cases of attempted biochar system diffusion will help future projects to learn what is necessary to make their great efforts pay off.

Methodology and Results

I carried out this study using a chain of varied methods. I reviewed literature about biochar, smallholder agriculture and livelihoods, diffusion of innovations theory, and biochar technologies and systems for the smallholder context. Based on the literature and background information, I formed some hypotheses regarding the diffusion of biochar systems. I then crafted three case studies of biochar system diffusion projects in the developing world smallholder agriculture context. I did this by interviewing people involved in the projects as well as gathering project information from other sources.

I analyzed the case studies based on my hypotheses. The first set hypothesized the importance of perceived compatibility of an introduced biochar system: The case studies supported the hypothesis that adapting a biochar system to local community traditions and values is an important part of the diffusion process. They also gave evidence that diffusion of biochar systems is more successful if there is a history of similar practices, such as applying charcoal or ash to soil. System components that were less locally familiar were indeed less compatible and less successful with diffusion. One case study supported the hypothesis that diffusion is more difficult if a community is extremely rural and doesn't have much experience with introduced innovations or the outside world, but no further supporting or rejecting evidence was found in other case studies. The hypothesis that diffusion success is higher when a biochar system addresses perceived needs within a community was supported as well.

The case studies also supported the observability hypothesis, suggesting that working with key community members increases the observability of a biochar system's benefits, which subsequently aids in diffusion.

Summary

Although smallholder context biochar system diffusion projects are currently in their early stages, the potential future benefits of widespread biochar system use are great. It is worth the time, energy and money to try to spread the integrative benefits of biochar systems to the places that need them most. However, it is also important not to waste resources on projects that will fail or take too long to implement. For this reason, this thesis recommends that change agents (the diffusers) put in great effort to learn about the local community in order to be able to make their biochar systems as compatible as possible. It is also imperative that people continue to examine and analyze current projects – their system designs and diffusion methods as well as the specific local contexts they are working in.

For beneficial change to happen on a large scale as a result of smallholder context biochar systems, a large and intimidating amount of diffusion must occur. However, if enough initial projects are successful, perhaps biochar systems will take hold and set an example for change agents and smallholder farmer communities around the world.

Chapter 1: A History of Biochar and *Terra Preta*

Although "biochar" is a relatively new term and field, the concept and practice of modifying soils with charcoal dates back thousands of years. The origins of the modern day biochar field are deeply rooted in traditional, historical practices and much mystery surrounding the creation of ancient black earths remains to be solved. Below is a timeline of history and events that shaped the biochar movement into what it is today.

A Timeline:

450 B.C. – 1500s A.D.: Over hundreds of years, Pre-Columbian Amazonian people modified plots of Amazonian soil with high concentrations of charcoal as well as other organic materials (including plant residues, animal feces, fish and animal bones.[19] This charcoal modification formed what we now call *terra preta*, the patches of black earth found in the Amazon. This earth was suitable for growing crops and sustaining large numbers of people for hundreds to thousands of years. *Terra preta* is shown in Figure 2.[20]

Figure 2. *Terra preta* (right) next to unamended Amazonian soils (left)

1542 A.D.: Spanish conquistador Francisco de Orellana and his men sailed through the Amazon. Orellana's scribe detailed his observations of large, flourishing civilizations in the middle of the Amazon rainforest:

> There was one town that stretched for fifteen miles without any space from house to house, which was a marvellous thing to behold. There were many roads here that entered into the interior of the land, very fine highways. Inland from the river to a distance of six miles more or less, there could be seen some very large cities that glistened in white and, besides this, the land is as fertile and as normal in appearance as our Spain. – Francisco de Orellana, 1542[21]

Based on archaeological evidence, it is estimated that the Amazon population at this time of Orellana's expedition was between 42 and 88 million people – a much larger number than it has ever been since.[22] This, along with Orellana's comment about fertile soils, suggests

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[19] Bruges, James. *The Biochar Debate*. White River Junction: Chelsea Green, 2009. Print.
[20] Photo source: Wikipedia Commons.
[21] Bruges, 25.
[22] Bates.

that *something* about the soils the Amazonian people were using for food cultivation was different than the standard, infertile and leachable Amazonian soils.

As Orellana and his men came in contact with the native people of the Amazon, they brought diseases to which the native people had no resistance. An estimated nine out of ten people died, and many of the survivors fled into the forest to escape disease and colonization.

1500s A.D., continued:

> When the civilizations of the Americas perished, with them perished the agricultural sciences gained from millennia of field trials. Countless valuable domestic cultivars, unable to self-propagate, went extinct. Where great shining cities had stood, vines and moss covered the façades; trees broke through the paving stones and engulfed buildings. Rain rotted away the roof timbers, and insects ate the parchment of scientific and literary manuscripts, leaving but a few to the bonfires of the conquerors. –Albert Bates[23]

By the time Spanish and Portuguese explorers arrived again years later, demographic collapse had occurred, the forest had reclaimed the towns Orellana had written of, and little trace of the thriving civilizations was left. It was assumed that Orellana's descriptions were delusional, because the typical reddish Amazonian soil was acidic and infertile and deemed unable to support the civilizations that Orellana described.[24]

1865: Following the United States civil war, many confederate farmers packed up and moved south. Many ended up in Brazil and wrote of the two-foot thick, rich, black loam in which their sugar cane thrived. Ballard S. Dunn wrote that this black soil generally extended no more than "half a mile from the face of the bluff," and that "after that the land is red sandy clay…"These settlers had noticed that the black earths were in patches surrounded by otherwise infertile soils.[25]

1868: James Orton, an explorer, geologist and clergyman visited confederate settlements in Brazil and reported that the soil was indeed very black and fertile.[26]

1874: During a geological survey of Brazil, Charles Frederick Hartt connected the *terra preta* soils to pre-Columbian human settlement. He published this connection in an 1874 paper.[27]

1895-1898: Friedrich Katzer led an Austrian geological exploration to study the black soils in Brazil. After his return he wrote over 140 scientific papers, many of which included studies of *terra preta* sampled from Brazil. Unfortunately, most of this collection was destroyed during the 1990s Bosnian conflict.[28]

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[23] Bates, 36.
[24] Bruges.
[25] Bates.
[26] Bates.
[27] Bates.
[28] Bates.

1903: Friedrich Katzer confirmed that the *terra preta* black earth was indeed anthropogenically modified earth, previously cultivated by pre-Columbian people residing in the Amazon. Katzer performed several chemical analyses of the *terra preta* soils and found that they contained charred plant materials, mineral residues, and decomposed organic material.[29]

1963: Following extensive research in Brazil, Wim Sombroek finished his Ph.D. thesis, "Amazon Soils." It contained his theories of about human origins of *terra preta*, and he published it as a book in 1966. With this publication came a surge of interest in Amazonian soils and ecology. Universities around the world began researching the topic.[30]

1966: Sombroek repeated Katzer's chemical tests on the *terra preta* and confirmed Katzer's results.[31]

1992: Sombroek published a work on *terra preta's* potential as a tool for carbon sequestration after returning to Brazil again.[32] Over the coming years, he gathered interested people together into a group called *Terra preta Nova*. Their aim was to "reinvent the ancient *terra preta* as a strategy for large-scale farming and as a carbon sink to recapture excess carbon dioxide from the atmosphere."[33] Thus began extensive biochar research around the world. Sombroek died in 2003 but his legacy continues.

2004: Although the term "agrichar" was already in use to describe biomass-derived charcoal for agricultural use, the term, "biochar," was recommended by Peter Read, a climate scientist from New Zealand.[34] Biochar refers only to the *char* part of *terra preta* or any other biochar-based input (such as a biochar compost mix). The char component is often mixed with other substances (i.e. compost or urine) when applied to soils (this is addressed in Chapter 4.2).

Note: In terms of biochar terminology, this paper will use the term "char" to refer to the charcoal product of pyrolysis, which has many different uses (fuel, medicine, soil amendment, etc.). The term "biochar" will refer *only* to char that ultimately goes into the soil.

2007: The First International Agrichar Conference was held in New South Wales, Australia. 107 participants from 13 countries attended. The association's name was changed to "The International Biochar Initiative" (IBI), which is both referred to and referenced in this paper.[35]

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[29]Bates.
[30]Bates, 13-14.
[31]Bates.
[32]Bates.
[33] Taylor, Paul. "Ch. 1: Ancient Origins, Modern Solution." *The Biochar Revolution*. Ed. Paul Taylor. Mt. Evelyn, Victoria, Australia: Global Publishing Group, 2010. 1-16. Print.
[34] Taylor, Paul. "Ch. 1: Ancient Origins, Modern Solution." P. 7.
[35] Taylor, Paul. "Ch. 1: Ancient Origins, Modern Solution." P. 7.

2008: 225 people from 31 different countries attended the second international conference, which was held in Newcastle Upon Tyne, UK.[36] Attendees and countries represented more than doubled from the previous year, showing the rapid increase in participation in the biochar field. It has since continued to grow and develop.

Present (2013): Biochar activity is currently happening on all continents except Antarctica. People are conducting research, trials, projects and workshops. Many people in the field agree that there is still much learning to be done and progress to be made in many areas.

***Terra preta* – what we know now**

Wim Sombroek's time on earth has passed, but his quest to recreate the long-lost *terra preta* recipe has been continued. Recent research has greatly increased the modern understanding of *terra preta*, which field studies have shown is made up of different mixtures in different places. Many different ingredients have been found in the *terra pretas* of the Amazon, but biochar is the first and most important ingredient. Other ingredients found include burnt clays and pottery shards; human and animal excrements; hunting, fishing, and cooking refuse; ash residue; and terrestrial and aquatic plant biomass.[37] *Terra preta* soils are found to be rich in nutrients such as nitrogen (N), phosphorus (P), calcium (Ca), zinc (Zn), and manganese (Mn), and they have high levels of microbial activity. While the surrounding Amazonian soils are generally acidic and prone to leaching, *terra preta* soils are not prone to leaching and are often alkaline.[38] The mechanism for the difference in leaching activity is described in Chapter 2.

Testing of *terra preta* has revealed some important soil measurements and comparisons that help to explain its extraordinary soil fertility. Albert Bates compares carbon content and organic matter depth of *terra preta* soils and surrounding, unmodified soils:

> Amazonian dark earths have up to 150 grams of hard carbon per kilogram of soil — 15 percent — in comparison to the surrounding soils with 2 to 3 percent. Total carbon stored in these soils is 100 to 200 times that of adjacent soils. The depths of organic matter go well below the 4 to 8 inches common in that region. Sixteen to 20 inches is average, and 80 inches is not unheard of.[39]

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[36] Taylor, Paul. "Ch. 1: Ancient Origins, Modern Solution." P. 7.
[37] Bates, 119.
[38] Bruges.
[39] Bates, 113-114.

Terra preta also appears to continually build and extend its carbon supply as its thriving, carbon-containing soil organisms die, decay and add carbon volume to the soil.[40] The mycorrhizal fungi that attach to the charcoal particles fix additional carbon. These fungi also "stabilize the soil with glomalin and increase nutrient transport to nearby plants, which provide roots that later shed and decompose to add still more carbon."[41] These impressive properties (as well as additional biochar properties mentioned in Chapter 2) affirm that the thriving and dense civilization written of by Orellana was not a hallucination. They help to explain how and why *terra preta* did and still does allow for the continuous successful cultivation of crops in the normally poor, incapable tropical soils of the Amazon.

Paul Taylor reports that *terra preta* is not created by the current practices of modern day Amazonian villages, which further supports the theory that the historical creation of *terra preta* for soil amendment purposes was intentional.[42] Although the tradition of *terra preta* creation has been lost, some of the ancient *terra preta* soils are currently in agricultural cultivation, demonstrating the soil's functioning and capabilities. As described by Albert Bates in 2010, "The *terra preta* soils formed on the bluff over the Rio Negro, where Orellana floated downstream 560 years ago, have been in continuous cultivation without fertilizer for the past 40 years. The farmers have no need to fallow their fields, and if they rotate their crops at all, it is more for weed control than to restore fertility."[43] In cleared, non-*terra preta* soils, research has shown that crop yields cannot be maintained for three straight seasons, even with the application of chemical fertilizers.[44]

If *terra preta* has so many different ingredients, why focus the research on the charred component in particular? Albert Bates explains, "Although clays, composts, and other factors may play a part, recalcitrant carbon is the backbone of the terra preta recipe." (The term "recalcitrant" refers to organic matter that is very stable and "not subject to release into soluble form.")[45] When Finnish researcher Janna Pietikäinen studied plant responses to zeolite, activated carbon, and biochar, all of which are high-porosity materials,

[40] Bates, 113.
[41] Bates, 113-114.
[42] Taylor, Paul. "Ch. 1: Ancient Origins, Modern Solution."
[43] Bates.
[44] Taylor, Paul. "Ch. 1: Ancient Origins, Modern Solution."
[45]"Recalcitrant definition." *Soil Dictionary*. science-dictionary.org, 2008.

she found that biochar was the only material that substantially improved microbial growth.[46]

A note on the history of black earths

The history of *terra preta* and the modern day research it has prompted is fundamental to the biochar movement and the possibility that biochar could have a huge positive impact on many interconnected world issues, including the agricultural issues this paper focuses on.

Although it was the discovery of *terra preta* that spurred the "biochar revolution," it is important to note that the traditional use of charcoal in soil is by no means unique to the pre-Columbian Amazonian people. Historical and current examples include charcoal use for soil modification practices in many places around the world. Albert Bates mentions dark earths found in Great Britain that date back to Roman times.[47] Other examples have presented themselves in historical texts. These include a 1697 Japanese writing describing "fire manure," the widespread Asian practice of using charred rice husks for fertilization, and an 1846 American agriculture book recommending charcoal use for nutrient conservation.

Certain native communities in Africa and India currently use traditional practices to carbonize organic waste for their soils. Dr. Christoph Steiner gives an example of a simple traditional technique that is currently used by some farmers in the tropical environment of northwest Cameroon. A layer of soil is put on top of dried grasses on fields, and the grasses are then burned. However, the soil layer reduces the oxygen flow so that the formation of char relative to ash is increased.[48]

It must not be ignored that anthropogenic modification is not the only way that these dark, fertile earths can be created. Dark, high-carbon earths are sometimes formed through natural processes such as grassland fires without any human intervention. This

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[46] Bates, 116.
[47]Bates.
[48] Steiner, Christoph via Taylor, Paul. "Ch. 1: Ancient Origins, Modern Solution." P. 6.

phenomenon and its resulting fertile soils greatly aids agriculture in places such as Romania, Russia, Ukraine, North American prairies, and the pampas of Argentina.[49]

Traditional agricultural charcoal use such as the Cameroonian practice described above is not widespread, but it does occur in locations around the world at present. This fact is quite relevant to this paper and will be further discussed in later chapters.

[49] Steiner, Christoph via Taylor, Paul. "Ch. 1: Ancient Origins, Modern Solution." P. 6.

Chapter 2: Biochar – What We Know Now

Black earths in the modern day

The past 20 years have seen rapidly expanding research on biochar. People are studying many different aspects and potentials of biochar under the umbrellas of soil science, pyrolysis technologies, application techniques, biological interactions, lifecycle assessments, carbon sequestration, climate change mitigation and other categories.

This paper focuses on biochar application as a soil improvement technique in smallholder developing world agriculture, while also addressing other related applications and incorporations that are relevant to these communities. These particular applications aim to improve long-term productivity and reduce environmental costs of agricultural activity and the poor rural lifestyle, while bringing social and economic benefits to adopters. Although biochar systems may emerge on different scales, this paper focuses on smaller scale, non-commercial, non-industrial systems due to the smallholder agriculture focus. While this chapter will discuss properties and knowledge of biochar itself (including pros and cons), later chapters will discuss how biochar can fit into the bigger picture of developing world smallholder agriculture, including applications, different uses, and the design and diffusion of biochar systems for this context.

Biochar systems

In this paper, the term "biochar systems" will be used to describe projects that incorporate the production and use of biochar as a soil amendment. These systems may address additional smallholder issues by integrating other features – they do not necessarily focus solely on biochar. An example of another aspect for incorporation is heat production for cooking.

Biochar in context

What is biochar made from?

Biochar is made from biomass – matter from living or recently living organisms. This often includes plant matter or plant-derived matter, such as manures. The original biomass that is then turned into biochar is called the "feedstock." There are many different options for biochar feedstock, because most biomass can be used. However, the choice of feedstock for a biochar system is something that must be carefully considered on both economic and environmental terms. For example, clearing tropical rainforest in order to use the biomass as feedstock for making biochar is quite unsustainable. It is imperative that biochar demand and production does not lead to further deforestation for biomass. Transportation distances are another factor that must be taken into account for both economic and ecological reasons.[50] In the smallholder context, biochar should be made using biomass waste materials, as is suggested by the International Biochar Initiative.[51] Examples of biomass waste materials that would likely be available in the smallholder context include agricultural residues (such as rice husks, corn stover, or wood from tree prunings), food wastes, and animal manures.[52] In this context especially, the main objective in feedstock choice is that it is an available, inexpensive source that does not lead to unsustainable biomass harvesting.

How is biochar made?

The chosen biomass feedstock is thermally modified through a process called pyrolysis to produce charcoal. During the pyrolysis process, the biomass is heated in a closed space with limited access to oxygen. This process usually takes place in a closed container at temperatures below 700° Celsius and over a varying period of time that can take up to several hours.[53] It is important to distinguish pyrolysis from burning, as it takes place under different conditions and yields different solid substances and gaseous products, which can be captured and used for energy. Char created through pyrolysis has high organic carbon content, while ash, the main solid product of burning, contains no organic carbon. This is the key factor when considering the uses and benefits of biochar.[54] For specifics on the physical and chemical characteristics and properties of biochar refer to "Biochar for Environmental Management," Chapters 1, 2, 3 and 4.[55]

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[50] Lehmann, Johannes and Stephen Joseph. "Ch. 9: Biochar Systems." *Biochar for Environmental Management: Science and Technology.* Ed. Johannes Lehmann and Steven Joseph. London: Earthscan, 2010. P. 147. Print.
[51] "Feedstocks." *International Biochar Initiative*. International Biochar Initiative, 2013. Web.
[52] "Feedstocks." *International Biochar Initiative.*
[53] Lehmann and Joseph. "Ch. 1: Biochar for Environmental Management: An Introduction."
[54] Lehmann and Joseph. "Ch. 1: Biochar for Environmental Management: An Introduction."
[55] Ed. Lehmann and Joseph, 1-67.

Biochar production

There is a range of different pyrolysis technologies for making biochar, which are employed for different purposes. While some technologies are being designed for larger scale production of biochar, these will not be further discussed or considered in this paper, as they do not fit into the smallholder agriculture context for a number of reasons. These reasons include: they are quite expensive and therefore cost prohibitive to poor farmers; most smallholder communities do not have the infrastructure (or market) to support them; and they require a huge amount of available biomass feedstock – an amount which smallholder farmers usually do not have sustainable access to. Cheaper, smaller-scale biochar technologies do exist, and these are more appropriate for the smallholder context (to be explored in Chapter 4.2).

When looking at biochar production technologies, as with feedstocks, it is important to consider environmental and economic impacts, such as emissions and efficiency. In fact, there are many traditional methods of charcoal making that are practiced around the world. Some of these existing methods are used to make charcoal for the purpose of soil application; in a sense, this charcoal *is* biochar. However, traditional methods of charcoal production tend to be "dirty" in multiple ways, including the infliction of environmental harm through high greenhouse gas emissions and inefficient biomass resource consumption (which often results in deforestation).[56] To avoid these particular pitfalls of traditional charcoal production, several small-scale biochar production technologies with lower emissions and higher efficiencies have been developed. One common, well-known strategy for cleanly producing biochar is the Top-Lit Up-Draft gasification method described below. Some specific small-scale biochar production technologies for the smallholder context will be explored in Chapter 4.2.

[56] Hirst, Peter. "Ch. 4: From Blacksmith to Biochar: The Essence of Community." *The Biochar Revolution*. Ed. Paul Taylor. Mt. Evelyn, Victoria, Australia: Global Publishing Group, 2010. P. 55. Print.

Biochar Production: TLUD gasifiers

There are multiple different technologies and designs for making biochar. In the biochar production field the most common technology used by small-scale devices is Top-Lit Up-Draft gasification (commonly referred to as "TLUD").

TLUD ovens and TLUD cookstoves are explored in Chapter 4.2.

What is gasification?

To understand the TLUD gasification process, one must first understand the regular burning process, which is described in Figure 3[57] at right.

In regular fires, the combustion, pyrolysis and oxidation processes occur almost simultaneously. Burning wood (or other biomass) in a normal fire (or traditional stove) results in incomplete combustion, which is what creates smoke. Combustion is incomplete mainly because the primary and secondary air enter simultaneously,[58] so the different reactions are not separated and not all of the pyrolysis gases ended up getting combusted.

However, the gasification processes (pyrolysis and char-gasification) may be more easily controlled if the gases are generated but not burned immediately. For the process of gasification, the key difference from normal burning is that the gasification and combustion reactions are separated – combustion occurs after the pyrolytic gasification of the biomass. This is achieved by limiting the oxygen flow and separating the entry of the primary air from the entry of secondary air. Because of this difference, combustion is complete and gasifiers burn much more cleanly than normal fires (this is because the carbon monoxide and

> **Combustion:**
> Gases created by the other two reactions (below) are combusted (whether fully or incompletely), creating visible flames. Oxygen, or "secondary air" (an air draft separate from the primary air draft) is required for this reaction.
>
> **Pyrolysis/carbonization:**
> This chemical transformation is caused by heat, releasing combustible gases and leaving charcoal behind.
>
> **Oxidation/char-gasification:**
> Carbon monoxide is created when the carbon is oxidized (also known as "char-gasification"). "Primary air" (the first draft of regular air) is required for this reaction. If the resulting carbon monoxide is kept concentrated and hot, it is combustible. The char-gasification leaves a residue of ash, which is non-combustible.

Figure 3. The three major chemical reactions of the burning process.

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[57] Information in Figure 3 comes from:
Anderson, Paul S. "TLUD Handbook: Draft 1 for Discussion." Revision 1.3. 20 Feb. 2010. Web.

[58] Anderson, Paul S. "TLUD Handbook: Draft 1 for Discussion."

methane pyrolysis gases are burned into much less harmful carbon dioxide, and less ash is created). Charcoal is a co-product of the process. It can either be combusted or used for other purposes, such as biochar.[59]

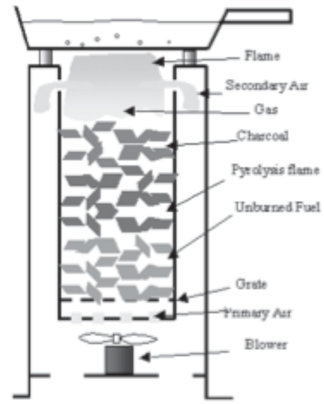

Figure 4. Diagram of a TLUD stove

TLUD technology

TLUD technology can be used for many different purposes (examples other than biochar retorts or stoves include water heaters or fruit driers).[60] All TLUD technologies use the gasification process described above, and so must contain certain design components.

Figure 4[61] graphically shows the basic design of a TLUD technology – in this case a stove. In ovens that are used solely for the purpose of making biochar, the pyrolysis gases are generally flared off in a chimney extending from a lid (in place of an open top for a cooking flame). Even if the flame at the top is not being used, it is important to burn the pyrolysis gases so that complete combustion occurs and the emissions are clean.[62] The Figure 4 diagram includes a blower at the bottom; however, this feature is not required, as discussed in Figure 5.

Figure 5[63] describes the three main components of a TLUD gasifier. From bottom to top they include a fuel container, a mechanism for secondary air entry, and a mechanism that assures a

Mechanism for assurance of draft:
While some designs have blowers to force a draft (such as in Figure 2), others create and use natural drafts. This can be done using chimneys.

↑

Mechanism for secondary air entry:
Strategically sized holes or gaps that are placed above the fuel but below where the flame should be. Different technologies depend on different variables for strategic placement and size.

↑

A fuel container:
Usually a vertical cylinder, as pictured in Figure 2. The bottom of the container must allow for the entrance of primary air, so it usually contains holes or a grate which have accessibility to airflow.

Figure 5. The three main components of a TLUD gasifier

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59 Anderson, Paul S. "TLUD Handbook: Draft 1 for Discussion."
60 Anderson, Paul S. "TLUD Handbook: Draft 1 for Discussion."
61 Information in Figure 4 comes from: Anderson, Paul S. "TLUD Handbook: Draft 1 for Discussion."
62 Anderson, Paul S., Reed, Thomas B., and Wever, Paul W. "Micro-gasification: What it is and why it works." *Boiling Point* N. 53, 2007. Print.
63 Information in Figure 5 comes from: Anderson, Paul S. "TLUD Handbook: Draft 1 for Discussion."

draft. Each of these three main components can influence the effectiveness of the others, so the overall structure must be thoughtfully designed and tested.[64]

Effects of biochar on soils and agriculture

Biochars vary greatly

It is important to look at specific effects of biochar on soil in order to gain understanding of the agricultural situations to which it could bring great benefit. Studies on the effects of biochar in soil must be reviewed with the understanding that there is not one worldwide standard recipe for biochar. Biochar is made using different combinations of feedstocks, different technologies, different heating times and temperatures, and other variables. In addition, there is extensive variation in soil types and climatic conditions in different locations around the world.

Especially in the small-scale context of this paper, the variation in biochars is necessary. This is because one particular uniform feedstock and technology is not available everywhere, and may not be suited to every location. Also, different soils benefit differently from different biochar recipes. Because the results of biochar use can vary greatly and different biochar systems and feedstock resources are available in different places, field trials must be performed in order to test the outcomes of a given biochar in a given location. If possible, it is also useful to test the biochars themselves and the soils to which they will be applied. Biochar and soil testing will not be addressed in this paper; however, useful information on this matter is provided in Chapters 8, 14, 15 and 16 in *The Biochar Revolution*.[65]

The article, "All Biochars Are Not Created Equal, How to Tell Them Apart: Version 2," provides simple, informal char-testing methods that allow for the determination of several key characteristics for a given biochar (see article for details). The article also affirms the significant variation in key properties of different biochars and the importance of being aware of the specific characteristics of a given biochar when adding it to soil. It emphasizes that "reports of the responses (whether favorable or unfavorable) of plants and soils to biochar applications are of questionable value without corresponding

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[64] Anderson, Paul S. "TLUD Handbook: Draft 1 for Discussion."
[65] Ed. Taylor, Paul. *The Biochar Revolution.*

knowledge of the characteristics of the applied biochars."[66] In the context of biochar projects like those investigated in this paper, accurate result reports may or may not be important to the diffusion of a biochar system. However, they are extremely useful to the biochar field as a whole and for the future of similar projects.

In general, biochar can have greater and lesser effects on different soil types and conditions. The International Biochar Initiative states that biochar can improve most soils, however locations with either nutrient-poor soils or low rainfall will likely benefit most.[67] The reasons for this will be discussed in following sections.

Mobile and resident portions of biochar

Even though different biochars bring different effects, there are some general components that exist in all biochars, even though the makeup of these components varies. All biochars have "mobile" (leachable) and "resident"(non-leachable) portions, each of which contain organic and inorganic components. While the mobile portion consists of biochar's short-term effects, the resident portion carries its long-term effects.[68]

Within the mobile portion, the organic part acts much like other degradable carbon sources (e.g. compost or detritus). It contains dissolved organic carbon and organic matter that is available to soil microbes. The makeup of the inorganic part varies depending on the feedstock, but may include fertilizers (e.g. potassium or phosphorus) as well as components that raise the soil pH. This can be useful if soils are acidic, but for alkaline soils, biochars with lower pH are better.[69]

Within the resident portion, the inorganic part (which again, depends on the biochar) may include minerals such as silica in stable, insoluble forms. These constituents are often slowly dissolved and re-deposited over time into soil aggregates. Carbon is sometimes locked up inside the mineral structures, resulting in long-term carbon sequestration. The resident organic portion of biochar becomes a permanent part of the soil. It is insoluble – it cannot be leached from the soil. It stays in the soil for a very long

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[66] McLaughlin, H., F. E. Shields, and T. B. Reed. *All Biochars Are Not Created Equal, How to Tell Them Apart: Version 2*. Boulder, CO: N. 2009. Print.
[67] "Biochar Use In The Field." *International Biochar Initiative.* Biochar International, 2013.Web.
[68] McLaughlin, Hugh. "Ch. 7: How Biochar Helps the Soil." *The Biochar Revolution.* Ed. Paul Taylor. Mt. Evelyn: Global Publishing Group, 2010. Print. p. 81-83.
[69] McLaughlin, "Ch. 7: How Biochar Helps the Soil." 81-83.

time – hundreds to thousands of years – remaining substantially unchanged. It is considered a "soil catalyst," because it fosters improvements in the soil environment inhabited by plants and microbes.[70] These improvements include enhanced nutrient exchange between the soil and plants.

The fact that biochar can bring both short and long-term benefits due to the presence of its mobile and resident portions is worth noting for the context of this paper. Although biochar's long-term benefits are what make it unique, the short-term benefits are crucial for its diffusion to potential adopters who want to see immediate beneficial results.

Chapter 2.1: Benefits to soil

Physical effects: Improved soil structure and drainage

"Biochar mitigates soil's physical deficiencies." – Hugh McLaughlin, Director of Biochar Research at Alterna Biocharcon Inc.[71]

Enhanced aeration and moisture retention

Biochar greatly improves soil drainage, and it does so in different ways for different soils. For example, soils that are too clayey or poorly aggregated do not drain effectively because they are too tight; this results in poor soil aeration. Biochar improves aeration in these soils and makes them less compacted.

On the other side of the spectrum, sandier soils, as well as certain other types of soils, drain too quickly. This shortens the duration of moisture's presence in the soil. Biochar provides "additional bulk moisture storage capacity" to these soils.[72]

Note: To improve upon either of the abovementioned soil structural problems using biochar, refer to specific application techniques mentioned on page 83 of "The Biochar Revolution."[73]

Increased resource efficiency

"Biochar helps the soil do more with less." –Hugh McLaughlin[74]

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[70] McLaughlin, "Ch. 7: How Biochar Helps the Soil." 81-83.
[71] McLaughlin, "Ch. 7: How Biochar Helps the Soil." P. 83.
[72] McLaughlin, "Ch. 7: How Biochar Helps the Soil." P. 83.
[73] McLaughlin, "Ch. 7: How Biochar Helps the Soil." P. 83.

Nutrient retention – cation exchange capacity

According to K. Yin Chan and Zhihong Xu, "one reason for the ability of Amazonian Terra Preta soils…to maintain high fertility (compared to adjacent infertile soils) is their ability to retain nutrients."[75][76] This section explores biochar's effect on soil nutrient retention and its relevant mechanisms that come into play.

Biochar has a property called cation exchange capacity. This capacity allows it to retain positive ions in a form that is exchangeable. These positive ions, vital nutrients such as ammonium or potassium cations, are made available to plants when they need them.[77] This is especially important, because oftentimes when regular fertilizers are applied to poor soils, the nutrients end up leaving the soil (via leaching, weeds, or microbial activity) before the crops can benefit. The resulting lack of nutrient uptake limits their growth.

The nutrients retained in the soil through biochar's cation exchange capacity may come from multiple sources, such as detritus, decomposing crop residues, and applied fertilizers, among others. Biochar itself also contributes both micro- and macro-nutrients that enhance plant growth. However, the specific nutrient composition and availability in a biochar depends greatly on the feedstocks used and the production conditions.[78]Biochar's capacity to store all these nutrients has been shown to increase over time.[79]

Nutrient leaching occurs when water percolates through soil, displacing the mobile soil nutrients to locations that are out of reach of plant roots.[80] It is a devastating yet common problem for many farmers, especially in tropical areas with high rainfall and poor soils.[81] Studies have shown that biochar by itself decreases nutrient leaching, and that

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[74] McLaughlin, "Ch. 7: How Biochar Helps the Soil." P. 83.
[75] Chan, K. Yin and Zhihong Xu. "Ch. 5: Biochar: Nutrient Properties and Their Enhancement." *Biochar for Environmental Management: Science and Technology.* Ed. Johannes Lehmann and Steven Joseph. London: Earthscan, 2010. 67-81. Print.
[76] Chan and Xu. "Ch. 5: Biochar: Nutrient Properties and Their Enhancement."
[77] McLaughlin. "Ch. 7: How Biochar Helps the Soil." P. 84.
[78] Chan and Xu. "Ch. 5: Biochar: Nutrient Properties and Their Enhancement."
[79] McLaughlin, "Ch. 7: How Biochar Helps the Soil." p. 84.
[80] Major et al. "Ch. 15: Biochar Effects on Nutrient Leaching." *Biochar for Environmental Management: Science and Technology.* Ed. Johannes Lehmann and Steven Joseph. London: Earthscan, 2010. Print. P. 271.
[81] For more on leaching, see Chapter 15 of *Biochar for Environmental Management*.

biochar mixed with soil decreases nutrient leaching as well. For this specific purpose, biochar is most valuable in sandy soils and regions of high rainfall.[82]

Another problem biochar has been shown to reduce is agricultural leaching and runoff, a process that deposits nutrients such as phosphorous and nitrate (among others) into water bodies. The runoff nutrients cause eutrophication, rendering the water quality unacceptable by developed world standards.[83] This is worth noting because of the health risks posed around the world by the increasing amount of agriculturally contaminated water, and biochar's potential to diminish this problem.

Biochar's capacity to help the soil retain important nutrients increases the efficiency of nutrient cycling, fostering increased nutrient uptake by plants and resulting higher biomass production.[84] It can also greatly reduce fertilizer requirements (if fertilizer is being applied). This property has the potential to bring both economic and environmental benefits to smallholder communities. For a more detailed discussion of nutrient retention and biochar's effects of nutrient leaching, refer to Chapters 5, 14 and 15 of Biochar for Environmental Management.[85]

Adsorption capacity – moisture retention

Adsorption is the adhesion of molecules or particles to a surface.[86] Many biochars have a high adsorption capacity because they have sizable internal surface areas.[87] Figure 6[88] is an electron microscope photo of biochar that shows its high porosity. When water availability in the soil is high, this internal surface area adsorbs moisture. When water availability in the soil is low (such as

Figure 6. Electron microscope photo of biochar, showing its high porosity

[82] Major et al. "Ch. 15: Biochar Effects on Nutrient Leaching." 272-273
[83] Major et al. "Ch. 15: Biochar Effects on Nutrient Leaching." 271.
[84] Chan and Xu. "Ch. 5: Biochar: Nutrient Properties and Their Enhancement."
[85] Lehmann, Johannes and Joseph, Stephen. *Biochar for Environmental Management: Science and Technology.* Ch. 5, 14 and 15.
[86] "Adsorption." *Rensselaer Polytechnic Institute.* Rensselaer Polytechnic Institute, 2000. Web.
[87] McLaughlin, "Ch. 7: How Biochar Helps the Soil." p. 84
[88] Photo credit: biocharproject.org

during low precipitation periods that commonly yield hot, dry soil), the previously adsorbed moisture is released back into the soil. This effect improves all-around moisture retention in soils, which can be extremely beneficial during low-rainfall periods and drought conditions. Not only can biochar improve moisture retention, but it can also increase the overall water holding capacity of soils to which it is added.[89]

The resulting increased moisture capacity and retention can extend growing seasons, which often end due to the scarcity of moisture that comes with dry seasons. This property can be especially useful when crop irrigation is not used, as is the case for many poor smallholder farmers. When irrigation is used, biochar's adsorption capacity still greatly aids farmers through its ability to conserve water.[90]

Promotes the growth of beneficial soil microbe populations

"Biochar restores the soil to its natural biological role." – Hugh McLaughlin

Biochar facilitates and promotes soil microbe populations by providing them with a protective, highly porous habitat. The extensive surface areas of biochar molecules (discussed previously) provide ideal surfaces for microbial colonies. Biochar also adsorbs compounds that hinder the growth of microbes, reducing their exposure to these compounds and therefore improving their growth. Their habitat is further improved by the soil moisture management properties of biochar, as previously discussed.[91]

Biochar's fostering of microbial communities is extremely beneficial because of the importance of microbes to plant growth: soil-plant nutrient exchanges require soil microbes for nutrient cycling. Soil microbes play many important roles that enable plants to access the nutrients they need. For example, the mycorrhiza fungus provides nutrients for plant uptake by extending their filaments into plant roots. The fungus receives nourishment in return. This symbiotic exchange often assists plants with the uptake of phosphorus, magnesium and other important minerals. Fungi also directly provide organic nutrients to plants by breaking down plant litter from the topsoil, adding it to their bodies,

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[89] Major et al. "Ch. 15: Biochar Effects on Nutrient Leaching."
[90] McLaughlin, "Ch. 7: How Biochar Helps the Soil." p. 84.
[91] McLaughlin, "Ch. 7: How Biochar Helps the Soil." p. 85.

dying and decomposing.[92] Another example of microorganisms that have a great, beneficial impact on plant nutrition are soil bacteria that mineralize organic nitrogen, turning it into forms that are available to plants.[93]

Multiple studies have shown that the *terra preta* soils have a "higher microbial biomass and abundance of culturable bacteria and fungi" than the surrounding, unmodified soils. *Terra preta* also displays significantly lower respiratory activity, resulting in a higher metabolic efficiency ("metabolic efficiency" refers to the "efficiency by which microbes convert assimilated carbon into biomass").[94],[95] These properties are some of the keys to *terra preta's* superiority as a growth medium compared to surrounding soils. Bringing these properties (via biochar) to agricultural soils in need has the potential to aid in improving the health of soils and agricultural outcomes.

Summary of potential effects of biochar on agriculture

As discussed above, biochar contains multiple properties that bring about a variety of beneficial changes to soils in which it is applied. Biochar improves soils structure and drainage, enhancing soil aeration and moisture retention; it increases the soils' resource efficiency through the facilitation of improved nutrient retention though cation exchange capacity as well as through its adsorption capacity; and it promotes the growth of beneficial soil microbe populations. Along with these benefits, biochar often also has a liming effect that moderates soil acidity.[96] It must also be noted that biochar reduces soil emissions of greenhouse gases[97] and has other positive environmental effects, although these will only be discussed in this paper in conjunction with effects on smallholder agriculture communities.

Biochar works in combination with other soil components (including soil microbes) to improve the overall soil dynamics – the conditions in which plants grow – over the long

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[92] McLaughlin, "Ch. 7: How Biochar Helps the Soil." p. 86.
[93] Major et al. "Ch. 15: Biochar Effects on Nutrient Leaching." P. 278.
[94] Herrona, Patrick, et al. "Microbial growth efficiencies across a soil moisture gradient assessed using 13C acetic acid vapor and 15N-ammonia gas." *Soil Biology & Biochemistry* 41 (2009): 1262–1269. Web.
[95] Chan and Xu. "Ch. 5: Biochar: Nutrient Properties and Their Enhancement."
[96] IBI "Biochar Use In The Field."
[97] Van Zwieten, Lukas, et al. "Ch. 13: Biochar and Emissions of Non-CO(2) Greenhouse Gases from Soil." *Biochar for Environmental Management: Science and Technology.* Ed. Johannes Lehmann and Steven Joseph. London: Earthscan, 2010. 227-243. Print.

term. This allows for better plant nutrition, improving plant growth and yield and bringing overarching benefits to agricultural soil productivity.

Although conventional fertilizers may provide short-term benefits, they require frequent reapplication and do not contribute to overall, long-term soil quality, which is one of biochar's most important, unique attributes. For the reasons described in this chapter, biochar presents significant potential for increasing the sustainability of agricultural systems. Its potential is especially great where soils are poor,[98] which is often the case in the smallholder context.

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98 McLaughlin, "Ch. 7: How Biochar Helps the Soil."

Chapter 3: Factors Affecting Smallholder Agriculture Communities in the Developing World

"Only a robust and holistic approach that intertwines the three strands of development - environmental, economic and social - will bring about sustainable development."[99] – Olav Kjørven, Director of the United Nations Development Programme's Bureu for Development Policy

Although this paper focuses on the *diffusion* of small-scale biochar systems to rural communities in the developing world, the *design* of these development projects is something that cannot be ignored, as it will have a great effect on diffusion and its consequences. In development projects like this, it is extremely important not to diffuse unsustainable systems, otherwise communities could end up worse off than they started. Therefore, it is important to heed the words of Olav Kjørven (quoted above) and address environmental, economic and social needs in development projects. For this reason, this chapter provides the background on not only the agricultural component but also the economic, environmental and social situations of smallholder communities in the developing world. The following chapter addresses how biochar systems can apply to these situations.

What is smallholder agriculture?

As discussed in the Introduction, smallholder agriculture is typically small-scale (less than 2 hectares) mixture of subsistence and cash crop farming.[100] The balance of these two activities varies greatly depending on many factors, but the main purpose of smallholder agriculture is to support of the livelihood of a family. Many specifics such as land holdings, size, techniques, and crops vary depending on the specific farm and its location. Smallholder farmers operate under a variety of different conditions and

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[99] Kjørven, Olav. "Road to Rio: Green is not enough." *United Nations Development Programme*. The United Nations Development Programme, 27 Mar 2012. Web.

[100] Zhou, Yuan. "Smallholder Agriculture, Sustainability and the Syngenta Foundation." *Syngenta Foundation for Sustainable Agriculture.* Syngenta Foundation for Sustainable Agriculture. Apr. 2010. Web.

livelihoods vary significantly. However, conditions are often resource-poor, technology and purchased inputs are often limited, and family labor is often relied on.[101]

Historically, smallholder farming has been practiced extensively in most parts of the world. However, the majority of current smallholder farms are located in the rural developing world. This paper focuses only on smallholder communities in the developing world, most of which exist in rural parts of Asia, Africa and Latin America.[102]

Climatic and land conditions in smallholder agriculture areas

The geography and climatic conditions vary greatly in these regions; however, much of the land area that is cultivated with smallholder agriculture is tropical or subtropical. Distinct tropical climatic categories include the tropical rainforest climate, which is characterized by year-round precipitation; the tropical monsoon climate, which is characterized by defined wet and dry seasons and heavy rains; and the tropical wet and dry climate, which is characterized by an especially pronounced dry season and overall lower annual precipitation.[103]

Climate and land conditions in these regions often bring with them poor agricultural conditions (discussed below), making it difficult for many smallholder farmers to sustain their livelihoods, evidenced told by high poverty rates for rural farmers (discussed in the Introduction).

The changing climate and other unchecked environmental problems are only worsening their difficulties by increasing the severity of climate conditions such as droughts. According to Yuan Zhou, climate change will disproportionally effect damage in tropical and sub-tropical latitudes. "Predictions from crop-climate models show that in tropical countries even moderate warming can reduce yields significantly, because many crops are already at the limit of their heat tolerance."[104] Struggling farmers often see no other option but to use unsustainable practices in order to get food on the table for the short-term. These practices only exacerbate the problems they face.

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[101] "Smallholder Mapping and Characteristics." *Syngenta Foundation for Sustainable Agriculture.* Syngenta Foundation for Sustainable Agriculture, 2013. Web.

[102] Zhou, Yuan. "Smallholder Agriculture, Sustainability and the Syngenta Foundation."

[103] McKnight, Tom L and Darrel Hess. "Climate Zones and Types: The Köppen System." *Physical Geography: A Landscape Appreciation.* Upper Saddle River, NJ: Prentice Hall, 2000. Print. pp. 205–211.

[104] Zhou, Yuan. "Smallholder Agriculture, Sustainability and the Syngenta Foundation."

Land and soil degradation in the smallholder context

Within the abovementioned world regions, this paper focuses on smallholder communities where biochar would bring the greatest benefits – places that face land degradation issues and have nutrient poor soils and/or low rainfall.[105] These poor agricultural conditions are commonplace in many of the world's developing countries with high rates of rural smallholder agriculture.

Land degradation

The largest, most general issue that many smallholder farmers around the world face is land and soil degradation. Within this umbrella lies a host of specific problems and negative consequences, which are explored below. Land degradation refers to a given land's impaired capacity to function. In the case surrounding smallholder agriculture, soils are the "critical component" that face degradation.[106] Up to 40 percent of the world's agricultural land is degraded, and this proportion continues to increase.[107] Figure 7[108] shows the severity of land degradation in different parts of the world. Asia has the largest affected area, with about 550 million hectares of degraded land. An estimated 500 million hectares of land in Africa, including 65 percent of the continent's agricultural land, have been

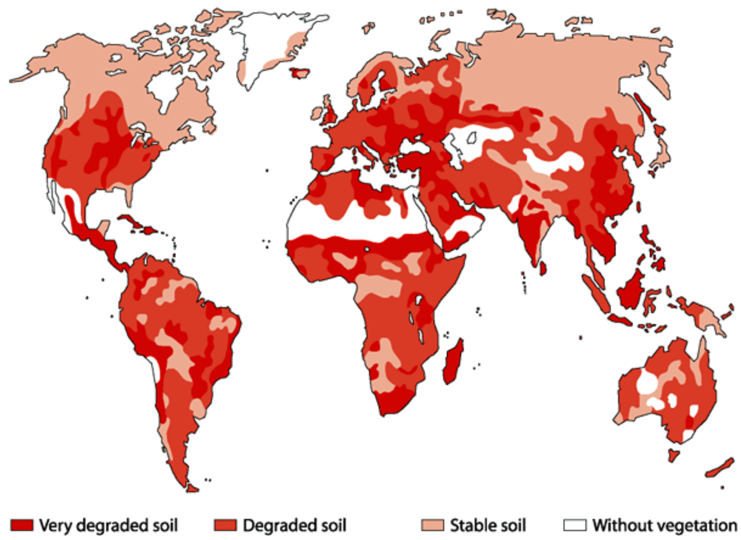

Figure 7. A map showing severity of land degradation around the world

[105] IBI "Biochar Use in Soils."
[106]Johnson, D.L. et al. "Meanings of environmental terms."
[107] "GEF Focal Area: Land Degradation." Global Environment Facility. 2013. Web.
[108] Photo source: http://www.grida.no/

degraded since 1950. About 300 million hectares of land in Latin America have been degraded.[109]

Soil degradation causes problems not only for individual farmers (and their livelihoods) but also for entire economies. For example, it is estimated that between 4 and 12 percent of Africa's entire GDP is lost due to environmental degradation, much of which is agricultural land degradation.[110] It is also estimated that land degradation's global costs "correspond to 3 to 5 percent of the global agricultural GDP."[111] Overall, around 40 percent of global land degradation occurs in the world's most impoverished areas, most of which are rural.[112] As land resources become less productive, food insecurity rises.

Nutrient and Organic matter Leaching
Most tropical soils are especially prone to leaching (described in Chapter 2) due to a number a factors including high incidence of rainfall and poor soil structure. The leaching is detrimental not only the soil organic content but also to microorganism communities.

Erosion
When deforestation occurs, the structures that keep soil in place (via protection from the elements and root structures) are eliminated, often leading to erosion of topsoil. Topsoil is critical to crop cultivation.

Decreased soil resilience
Many lands face both leaching and flooding while others face drought and parching. Some face both at different times of year. Without native plant cover to protect the land, extreme weather conditions (which are becoming more common as climate change occurs) can devastate harvests.
Land degradation reduces the resilience of soils and their ability to sustain crops through extreme conditions. For example, structural issues will reduce the soils' abilities during moisture shortages (droughts) or excess moisture periods (monsoons), as discussed in Chapter 2.

Figure 8. Agricultural issues faced by smallholder farmers and exacerbated by land degradation

Smallholder context: poor agricultural conditions are exacerbated by land degradation

There are six general categories of soil degradation: water erosion; wind erosion; water logging and excess of salts; chemical degradation; physical degradation; and biological degradation.[113] Smallholder farmers may face any combination of these issues, which can be caused by many different factors.

[109] "Tackling land degradation and deforestation." *The International Fund for Agricultural Development.* The International Fund for Agricultural Development, 18 Dec. 2013. Web.
[110] Ed. Ammann, Walter J. "Background Document: The Economics of Desertification, Land Degradation and Drought: Methodologies and Analysis for Decision-Making." 2nd Scientific Conference. United Nations Convention to Combat Desertification. Bonn, Germany. Web.
[111] Ed. Ammann, Walter J. "Background Document: The Economics of Desertification, Land Degradation and Drought: Methodologies and Analysis for Decision-Making."
[112] "TST Issues Brief: Desertification, Land Degradation and Drought." United Nations Department of Economic and Social Affairs, Division for Sustainable Development. Web.

Common causes include land clearance, soil nutrient depletion due to poor agricultural practices, and livestock overgrazing.[114]

Specific common problems faced by smallholder farmers include topsoil erosion; flooding; nutrient and organic matter leaching; soil parching and desertification; weakening of soil structure; loss of soil nutrients and carbon content; loss of organic matter and loss of important microorganisms. Some of these are discussed in further detail in Figure 8 (previous page).

All of these issues contribute to a fast decline in the productive capacity of the land, causing diminishing crop yields – often land can only be farmed for 2-3 years. These issues occur in different combinations and severities in different locations, but the majority of smallholder farmers face degradation problems. Land degradation issues that affect smallholder farmers are often caused by a combination of factors, of which deforestation; climate and geographical conditions; and agriculture practices are strong contributors. However, areas with traditionally poor soils are especially prone to degradation effects in the first place, as discussed in Figure 9.[115],[116],[117]

Humid Rainforest Climates
Soils in the humid rainforest climates are often acidic and nutrient poor[1] (as previously discussed regarding the infertile Amazonian soils surrounding the *terra preta* sites). Many are sandy and have poor structural stability.[1] Nutrient leaching is a widespread problem in humid tropical agriculture.

Dry Tropical Climates
Meanwhile, in dryer tropical climates, the hot sun, low moisture delivery, and periods of drought make it difficult for thirsty crops to survive, especially when soils don't have good moisture holding capacity. Parching of soils via heat exposure can worsen their structure and destroy microbial communities.

Figure 9. Traditionally poor soils are especially prone to degradation effects.

Land transformation

Land often goes through several phases as it goes through the degradation process. In this context, most farmlands originate as forest, which is then deforested to make room for crops. Another rampant cause of deforestation is demand for biomass cooking fuel,

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113 "Chapter 3: Land degradation" FAO. Web.
114 "Land Degradation and Soil Erosion" City of Cape Town. 2012. Web.
115 Tiessen, H., E. Cuevas, and P. Chacon. "The role of soil organic matter in sustaining soil fertility." *Nature* 371. (Oct 27,1994): 783-785. Web.
116 Blanchart, E. et al. "Organic Matter and Biofunctioning in Tropical Sandy Soils and Implications for its Management." FAO. 2007. Web.
117 "Effects of Deforestation." Satellite Events Interprises Inc. 1999. Web.

which will be discussed in a later section. Once deforestation occurs and the land is no longer protected, it becomes vulnerable to different types of land degradation (described above), especially when the lands are deliberately kept clear for farming. Poor soils in deforested areas are often depleted of nutrients after just a few crop seasons. Due to the clearance of vegetation, these soils no longer have any natural source of nutrients or organic matter, so recovery is an extremely slow process and can take generations.[118]

FOREST
⇓
FARM
⇓
PASTURE
⇓
DESERT

Figure 10. Common land progression to desertification.

Unfortunately, depleted and degraded farmlands are not often given the chance to recover. Instead, smallholder farmers commonly turn their farmland into pasture when it will no longer yield crop, because they still need to make a living. Eventually, the land gets too degraded to support pasture (due to overgrazing). In dryer areas, this land often turns into desert. Figure 10 illustrates this common phenomenon, known as *desertification.* Twelve million hectares of arable land are lost to desertification each year (and the rate is increasing),[119] forcing many farmers to choose between migration and starvation. Desertification disrupts natural water and nutrient cycles, causes dust storms and water sedimentation and reduces resilience to climate variation. It also exacerbates and lengthens droughts and famines.[120] Figure 11[121] shows a world map of where desertification occurs, and

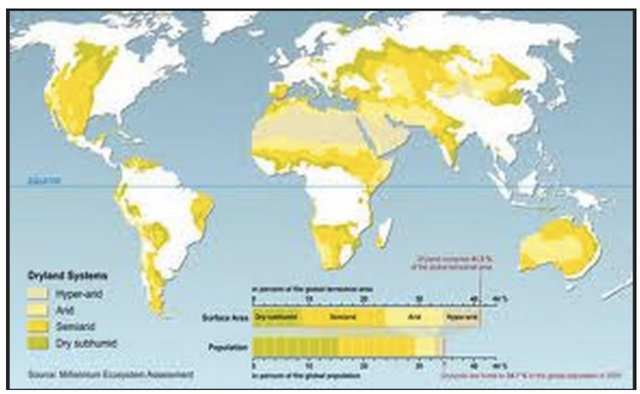

Figure 11. World map showing areas where desertification occurs.

In wetter areas, this land often suffers greatly from erosion. Either way, these land transformations result in a loss of arable land. The current annual loss of arable land is

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118"Effects of Deforestation." Satellite Events Interprises Inc.

119 Raihan, Selim, Sohani Fatehin, and Ifthekharul Hague. "Access to land and other natural resources by the rural poor: the case of Bangladesh." June 2009. South Asian Network on Economic Modeling (SANEM), Department of Economics, University of Dhaka, Bangladesh. Web.

120 Raihan, Selim et al. "Access to land and other natural resources by the rural poor: the case of Bangladesh."

121 Image credit: awcungeneva.com.

over 38,610 square miles per year (out of 12 million square miles of arable land on Earth), which has negative implications for the future of food security.[122] When previously cultivated land is lost, farmers must find new land to cultivate (if possible) in order to sustain their livelihoods. This progression often leads to unsustainable agricultural practices that perpetuate land degradation and transformation.

Smallholder agriculture practices contribute to land degradation – A couple examples

Modern smallholder farmers practice different techniques depending on many varying factors such as location, traditions and crops. Most do not have access to modern first world farming technologies. In general, smallholders usually cannot afford much (if any) high quality agricultural land, and they face the degradation problems described above.

For this reason, their yields are fairly low and it is "necessary for them to collectively cultivate a larger total area." Much of this land is often marginal and subject to bad erosion.[123] These conditions make it difficult for smallholder farmers to sustain their livelihoods, and their decision-making often aims for short-term sustenance and risk minimization. This often results in unsustainable agricultural practices that are detrimental to the environment and their long-term livelihoods. This section presents a few examples of common unsustainable agricultural practices.

Shifting cultivation

This method is especially common in tropical areas due to the poor soil fertility mentioned above. In 1996, it was estimated that shifting cultivation supported the livelihoods of 300-500 million people.[124] Crops are grown in a patch of cleared land. However, after a few to several years, the soil is no longer productive. At this point, cultivation of that patch is terminated and a new patch of land is cleared and used to continue cultivation.[125]

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[122] Guffanti, Rich. "Chapter 1: Science & the Environment."
[123]Tinsley, Richard. "Smallholder Agriculture." 2006. Web.
[124] Brady, N. (1996). Alternatives to slash-and-burn: a global imperative. Agriculture, Ecosystemsand Environment, 58 (1), 3-11. Web,
[125] Nair, PK Ramachandran. An introduction to agroforestry. Springer, 1993. (55-63). Web.

Methods of shifting cultivation vary. For example, *cyclical farming practices* involve long fallow periods but eventual return to planting the same patches of land after regeneration. Unfortunately, regeneration of a depleted field can take generations in poor, tropical soils, especially if intensive farming strategies were employed. [126]

Modern intensive farming leaves soils depleted for long periods of time, and although cyclical farming has been practiced sustainably in the past (and is still sustainable in some cases), many of the modern shifting cultivation practices are no longer sustainable. Fallow patches of land are often put to use again before fully recovering, due to economic pressures. This causes permanent soil degradation, further land transformation and additional deforestation.[127]

The *slash and burn* strategy is similar to and often used in shifting cultivation. While there are many variations of slash and burn strategies, the basic idea is to clear and burn areas of forest for planting. When yields on a current cultivated patch decrease, another patch of forest is burned in order to have a fresh new tract of land to cultivate. The ash from the recent burns provides temporary fertilization. The old, depleted patch is abandoned or turned to pasture, subjecting it to further depletion and degradation. Unfortunately, with most current slash and burn practices in tropical areas, the newly burned patches of land produce good yields for only a couple of years, and then farmers must move on again to slash and burn more forest. This practice causes rapid deforestation, diminishes important forest resources, and releases high amounts of greenhouse gases into the atmosphere.[128]

Traditional charcoal use

As previously discussed, traditional agricultural charcoal use does still exist in some smallholder communities. However, traditional agricultural charcoal production practices

[126] Nair, "An introduction to agroforestry."
[127] Prasad, Ambika. "5 Major Causes of Deforestation in India." PreserveArticles.com. 2012. Web.
[128] "Slash-and-burn Agriculture." Encyclopedia Brittanica. Web.

release a large quantity of harmful emissions including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO).[129] They also often use forest resources.

Fertilizer use

When affordable, fertilizer use (in some places encouraged and subsidized by the government) is used as a quick-fix input to increase crop yields. While chemical fertilizers can greatly increase yields, unfortunately, results are only temporary. Fertilizer must be reapplied annually, and even when reapplied, many of the nutrients may not reach the plants when they need them due to leaching. Fertilizer use can also weaken the soil structure and damage soil life.[130] While chemical fertilizer application may help farmers sustain their livelihoods in the short term, they do not provide a long-term remedy to land and soil degradation issues.

The smallholder livelihood

Although the poor agricultural conditions described above greatly contribute to the hardships smallholder farmers face, these issues are interconnected with many other problems and events that have also contributed to the difficult livelihoods faced by smallholders. This section will discuss the typical smallholder livelihoods and some of the factors that influence them.

A bit of history: the effect of the agricultural revolution and globalization on rural smallholder farmers

While the modern agricultural revolution penetrated the developed world and parts of the developing world, it did not reach many farmers in the developing world – especially rural smallholder farmers. The agricultural revolution led to a widespread fall in world agricultural prices – not only of surplus products, but also of tropical export commodities due to new substitutes that were being mass-produced in developed countries (for

[129] Pennise, D. M., et al. "Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil" *Journal of Geophysical Research: Atmospheres (1984–2012)*, Volume 106, Issue D20, pages 24143–24155, 27. October 2001. Web.

[130] "A Word About Soil Structure." Petrik Laboratories Inc. No Date. Web.

example, in the last 100 years, the real price of sugar has fallen by over two-thirds and the real price of rubber is one-tenth of what it used to be).[131]

Due to limited capital and accessibility, many rural smallholder farmers were (and still are) unable to invest in the modern agricultural technology (which included mechanization, special crop varieties etc.) and therefore unable to achieve significant productivity gains. Unfortunately, the falling crop prices affected these farmers too, greatly impacting their incomes and subsequent purchasing power. This left them incapable of investing in updated farming equipment or useful inputs – effectively blocking their development and bringing many of them below the "economic renewal threshold" – "their cash income is no longer sufficient to renew farm tools and inputs, to buy the few vital consumer goods they cannot produce themselves and…to pay taxes."[132]

Current effects

The resulting deterioration of farm equipment, diet and health is detrimental to the farmers' livelihoods and work capacity. This causes their focus to shift to short-term returns and away from maintaining the "cultivated ecosystem." This is the point at which farmers resort to unsustainable agriculture practices, as discussed above. This also leads to the simplification of farming systems, reducing crop diversity and quality and further increasing crop vulnerability in the already degrading land.[133]

The above history demonstrates the interconnected nature of agricultural, social, economic and environmental issues faced by smallholder communities. While livelihood circumstances of smallholder farmers vary around the world, the effects of the agricultural revolution and resulting price drops (which are still occurring) influence rural smallholder communities worldwide. Other livelihood influences include national and local politics, environmental and land conditions, local infrastructure, market access, and land holding laws, among others.[134]

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[131] Mazoyer, Marcel. "Protecting Small Farmers and the Rural Poor in the Context of Globalization." Food and Agriculture Organization of the United Nations. 2001. Web.
[132] Mazoyer, "Protecting Small Farmers and the Rural Poor in the Context of Globalization."
[133] Mazoyer, "Protecting Small Farmers and the Rural Poor in the Context of Globalization."
[134] Mazoyer, "Protecting Small Farmers and the Rural Poor in the Context of Globalization."

Poverty traps

The theory of poverty traps suggests the existence of "self-reinforcing mechanisms" that cause the persistence of poverty.[135] According to Jeffrey Sachs,

> The poor start with a very low level of capital per person, and then find themselves trapped in poverty because the ratio of capital per person actually falls from generation to generation. The amount of capital per person declines when the population is growing faster than capital is being accumulated ... The question for growth in per capita income is whether the net capital accumulation is large enough to keep up with population growth.[136]

Sachs argues that health problems and lack of capital and knowledge (e.g. about the benefits a certain behavior or choice will bring) that the impoverished suffer spoil their potential to rise out of poverty. He argues that aid is necessary to lift them out.[137] On the other hand, William Easterly argues that aid creates a culture of dependency that causes the poor to remain poor.[138] Regardless of this debate, it is important to be aware of the poverty trap concept when looking at the current situation of smallholder farmers around the world.

As previously discussed, a large proportion of rural smallholder farmers live in poverty. They have very little capital – many can't even afford cheap inputs. The effect of the agricultural revolution has caused generational decreases in the ratio of capital per person, and this has been exacerbated by worsening land degradation leading to lower productivity, food insecurity, and health issues (which will be discussed below).

Although poverty traps are not a central theme of this paper, they are very relevant to development projects and diffusion. It is worth noting that Abhijit Banerjee's and Esther Duflo's book, "Poor Economics," shows that delivery mechanisms can drastically change outcomes of development and aid projects.[139] In one of their studies, fertilizer use by Kenyan farmers was increased by 50 percent solely due to a change in delivery method. The farmers would not buy half-price fertilizer at sowing time, but would buy full-priced

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[135] Costas Azariadis and John Stachurski, "Poverty Traps," Handbook of Economic Growth, 2005, 326.
[136] Sachs, Jeffrey D. *The End of Poverty.* Penguin Books, 2006. Print. P. 244
[137] Sachs, *The End of Poverty*.
[138] Easterly, William. *The white man's burden: why the West's efforts to aid the rest have done so much ill and so little good*. Penguin. 2006. Web.
[139] Banerjee, Abhijit and Esther Duflo. *Poor economics: A radical rethinking of the way to fight global poverty.* PublicAffairs Store, 2011. Web.

fertilizer vouchers right after the harvest. The reason was that they had enough money directly after the harvest, but not enough savings left to afford fertilizer at sowing time.[140]

This finding is quite relevant to the success of biochar system diffusion in rural, impoverished smallholder communities, because it speaks directly to the importance of design and diffusion strategy. Decca Aitkenhead sums up this important takeaway from "Poor Economics": "When aid is carefully designed to navigate the specific socio-cultural landscape of its recipients' lives, it begins to deliver the sort of results Sachs claims."[141][142]

Cooking methods

While specific cooking methods vary by tradition, most smallholder communities use the same general heating strategy. Around three billion people worldwide, most of whom are poor and live in developing countries, burn biomass (e.g. wood, charcoal, dung) to cook and heat their homes.[143] They use open fires or simple stoves, of which there are many variations. This practice – which is the only choice for most who use it – is problematic in multiple ways.

Environmental impact

Fuel wood collection is a significant cause of deforestation in many locations around the globe (e.g. Haiti, India), contributing to environmental problems and exacerbating land degradation problems. The inefficiency of the fuel use requires large amounts of fuel for each meal.

Also, these fires and stoves, which are generally used at least twice a day for meals, result in inefficient combustion of biomass that causes particulate emissions, also known as "soot" or "black carbon". These emissions contribute to Atmospheric Brown Clouds (ABCs), which are now recognized by the UN Environment Program as a major contributor to

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[140] Banerjee and Duflo, 191-194.
[141] Aitkenhead, Decca. "Abhijit Banerjee: 'The poor, probably rightly, see that their chances of getting somewhere different are minimal.'" *The Guardian*. Sunday April 22, 2012. Web.
[142] Banerjee and Duflo.
[143] "Indoor air pollution and health." World Health Organization. September 2011. Web.

climate change.[144] Some people use charcoal for fuel, but the charcoal is made using traditional methods with high greenhouse gas emissions.

Time consuming or costly

In most smallholder communities, women are responsible for procuring fuel. Firewood collection often takes a significant amount of their time, and it can also cause physical stress and other risks, depending on the situation. Some people buy their fuel, but high prices often render this option unaffordable for many of the rural poor. Because the fires and stoves are inefficient, women spend a lot of time cooking – time when they could be doing other things.

Health impacts

The cooking often happens indoors, and as previously mentioned, the fire and stove emissions are highly polluting and quite harmful. This is causing a rampant indoor air pollution problem that disproportionately affects women and children, because they spend more time by the cook fire. Homes often fill with smoke, during cooking, as shown in Figure 12,[145] a photo taken of a traditional stove in India during a biochar stove diffusion project. According to the World Health Organization, around 2 million people die prematurely each year due to illness caused by indoor air pollution from household solid fuel use; around half of child (under five-years-old) pneumonia deaths are caused by inhalation of particulate matter from indoor air pollution; and over 1 million people die annually due to chronic obstructive pulmonary disease (COPD) that develops because of indoor air pollution exposure.[146]

Figure 10. Traditional cookstoves are very smoky.

[144] V. Ramanathan, et al. "Atmospheric Brown Clouds: Regional assessment report with focus on Asia, Summary." United Nations Environment Program, 2008. Web.
[145] Photo credit: N. Sai Bhaskar Reddy (via Picasa).
[146] "Indoor air pollution and health." World Health Organization. September 2011. Web.

Even though current cooking methods in smallholder communities are harmful to the people in many ways, including direct health consequences and daily discomfort, billions of people use these harmful stoves. This is because many people do not have access to non-biomass cooking methods. Gas stoves are a higher initial investment, and are often cost prohibitive for smallholder farmers (if they even know about them). Rural smallholder communities may not have the infrastructure, market accessibility (for fuel) or resources needed to support a cooking technology with an alternative fuel source. The current cookstoves used by smallholders – and their consequences – are tightly tied in to a web of common smallholder problems shown in Figure 13 at the end of this chapter.

Risks

As we have seen, smallholder famers face many risks. Agricultural risks (bad yields, crop failure, crop disease etc.) are worsened by soil and land degradation issues. Agricultural risks are often food security risks for smallholder farmers who produce their own food. Health risks are worsened by indoor air pollution (as well as lack of public health infrastructure, sanitation systems, etc.). Many risk factors are completely outside of their control, including weather, pests, disease, and volatile crop prices.[147]

Smallholders often lack access to insurance and other risk management strategies, and facing a shock can cause devastation to families that don't have much to begin with. Because of this, poor farmers usually try to avoid risks when making decisions.

Land tenure

Although land tenure will not be explored in depth in this paper, it is an important factor to be aware of – land tenure systems can have a large influence on the outcomes of development projects. Access to land and land tenure security is an important factor in the decision making of poor, rural people, such as smallholder farmers.[148] For example, smallholder farmers would not be inclined to make a long-term investment (e.g. biochar application) in their land if it might not be their land in five years.

[147] Gradl, Christina, et al. "Promising Agribusiness."
[148] "Rural Poverty in the Developing World." United Nations Publications. N.d.

> Issues of land access and security of land tenure strongly influence decisions on the nature of crops grown, whether for subsistence or commercial purposes. Such issues also influence the extent to which farmers are prepared to invest (both financially and in terms of labor) in improvements in production, in sustainable natural resources management, and in the adoption of new technologies and promising innovations.[149]

Land can also be an important aspect of social and cultural identity. It is important to understand the functioning of a local land tenure system. Especially with agriculture-based activities, specific functioning of land tenure systems often determines how benefits are divided.[150]

Environmental Problems

There are several environmental problems (most of which have been previously mentioned) that are tightly linked with smallholder communities. Many of these problems both affect and result from the smallholder lifestyle. It is important to also acknowledge the variety and extent of harm to the natural environment that results from the smallholder situation.

Deforestation and loss of vegetation is a huge environmental problem that has strong linkages with smallholder communities, who both suffer from it and contribute to it. It is caused mainly by fuel collection, agricultural practices, and outside forces, and results in a loss of biodiversity and valuable ecosystems. It simultaneously harms smallholder agriculture in many ways, one of them being the resulting land degradation and reduction of ecosystem services. Deforestation can also cause permanent local climate change that increases and exacerbates extreme whether conditions such as droughts and floods.[151] Permanent land change such as desertification can result as well.

In terms of emissions, deforestation and poor soil management themselves greatly contribute to the greenhouse gas emissions that are speeding up climate change.[152] Inefficient combustion from biomass burning is also a large contributor to atmospheric brown clouds. There are also many more specific local or regional level environmental

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[149] "Rural Poverty in the Developing World." United Nations Publications.
[150] "Rural Poverty in the Developing World." United Nations Publications.
[151] Bagley, Justin E. et al. "Drought and Deforestation: Has land cover change influenced recent precipitation extremes in the Amazon?." *Journal of Climate* 2013 (2013).
[152] Johnson, Toni. "Deforestation and Greenhouse-Gas Emissions." Dec 2009. Council on Foreign Relations. Dec 2013.

issues that occur in smallholder communities throughout the world. The impacts of global environmental degradation and climate change also have an impact on smallholders.

Problem Mitigation Techniques

Many techniques can be used to improve upon previously discussed smallholder agriculture problems and practices. Some of these including tree planting or using specific cover crops to restore ecosystems and combat land degradation, erosion and drought frequency; alternative sustainable agricultural systems such as organic farming, conservation tillage farming, and agroforestry; and strategies such as polyculture cropping, crop rotation, cover cropping, using certain crop varieties in certain places, composting and integrated pest management.

All of these strategies have value, and in the approach to improving smallholder agricultural situations, the diffusion of one technique should not exclude the possibility of another (unless they are substitutes or will not work well together). In fact, many of the techniques mentioned above would work well with each other, and perhaps with biochar as well. The context and content of this paper should not exclude the above possibilities in the event of biochar diffusion. However, it is important to note that many of the above strategies take a long time to deliver results (e.g. tree planting encourages indirect soil development), and are likely to seem fairly uncertain to farmers who are living on the margin. Also, many of them would only be viable or beneficial in certain locations and situations.

Smallholder communities have many interconnected issues

This chapter discusses many factors that influence the lives of developing world rural smallholder farmers and their communities. Figure 13 below depicts a complicated web of interconnected smallholder issues, many of which perpetuate themselves or each other. While many different social, economic and environmental factors affect the livelihoods of smallholder farmers, it is clear that the poor agriculture conditions described above play an influential role in the problems smallholder farmers face. When it comes down to it, smallholder farmers depend on agriculture for survival. Therefore, it is vital to address issues such as land degradation that are contributing to the unsustainable nature of their livelihoods.

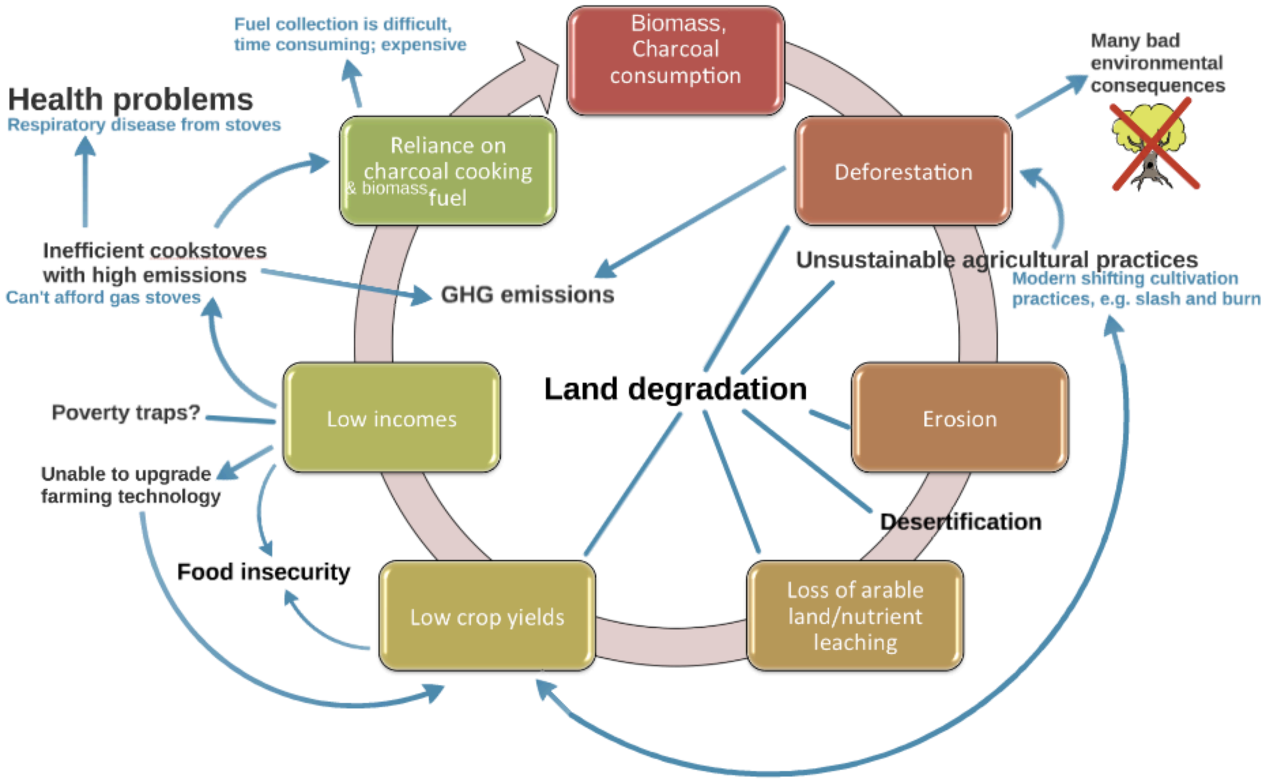


Figure 11. Smallholder communities face a web of interconnected issues.

Chapter 4: Smallholder Agriculture and Biochar: What is the Potential? What are the Barriers?

Situation: Problems faced by many smallholder farmers

As discussed in the previous chapter, smallholder farmers around the world face many different kinds of challenges and obstacles, some of which are exacerbating as time continues and resources are depleted. Land and soil degradation are some of the biggest threats to their livelihoods, which depend on their ability to grow food to eat and (in many cases) sell crops for a small amount of needed cash. Current practices of wood and charcoal use for cooking and heating also negatively effect their livelihoods in a number of ways, leading to health (specifically respiratory and eye) problems; increased deforestation (and worsening land degradation); high amounts of time and effort spent on fuel collection and cooking; and increasing fuel costs resulting in economic strain (for those who buy their fuel); among other things. In many cases, these issues and the farmers' resulting actions exacerbate the very problems they are dealing with. These major difficulties (among other local issues) faced by smallholder communities are worsening as time continues. Their influence on the future of food security and the earth continues to grow as vast amounts of once-arable land are rendered permanently destroyed.

In the meantime, the natural environment is facing ongoing and quickening destruction. In addition to the myriad harmful consequences of deforestation on the ground, emissions from deforestation and inefficient biomass burning are joining the greenhouse gases in the atmosphere in speeding up climate change.

Some land degradation remedies mentioned previously (such as tree planting, agroforestry, etc.) have been adopted in some places. However, none of these remedies have been successfully diffused on a widespread basis to smallholder communities around the world. There is a need for a fast-acting, long-lasting, agriculture-based remedy that is adoptable by smallholder farmers. The system surrounding it should comprehensively address social, economic and environmental smallholder issues.

Looking toward biochar systems

The overarching question is: **Can we effectively address the smallholder issues described in Chapter 3 using biochar systems?**

To answer this question, there are a number of more specific questions we must investigate.

Could biochar be a useful and widespread remedy for the land degradation problems faced by smallholder farmers?

When looking at the problems both faced and contributed to by smallholder agriculture alongside our current knowledge of biochar and its history, there appear to be certain compatible themes. Farmers struggle with soil degradation; biochar appears to be especially effective at bettering poor, degraded soils. Yields are meager due to leaching of nutrients from soil; biochar can aid in nutrient retention. Poor soils will yield crops for only a couple years before declining; biochar can boost fertility and keep the same land workable for many years on end. Droughts shorten seasons and reduce crop yields around the world; biochar can aid in moisture retention. Farmers struggle to make their depleted soil feed their hungry crops; biochar promotes and harbors beneficial microorganisms and fungi. Amazonian soils can barely produce intensively cropped yields for more than two years in a row, *terra preta* soils continually yield healthy, good yields.

With biochar, as opposed to short-term input "solutions" such as fertilizer application or slash-and-burn, one need not race a clock to get more money for fertilizer each year or to try to find more land to burn and cultivate. Biochar delivers observable benefits immediately (as discussed in Chapter 2), while also bringing long-term benefits that may last for hundreds to thousands of years (as evidenced by *terra preta* and scientific studies). Biochar's permanent improvements (refer to Chapter 2), result in ongoing benefits, including continuous cultivation with plentiful yields as well as the buffering of extreme weather events and conditions, in some cases saving entire harvests; for example, biochar's adsorption capacity and moisture retention may pull a season's crops through a drought period. Biochar's permanent improvements to soils have the potential to greatly reduce the need to deforest for cropland or use damaging, short-term inputs.

In addition to scientific evidence and field trials that demonstrate biochar's beneficial effects, the history of *terra preta* and its great impact on the pre-Columbian Amazonian societies is further evidence that biochar can be useful to remedy many agricultural problems faced by smallholder farmers.

A simple answer is *yes – biochar could be a useful remedy for the land degradation problems faced by many smallholder farmers*. However, being a *widespread* remedy depends on many more factors, including success in diffusion of biochar systems.

It must be remembered that land degradation is interconnected with many other problems (as discussed in Chapter 3). Beyond looking at biochar as solely a soil remediation tool, it is important to investigate other benefits that biochar systems have the potential to integrate, and the benefits these systems as a whole could bring to smallholder agriculture communities.

Chapter 4.1: Biochar System Technologies and Methods for the Smallholder Context.

Are there biochar technologies that fit and can be diffused to the smallholder context? What can they do?

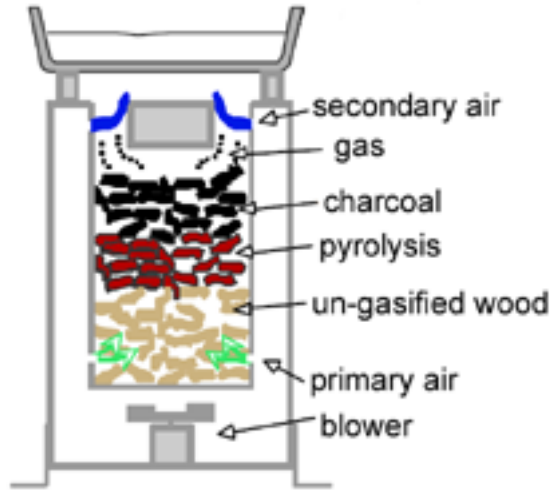
Is anyone working on this type of stuff?

Indeed, some people have indeed turned their attention to biochar systems for the purpose of remedying some of the many interconnected problems that are common in smallholder communities. The past decade has seen tremendous growth in interest and execution of smaller-scale, developing world context biochar projects. Chapter 5 presents and analyzes three different case studies of current biochar system diffusion projects in the developing world smallholder context. These case studies look at NGO-run biochar-related projects in smallholder communities in Haiti, Costa Rica and India.

Smallholder context biochar system technologies

Several types and variations of biochar technologies have been developed with intention for use in the rural smallholder community context. Due to many circumstances discussed in Chapter 3, these technologies must be cheap, easily made, and preferably producible from locally sourced materials. This section introduces a few different technologies that are used in the Chapter 5 case studies. All[153] of the technologies that are incorporated and fundamental to the biochar systems in the Chapter 5 case studies use Top-Lit Updraft (TLUD) gasification, which was described in Chapter 2 and is pictured in Figure 14.[154]

Figure 124. Diagram showing the processes within a TLUD gasification cookstove.



Biochar cookstoves

Biochar cookstoves are a central component to the projects in Costa Rica and India. There are many different designs and variations of biochar cookstoves, but most use TLUD gasification technology. They use biomass as fuel, which is put inside of the stove chamber. It is then pyrolyzed (turned into biochar) during the cooking process (due to controlled oxygen flow). The pyrolysis gases from the biomass are burned at the top

Figure 15. The Estufa Finca cookstove from the Costa Rica project.

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153 Note: The India project also uses methods other than TLUD gasification because they have many different stove models. However, many of their stoves use TLUD gasification, which is by far the most common small-scale biochar production process (and is the only process described in this paper).

154 Figure credit: International Biochar Initiative.

of the stove, creating a clean flame for cooking. After cooking each meal, the biochar can be emptied for later use. Different stove designs fit different biomass waste materials (e.g. local agricultural residues) to be used for fuel, and designs can be modified to meet specific cooking needs.

Due to the TLUD technology, emissions are greatly reduced from traditional stoves. For example, laboratory testing of the stove used in the Costa Rica Estufa Finca project showed reductions in particulate matter emissions by 92 percent and in carbon monoxide emissions by 87 percent compared to an open cooking fire.[155] The Estufa Finca stove is pictured in Figure 15[156] on the previous page.

Figure 16. The Magh CM Laxmi biochar cookstove, one of the stoves used in the India case study

The stoves are also more fuel-efficient, so fuel collection time (or money spent on fuel) is reduced. The Costa Rica project did pilot testing that yielded a fuel use drop of 40 percent for beans and 71 percent for chicken.[157]Because biomass waste can be used, fuel is often readily available for farmers, and cooking can be a means of disposing of waste. The improved efficiency of the stoves and use of biomass waste is an alternative to deforesting for cook fuel. Cooking time is also reduced. The Costa Rica project pilot tests showed an average cook time reduction to be between 31 and 47 percent, depending on food type.[158] This gives women more free time to do other things.

Figure 16[159] shows another biochar cookstove example from the India "Good Stoves" project. This stove can take any type of biomass fuel.

155 Stacey Schultz. "Biochar Cookstoves Boost Health for People and Crops." National Geographic News. January 29, 2013. Web.
156 Photo credit: Art Donnelly (via Picasa).
157 Tom Ternes, Susan Bolton, Art Donnelly. "Estufa Finca—Santos Pilot Project Results Report." April 8, 2011. SeaChar.org. Web.
158 Ternes, Bolton and Donnelly. "Estufa Finca—Santos Pilot Project Results Report."
159 Photo credit: Sai Bhaskar Reddy (via Good Stoves website).

Scalable Biochar TLUD Ovens and Retorts

Biochar ovens are used by all three NGOs. They are great for scaling up the production of biochar, because with sole use of cookstoves for biochar production, it would take quite a long time for one stove to produce a significant amount.

A standard, design for the smallholder context that can often be locally sourced using a 55-gallon drum, a piece of sheet metal, and a chimney fashioned from corrugated metal, as pictured in Figure 17.[160] These materials can usually be acquired quite cheaply in developing countries, and assembly takes only a matter of a couple hours. This design uses the same TLUD technology described above. Primary air enters through the bottom, and secondary air usually enters near the top of the drum. A chimney is used to flare the pyrolysis gases (rather than flaring them at the top of a cookstove) and create a natural draft (other models create draft using blowers). There are many variations of technology.

According to International Biochar Initiative, a standard 55-gallon drum unit typically produces about 8 to 12 kilograms of biochar per batch.[161] Generally, these kilns yield a mass of biochar that is 20-30% of the original feedstock mass. Batches take from 1-4 hours. If multiple ovens are run multiple times per day, biochar can amass fairly quickly for a small-scale situation. This design can also be scaled up by using two 55-gallon drums in the "Jolly Roger Oven" or "J-RO" design, as pictured in Figure 18[162].

Figure 17 (right): A TLUD oven used in the Haiti case study project.

Figure 18 (left): A scaled up biochar oven used in the Costa Rica case study project.

A variation on this technology that use similar materials is called a biochar *retort*. The difference is that the biomass is inside an enclosed chamber, so it is never lit on fire. To achieve this, a 30-gallon inner drum can be added to the oven design described above. Heat from the fire outside

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[160] Photo credit: Carbon Roots International (via website).
[161] "Biochar Production Units." *International Biochar Initiative*. International Biochar Initiative, 2013. Web.
[162] Photo Credit: Art Donnelly (via Picasa).

the enclosed chamber heats the biomass and its pyrolysis gases escape and are burned outside the chamber. No oxygen enters the inside chamber; only pyrolysis occurs. Some hybrid TLUD-Retort models have been developed, combining the two methods.[163]

Green charcoal briquettes

Due to demand for cheaper charcoal cooking fuel, the Haiti project uses biochar produced in TLUD retorts to make compacted charcoal briquettes for cooking. These briquettes are used as replacement for regular cooking charcoal – they can be dropped right into traditional stoves. The char they are made from is produced from agricultural waste, substituting for deforested fuel. The briquettes are also cheaper than regular charcoal, and they burn cleaner and hotter, shortening the time required to cook.

These briquettes are easily manufactured from char using hand tools or larger production tools, as pictured in Figures 19[164] and 20.[165]

Figure 19 (top). A mechanical hand tool can create briquettes.

Figure 20 (bottom). Many green charcoal briquettes are produced at a time using a larger tool in the Haiti case study.

The smallholder biochar technology situation

This section demonstrates that there *are* biochar technologies that fit the smallholder context. Biochar cookstoves, retorts, and green charcoal briquettes do not represent all smallholder context biochar-related technologies. However, they are often central innovations for

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[163] Hirst, Peter. "Ch. 10: From Colliers to Retorts." *The Biochar Revolution*. Ed. Paul Taylor. Mt. Evelyn, Victoria, Australia: Global Publishing Group, 2010. Print. 140-142.
[164] Photo credit: Biochar India website.
[165] Photo credit: Carbon Roots International (via Facebook).

smallholder context diffusion projects. It is worth noting the integrative nature of these technologies and the ways in which they can combine to address multiple problems.

Important Details for Biochar Use: Conditioning and application

It is important to note that certain methods accompany biochar production and application in order to maximize its benefits. When biochar is taken straight from production and applied to soil without any conditioning, it has been found to be less effective than if it charged with nutrients and inoculated with living organisms. Also, applying raw biochar that has not been given a chance to absorb anything yet can run the risk of temporarily binding up soil nutrients that are needed by plants.[166]

Soaking biochar in nutrient and microorganism rich solution helps to inoculate the biochar pores with nutrients and microorganisms. One recommended way to do this is to mix biochar with compost, compost tea, or manure, letting it sit for a few weeks before application.[167] Charging with urine (whether from humans or livestock) is another effective charging practice, especially if compost or manure isn't available.

Application technique is another important detail for biochar diffusion projects. Biochar is typically added during the planting stage, and should be applied near the soil surface and plant roots – where microbial activity is high.[168] The amount of biochar that should be added varies greatly depending on the biochar and soil conditions, so testing (local field trials) is recommended. According to Julie Major, "at this time, insufficient field data is available to make general recommendations on biochar application rates according to soil types and crops…often when several rates are used, the plots with the higher biochar application rate show better results."[169] According to James Joyce, the amount of conditioned biochar that is generally added to soils in within the range of 2 to 20 tons of biochar per hectare (equivalent to .2 to 2 kilograms per meter squared; .2 to 2% by soil weight; .5 – 5% by volume. See source for more details).[170] Specific application technique

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[166] Joyce, James. "Ch. 15: Conditioning Biochars for Application to Soils." *The Biochar Revolution*. Ed. Paul Taylor. Mt. Evelyn, Victoria, Australia: Global Publishing Group, 2010. Print. P. 232.
[167] Joyce, "Ch. 15: Conditioning Biochars for Application to Soils." P. 232.
[168] Joyce, "Ch. 15: Conditioning Biochars for Application to Soils." P. 241.
[169] Major, Julie. "Guidelines on Practical Aspects of Biochar Application to Field Soil in Various Soil Management Systems" International Biochar Initiative. 2010.
[170] Joyce, "Ch. 15: Conditioning Biochars for Application to Soils." P. 242.

should be chosen based on local conditions, taking care to minimize dust and avoid wind erosion and surface runoff.

Chapter 4.2: Barriers to Biochar System Adoption in the Smallholder Context

The biochar technologies above address multiple smallholder issues, including soil remediation, indoor air pollution, and deforestation. These technologies demonstrate potential for integrative biochar systems that serve the smallholder context. If biochar could be greatly beneficial to smallholder agriculture and remedy other smallholder problems as well, why don't smallholder communities simply adopt biochar technologies?

What are the barriers to adopting biochar systems for smallholder communities?

Unfamiliarity or limited knowledge

One of the most obvious reasons people who could benefit from biochar don't use it is because they have no-to-limited knowledge about it. While some communities use char in soil and have been for centuries, biochar systems are still considered "new" technologies to these places because they use different technology and guidelines. For example, most traditional char production techniques release harmful emissions into the environment (as previously discussed) and are considered inefficient due to low char yields. In many cases, these methods still cause deforestation and land degradation problems. Biochar systems discussed in this paper have the potential to bring agricultural, economic, social and environmental, benefits even to places that traditionally practices agricultural charcoal.

Other smallholder agriculture communities remain completely unfamiliar with the concept of biochar. Some are even unfamiliar with organic biomass application. Degrees of familiarity with the concepts involved in biochar differ, but no rural smallholder community carries full resources and knowledge of biochar systems unless diffusion has recently occurred there.

Diffusion of technologies is complicated

If biochar could greatly help smallholder communities that don't know about it, why not bring the biochar knowledge and technology to them and teach them how to use it?

Technology diffusion is a complicated subject that has been academically examined. Looking into literature on diffusion helps to identify possible barriers to biochar adoption on a more specific level, as well as how they can be avoided and how to go about the diffusion process.

Chapter 4.3 reviews literature on the diffusion of innovations, focusing specifically on details that are relevant to biochar diffusion in rural smallholder agriculture communities. The main source is the book, "Diffusion of Innovations,"[171] by Everett M. Rogers, a well-known scholar who popularized the diffusion of innovations theory.

The following review helps in formulating hypotheses and performing analysis on the important question: ***What can a change agent do to increase the likelihood of success of the diffusion of biochar systems to smallholder communities?***

Other relevant barriers: poverty traps and risk avoidance

Before launching into diffusion theory, a couple more possible barriers to diffusion must be acknowledged. Poverty traps, as discussed in Chapter 3, may leave poor farmers unable to adopt biochar practices even if they would like to. While other farmers may be financially able to adopt, risk avoidance and conservative choices of farmers living on the margin may deter diffusion. Land tenure situations may also present a barrier in some places, because farmers have no incentives to make long-term investments in land that might not be theirs (or their kin's) in coming years.

Chapter 4.3: Diffusion of Innovations Theory as Applied to Biochar Systems

The purpose of examining diffusion theory is to gain informed insight about the diffusion process and how it works. Hypotheses are made following this section, and then biochar system diffusion case studies are examined and analyzed.

Diffusion

"Diffusion is the process by which an innovation is communicated through certain channels over time among members of a social system." – Everett M. Rogers[172]

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[171] Rogers, Everett M. *Diffusion of Innovations.* New York: The Free Press, 1995. Print.
[172] Rogers, 5

There are four main elements in the diffusion of innovations: the innovation, communication channels, time, and a social system. At its most elementary form, the diffusion process involves an innovation (a biochar system), a party with knowledge of or experience with the innovation (project implementers, also known as "change agents"), a party without knowledge or experience with the innovation (rural smallholder farming communities, in this case), and a communication channel connecting the two parties.[173]

Seven roles of change agents in the process of introducing an innovation:

1. To develop a need for change
2. To establish an information-exchange relationship
3. To diagnose problems
4. To create an intent in the client to change
5. To translate an intent to action
6. To stabilize adoption and prevent discontinuance
7. To achieve a terminal relationship

Figure 131. Seven roles of change agents

Change agents

A *change agent* is an individual or group who influences the innovation-decisions of individuals in the desired direction of the change agency. In this study, the change agencies are the NGOs in the case studies of Chapter 5: Carbon Roots International, SeaChar and GEO. The individuals who they are attempting to influence are the farmers and other inhabitants of the smallholder agriculture communities they visit in Haiti, Costa Rica and India. The innovation-decisions regard whether or not to adapt the biochar system introduced by the change agents.[174] The seven roles of change agents are described in Figure 21.[175]

Change agents are usually educated professionals who are heterophilous from their typical clients. *Heterophily* refers to the degree to which two or more individuals who interact are different in certain attributes, such as beliefs, education, social status, etc. *Homophily* refers the degree to which two or more individuals who interact are similar in these attributes.[176]This common heterophily makes effective communication regarding the

[173] Rogers, 10
[174] Rogers, 27-28
[175] Info source for Figure 21: Rogers.
[176] Rogers, 18-19

innovation more difficult.[177] For this reason, it is especially important that change agents make an effort to get their message across in a simple manner using simple language.

Change agencies often employ *aides*, people who are at a lower professional level who are homophilous with the average citizen. *Aides* help to close the gap between the change agencies and the clients. In each case study, there is a high degree of heterophily between the change agents and the smallholder communities, although less so culturally in the case of the Indian case study. In the cases of Haiti and Costa Rica, aides from the local communities are hired, helping to bridge the gap, because more effective communication occurs when it is more homophilous.[178]

The Innovation

In this case, the innovation is not only biochar, but also whatever action is done surrounding biochar – the technology, the application and whatever systems are put in place with its introduction.

A technology usually has two components: The first is the *hardware aspect* – the physical part of the technology. In this case, the hardware aspect is the technology for making the biochar, as well as any other new technology in the biochar system. The other component is the *software aspect* – the knowledge and information surrounding the tool.[179] This component constitutes everything that has to do with making and using biochar, including how to build and operate the technology, how to apply to the biochar, the reasons for using the new system, and how to participate in whatever biochar system is implemented, if it goes beyond the individual level.

In the case of most biochar implementation projects in smallholder agriculture communities (including those discussed in this paper), a biochar system is considered a "technology cluster." This means it includes multiple different yet interrelated technological elements.[180] Although the exact structures and technologies of biochar systems differ, each one contains a way to make the biochar, a methodology of application,

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[177] Rogers, 27-28
[178] Rogers, 28
[179] Rogers, 12
[180] Rogers, 15

and other additional aspects, such as cookstove operation. The spreading of each of these innovations in the "set" is interdependent.

The innovation-decision process

The *innovation-decision process* is when an individual (or other decision-making unit) goes through the decision-making process about a newly introduced innovation. For the context of this paper, it is important to be familiar with the innovation-decision process, because it is what smallholder community members are faced with when a biochar-related project (such as the case studies in Chapter 5) comes to their locality. There are five main stages of the innovation-decision process, as shown in Figure 22.[181]

Adoption refers to a decision to make full use of an innovation as the best course of action available, while *rejection* refers to a decision not to adopt an innovation. In the *confirmation* stage, the individual may reverse their previous decision (of adoption or rejection) if exposed to conflicting messages about the innovation (such as in the case of *discontinuance* of the tractor in Punjab, as told by Rogers).[182]If diffusion is successful, adoption of innovations usually occurs in a certain pattern that is stretched out over any amount of time: At first, just a few individuals adopt, then more and more individuals start to adopt, then adoption rate shoots up and then slows back down again. This distribution looks like an S-shaped curve when it is plotted on a cumulative frequency basis over time. The main point is that to hit a take-off point, diffusion needs to reach a certain threshold of adopters – generally between 10 to 40 percent of a population.[183]

Figure 22. Five main steps of the *innovation-decision process*

1) ***Knowledge*** – when an individual learns of the innovation's existence and gains some understanding of how it functions.
2) ***Persuasion*** – when an individual forms a favorable or unfavorable attitude toward the innovation.
3) ***Decision*** – when an individual engages in activities that lead to a choice to adopt or reject the innovation.
4) ***Implementation*** – when an individual puts an innovation into use.
5) ***Confirmation*** – when an individual seeks reinforcement of an innovation-decision that has already been made.

[181] Info source for Figure 22: Rogers, 20-22
[182] Rogers, 20-22
[183] Rogers, 11, 22

Characteristics of innovations

There are five main characteristics of innovations that are perceived by individuals, and past research suggests that each of these characteristics affects the rate of adoption of an innovation. The higher the perceived relative advantage, compatibility, trialability and observability and the lower the complexity, the higher the rate of adoption is likely to be.[184]

In Chapter 5, this paper will analyze biochar system diffusion case studies mostly based on the characteristic of compatibility, but with some extra attention to observability as well. Briefer descriptions of the other innovation characteristics (relative advantage, complexity, trialability and observability) will be given below.

Relative advantage is the degree to which an innovation is perceived as better than the idea it supersedes. A host community for a biochar project might ask, “How is this biochar system better than what we are doing now?” Their perception of relative advantage will vary based on the biochar system itself, the community’s alternative (what they are doing before the system is introduced), and other relevant local factors.

Complexity is the degree to which an innovation is perceived as difficult to understand and use. In this context, this perception will vary depending on a community’s prior knowledge and experience with soil carbon, nutrients, inputs, etc. The perceived complexity will also vary depending on a community’s exposure to technology in general, as well as how the technology and ideas are taught. Diffusion of a biochar system will be more successful if the technology is easy to produce, learn and understand for the local people. An example based on the biochar-related technologies described above: Dropping a new kind of fuel into an existing stove is easier (and perceived as less complex) than learning how to operate a new stove.

Trialability is the degree to which an innovation may be experimented with on a limited basis. In this context, trialability will vary depending on the biochar system, the implementation techniques (are they given free biochar or other incentives?) and the available time and resources of potential adopters.[185]

The last two characteristics of innovations, *observability* and *compatibility,* are discussed in detail in their own sections below.

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[184] Rogers, 15-17
[185] Rogers, 15-17

Observability

Observability is the degree to which the results of an innovation are visible to others.[186] In the context of this paper, observability depends on the project implementation methodology and how observable change agents are able to make the biochar system and its results. They often using the help of community members. Observability also depends on community factors, such as how close together and communicative people are.

The impact that local community members can have on the observability of an innovation is central to a hypothesis stated later in this paper. The section below aims to familiarize the parts of diffusion theory that discuss opinion leaders and early adopters.

Opinion leaders and adopter categories

Opinion leaders provide information and advice about innovations to many in the system – in this case, to fellow smallholder community members. “Opinion leadership is earned and maintained by the individual’s technical competence, social accessibility, and conformity to the system’s norms.” Interpersonal networks allow opinion leaders to be social role models. Other community members imitate their innovative behavior.[187]

Based on innovativeness,[188] members of a social system can be classified into *adopter categories* – the innovators, early adopters, early majority, late majority, and laggards.[189] According to Rogers, the most effective diffusion strategy is to target early adopters because they are well respected in the community yet on the same social level as most others. Because of this, they have the strongest opinion leadership. The earlier adopters serve as role models in the very-social process of diffusion, much of which consists of “the modeling and imitation” by potential adopters of those who have already adopted.[190] Community members ask early adopters for information and advice about

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[186] Rogers, 16

[187] Rogers, 26-28

[188] Innovativeness refers to the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than the other members of a system.

[189] Establishing and sorting into adopter categories is discussed in further detail in “Diffusion of Innovations” Chapter 7 (Rogers).

[190] Rogers, 257-274

innovations.[191] In all three case studies in Chapter 5, the strategy of identifying and working with early adopters is used.

The case study analysis in Chapter 5 will explore the intersection between observability and opinion leaders/early adopters based on the idea that particular smallholder community members and their actions, such as attending a biochar workshop or applying biochar to their fields, may be especially visible to their peers.

Compatibility

Compatibility is the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters. The more closely an innovation fits with an individual's life situation, the more compatible it is. The less uncertainty an innovation presents to an individual, the more compatible it is. For potential adopters, compatibility "gives meaning to a new idea," which makes it feel familiar. According to the diffusion of innovations theory, "compatibility of an innovation, as perceived by members of a social system, is positively related to its rate of adoption."[192]

An innovation, in this case a biochar system, can be compatible or incompatible in multiple different ways. Three different subcategories of compatibility are discussed below: compatibility with sociocultural values and beliefs; compatibility with previously introduced ideas; and compatibility with client needs for the innovation. For biochar system diffusion, compatibility will vary based on different perceptions different communities.

Compatibility with values and beliefs

It an innovation is perceived as incompatible with local cultural values, diffusion is more likely to fail. Many change agents face the difficult task of promoting innovations that are not consistent with strongly held values in the host community. Cultural incompatibility sometimes occurs when an idea designed for use in one culture is spread to

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[191] See characteristics (socioeconomic status, personality values, and communication behavior) of earlier adopters starting on p. 269 of "Diffusion of Innovations" (Rogers).
[192] Rogers, 224-242

a place with different cultural values.[193] This is why it is important look at biochar systems in smallholder communities on a case-by-case basis. There are many other ways and reasons that cultural incompatibility can occur, and many examples in history that exemplify it.

One example given by Rogers describes how the people of a Peruvian village would not adopt the practice of water boiling (for the purpose of health and sanitation measures) because it did not fit with their belief in a "hot–cold" system, in which hot foods are linked with illness and boiled water is only acceptable for the sick. Village cultural norms prohibit anyone who is not ill from drinking boiled water. The innovation, water boiling, was incompatible with their cultural beliefs, and was therefore rejected by 95 percent of the population.[194]

In the 1960s, "miracle" rice varieties (along with heavy chemical inputs) were spreading rapidly through Asia, as much as tripling yields. However, the crop breeders had not paid attention to taste. Farmers in South India (and other locations) reported that the new variety tasted weird, and continued to plant their own traditional rice for eating with family. The miracle rice was taken to market. Thirty years later, farmers were still growing their traditional rice varieties for personal consumption, and the miracle rice was selling for 20 percent less than local varieties. The incompatible taste of miracle rice blocked its adoption into the daily meals of farmers and others.[195]

Many other examples of incompatibility with values and beliefs are given, including India's persistent norm against eating food with the left hand (of which the reasons have long expired) and American farmers' resistance to adopting soil conservation innovations, which they perceive as conflicting with farm production increase (a strong value of theirs).[196]

The strong presence of social norms (which can be a barrier to change) and the pervasive phenomenon of modeling behavior in every social system magnifies the importance of cultural compatibility. Even if a biochar system or system component has the

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[193] Rogers, 224-225
[194] Rogers, 1-5
[195] Rogers, 224-225
[196] Rogers, 224-225

potential to bring significant benefits to adopters, if community opinion leaders perceive it to be misaligned with the local norms, values and beliefs, the prospects for diffusion could be ruined – community members who model their behavior on those opinion leaders will imitate their decisions of rejection.

Much work must be done by the designers of an innovation and by change agents to ensure that the innovation is compatible with local values and beliefs. In the smallholder context, this principle refers to the entire biochar system – not only the technologies, but also the concepts, practices and systems that surround them. The perceived compatibility by local community members can even be affected by how a biochar system is presented.

Compatibility with previously introduced ideas

Compatibility of an innovation is affected not only by deeply embedded cultural values but also by previously introduced ideas and practices. The main mental tools used to assess new ideas are old ideas, since innovations are dealt with based on the familiar. "Previous practice provides a familiar standard against which an innovation can be interpreted, thus decreasing uncertainty." Similarity of an innovation with its preceding technology can either speed up or hold back its rate of adoption.[197]

In the case of biochar systems, there are many components that are similar to previously introduced or practiced ideas in local communities; however, these historical practices and familiar concepts vary from place to place. While some places are familiar with using charcoal in soil – a similar concept to biochar, this practice is completely foreign in other places, as are the concepts behind it. Applying inputs or any kind or organic matter to fields is quite different from biochar, but is based upon some related concepts. Compatibility with previously introduced ideas of a given biochar system could be very high in one community and very low in another – it strongly depends on local factors relating to familiarity of different concepts and practices.

The concept of compatibility with previously introduced ideas is more complicated than it might seem. Rogers writes of some cases where perceived compatibility of a new idea with previous experience led to adoption, but then to incorrect use of the innovation.

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[197] Rogers, 225-226

One example he gives is of the introduction of tractors to Punjabi farmers:

> Tractors were perceived as giving social prestige to the owner, much as had the bullocks that the tractor replaced as a means of farm power and as transportation to market towns. Punjabi farmers, however, did not carry out basic maintenance of their tractors, such as cleaning the air filters and replacing the oil filter. As a result, a new tractor typically broke down after a year or two, with the farmer often failing to repair it…To Punjabi farmers…cleaning the air filter and changing the oil filter on their tractor was not compatible with their previous experience with caring for their bullocks.[198]

Another example given by Rogers is of the introduction of chemical fertilizers and pesticides to a Colombian peasant community:

> Farmers applied chemical fertilizers on top of their potato seed, (as they had done with cattle manure), thereby damaging the seed and causing a lower yield. Other peasants excessively sprayed their potatoes with insecticides, transferring to the new idea their old methods of watering their plants. Given their lack of understanding of the principles – knowledge of how chemical fertilizer and insecticides affected potato yields, the Colombian farmers gave meaning to these innovations in terms with which they were familiar.[199]

These examples show that presumed compatibility with a previously introduced idea can cause *overadoption* or *misadoption*. It is important to be cognizant of this phenomenon when diffusing of biochar systems, because they contain many elements that are similar to old ideas that exist in many places, but require certain modifications to old practices. One example is the step of conditioning the biochar before it goes into the soil. If biochar is regarded and treated as a new kind of fertilizer, farmers may skip the inoculation/charging processes, which would be likely to depress biochar's immediate benefits (as previously discussed in Chapter 4.2). Similarly, if the technology of a given biochar cookstove is not properly maintained, as in the case of the tractors in Punjab, it may continue to cook food but the added benefits (pollution reduction, biochar production, cook time improvements, etc.) may cease to function, defeating its purpose. If the user's previous cookstove did not require any maintenance and the biochar stove is perceived as a similar object with similar treatment, the user is unlikely to perform maintenance on a biochar stove (if needed) unless specifically instructed on how to do so. This could lead to reverting back to using the old stove – *discontinuance*.

This phenomenon has actually been discovered to be a problem in the clean cooking sector. There is a development movement surrounding the diffusion of clean cookstoves

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[198] Rogers, 226
[199] Rogers, 226

(this existed before biochar cookstoves became a new part of it), and there have already been various cookstove projects around the world. However, the lasting effect of these projects was questioned, and a study by Rema, Duflo and Greenstone, "Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves," found that usage of diffused clean cookstoves had often dropped off after a couple years in real world settings. "The difference between the laboratory and field findings appears to result from households' revealed low valuation of the stoves. Households failed to use the stoves regularly or appropriately, did not make the necessary investments to maintain them properly, and usage rates ultimately declined further over time."[200] These results are relevant and important to the diffusion of biochar cookstove technology, which is very similar but has some distinct characteristics that could be defining. Diffusers should be especially aware of the possibility of discontinuance of the cookstoves.

Change agents play a significant role in perceived compatibility with previously introduced ideas. Rogers gives an example of the diffusion of Roman Catholicism in Eastern Pueblo Indians versus Western Pueblo Indians: Eastern Pueblos, who had a "heavily patrilineal, father-oriented" family structure, embraced the religion, while Western Pueblos, who had "mother-centered" beliefs, rejected the religion. "Perhaps if the change agents had been able to emphasize the female-image aspects of Catholicism (such as the Virgin Mary), they would have achieved greater success among the Western Pueblo tribes, speculates Rogers.[201]

The manner in which change agents teach and frame biochar systems is critical to its locally perceived compatibility. Many factors should be taken into account, such as the language used (generally, academic jargon should be avoided), the concepts described, and the depth of description. Diffusion approach should change in different places based on the previous history, knowledge and ideas of a community.

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[200] Hannah, Rema, Esther Duflo and Michael Greenstone. "Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves." Social Science Research Network. April 16, 2012. Web.

[201] Rogers, 227

Indigenous knowledge systems

Part of adhering to compatibility with previously introduced ideas is remembering that every community already has its own ideas, whether they derive from the community itself or from elsewhere. According to Rogers, change agents sometimes forget this fact and the fact that people evaluate innovations based on their previous experiences with something they consider similar. When they make this mistake, it often proves problematic for the diffusion of their innovations:[202]

> Change agents and others who introduce an innovation often commit the *empty vessels fallacy* by assuming that potential adopters are blank slates who lack a relevant experience with which to associate the new idea…Why are indigenous knowledge systems often ignored by those individuals introducing an innovation? A strong belief in the relative advantage of the new idea often leads technocrats to assume that existing practices are so inferior that they need not be considered at all…Such a superior attitude often leads to the empty vessels fallacy, and to the introduction of an innovation that is perceived as incompatible with the ideas that it seeks to replace.[203]

To avoid committing the empty vessels fallacy, change agents must seek to understand the local past experiences and practices that their innovation would replace; they must seek to comprehend the local indigenous knowledge systems.

This lesson on accounting for indigenous knowledge systems is quite important with regards to biochar system implementation in smallholder agriculture communities, some of which are specifically indigenous communities. Agriculture and cooking – two cultural aspects that biochar systems often affect – are often very connected to traditional local practices that must be carefully learned and regarded. Agriculture and cooking practices in the rural developing world are also commonly perceived (by people who have gone through traditional western education systems) as lacking modern knowledge and technology. It is important for change agents to learn about indigenous knowledge systems in a given location and to try to understand how these systems can serve as a bridge for the innovation – for a biochar system.

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[202] Rogers, 240-242
[203] Rogers, 240

Compatibility with Needs

Another dimension of an innovation's compatibility is the amount it meets a "felt need." Faster rates of adoption usually occur when felt needs are met.[204] Change agents go in, in this case to a smallholder community, and seek to determine the needs of the local community members. They then recommend innovations – in this case encompassed in their biochar systems – that fulfill the determined needs.

Determining the felt needs of a community is not a simple matter. Accurately assessing perceived needs requires lots of empathy and connection with local community members. To determine local needs for innovations, change agents use many different techniques. These include client surveys, "informal probing in interpersonal contacts" with local individuals, and local advisory committees.[205]

In the case of biochar systems, which can be designed and used in many different ways, this process of discovering local perceived needs is very important and useful. Multiple of the change agents in the Chapter 5 case studies spent significant amounts of time and effort assessing the needs of their local clients using some of the techniques mentioned. It paid off – each separate project was able to make adjustments to make their projects more compatible with the needs of the communities they work in.

Potential adopters may not perceive a need for an innovation until they learn about the innovation and its consequences. When this is the case, change agents may seek to invoke perceived needs among the local population. However, Rogers notes that caution must be taken when doing this, or else "the felt needs upon which a diffusion campaign is based may be only a reflection of the change agent's needs, rather than those of clients."[206]

This idea of creating needs within a population is quite relevant to the diffusion of biochar systems because many people haven't heard of biochar, and agricultural charcoal and the concepts behind it may be a completely foreign concept in some places. If people aren't familiar with a certain kind of remedy to problems that they face, they may not feel a need for the remedy.

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[204] Rogers, 228-234
[205] Rogers, 228
[206] Rogers, 228

Incentives

In the context of poor farmers, the topic of incentives fits in nicely with compatibility with needs. *Incentives* are payments (there are many kinds - direct or indirect, cash or other benefits…) that are given to clients in order to encourage a specific behavioral change that brings about adoption of an innovation. The purpose of an incentive is to increase the degree of relative advantage of the innovation for adopters. Many change agents use incentives to increase the adoption rates of their innovations.[207]

Incentives are included in this discussion of compatibility with needs for a few reasons. First of all, monetary incentives correspond with needs of many smallholder farmers because of the poor economic situations and livelihoods that many face. While a small increase in income is very unlikely to change the life of someone who is living quite comfortably, it can have a huge impact on someone who is living on the margin. Second, incentives can be directly built into biochar systems, as they are in some of the case studies below. If ongoing monetary incentives are built into biochar systems, it may work like this: "If I continue to produce biochar and sell it back, I will have a higher monthly income. I need a higher income to be able to buy new farm tools. Therefore, I will produce biochar from my waste." Or, perhaps a need for agricultural charcoal is already felt, so biochar already has value: "If I use this new cookstove, I will have a free source of charcoal. I need charcoal for my fields. Therefore, I will use the cookstove."

These kinds of self-perpetuating, built-in incentives (as opposed to one-time deals) resonate with poor farmers who feel a need for higher income in order to meet livelihood needs that aren't being met (e.g. healthcare, education, or whatever is perceived). Because the incentives continue through time, adopters are continually encouraged to keep using their new adoption.

Compatibility is strongly linked to biochar system diffusion

This literature shows that compatibility is a complicated, multifaceted, perceived characteristic of innovations that is of great influence and importance in diffusion. Its application to the diffusion of biochar systems in smallholder communities is especially

[207] Rogers, 219-221

strong, because communities around the world that could benefit from biochar systems have extremely varied cultures, histories and perceived needs (although similarities are present among different communities as well). Compatibility will be further explored and analyzed as applied to the case studies in Chapter 5.

Chapter 4.4: Biochar System Diffusion Hypotheses

By examining some of the barriers to biochar system adoption as well as examining some innovation and diffusion theory, hypotheses may be formed regarding diffusion of biochar systems to smallholder communities. Although there are many different aspects to the design of a biochar system and how to diffuse it, this paper focuses on the importance of *compatibility* and *observability* when bringing biochar systems to rural smallholder communities, in which people often have less experience with exposure to new innovations, and are therefore less likely to adopt them.

In answering the question above, "***What can a change agent do to increase the likelihood of success of the diffusion of biochar systems to smallholder communities?"*** focusing on compatibility and observability of a biochar system is of great importance. Other aspects of the diffusion theory are important, influential and valuable to biochar system diffusion as well, but will not be further analyzed in this thesis.

Compatibility hypotheses

According to the Diffusion of Innovations hypothesis, the higher the compatibility, the better for diffusion (and the higher the adoption rate). Compatibility is higher the more biochar system concepts are familiar and fit in with the local values, experiences and (perceived) needs. Based on these elements, there are a few different subsets of compatibility: compatibility with values and beliefs, compatibility with previously introduced ideas, and compatibility with needs. Below are a few hypotheses connected to these elements of compatibility and diffusion success. These will be applied to the case studies in Chapter 5.

1. Adapting a biochar system to fit in with community traditions and values is likely to increase the success of diffusion.

2. Diffusion of biochar systems is more successful if there is a history of similar practices, such as applying charcoal or ash to soil. Systems or system components that are less locally familiar and compatible will have less successful diffusion.

3. Diffusion of biochar systems is more difficult in extremely rural communities than in less rural communities that have more experience with the outside world and with introduced innovations.

4. A biochar system that addresses a variety of perceived needs of the community is likely to increase the success of diffusion.

Observability hypothesis

Observability is the degree to which the results of an innovation are visible to others. According to the Diffusion of Innovations theory, the higher the observability, the better for diffusion (and the higher the adoption rate). Observability is higher the more visible the innovative aspects of a biochar system are (these aspects being, for example, increased yields due to biochar, or cleaner stove emissions). According to the Diffusion of Innovations theory, in depth communication with the local community is key. The *early adopters* in a community serve as a role model for many citizens and are also more likely to initially try out a new innovation.

Below is a hypothesis based on the diffusion literature regarding the connection between observability and diffusion success. It takes into account the role community members play in diffusion. The hypothesis will be examined as applied to case studies in Chapter 5:

Identifying and working with key community members (i.e. early adopters) will increase observability of biochar system benefits. This increased observability will lead to increased adoption rate of the project technologies.

Now that hypotheses concerning the diffusion of biochar systems have been established, it is important to look at real biochar system diffusion case studies in order to test the hypotheses and get a sense of what the diffusion process is really like. Chapter 5 presents three case studies accompanied by an analysis section.

Chapter 5: Biochar Project Implementation Case Studies

In the last decade, a number of biochar-related projects have been executed in the developing world smallholder community context. They use a variety of technologies, strategies and ideas. Many of these projects attempt to comprehensively address multiple smallholder issues. Project implementation strategies and influential factors such as location, situation, and local culture vary widely throughout these projects.

The following case studies tell the stories of three of these biochar-related diffusion projects, each of which take place in the poor, rural, smallholder community context. The first one is the story of a project in Haiti run by American NGO Carbon Roots International (CRI). The second is the story of a project in Costa Rica that is run by American NGO SeaChar. The third is the story of a project in India run by Indian NGO Geoecology Energy Organization (GEO). Each of the written case studies was constructed using information from personal interviews as well as public sources.

The purpose of examining these case studies and of performing personal interviews with those involved is to get a glimpse into the on-the-ground realities for projects like these, and to see how much local factors vary and influence these diffusion projects. The case studies are presented and then analyzed based on the compatibility and observability hypotheses stated above, providing valuable insight on how these diffusion theories influence the diffusion of biochar systems in the smallholder context. The hope is that this analysis may be useful to design and diffusion of biochar systems in the future.

Chapter 5.1: Case Study 1 – Haiti (CRI)

Background

Carbon Roots International (CRI) is a non-profit organization from Seattle, Washington, USA. It was founded in 2010, but their biochar-related work, which takes place in rural smallholder communities in northern Haiti, dates back to 2003.

Although CRI has multiple biochar-related projects in Haiti, this case study will focus on their primary project, the Char Social Enterprise. Their other biochar-related projects include biochar production and application workshops, peanut field trials for aflatoxin mitigation, and biochar demonstration plots. Although technically separate projects, these are referenced in the case study when they interlink with CRI's biochar-system diffusion in general. Co-founder and executive director Eric Sorensen was interviewed for this study and provided valuable insight and information.[208]

Description and context – rural Haiti

Land in Haiti

Ownership and tenure

Land is relatively evenly distributed in Haiti. "Most holdings are small (approximately three acres), and there are very few landless households."[209] Most property is privately held and farmed by what Sorensen describes as "the average smallholder farmer."

There is a high rate of land ownership, but because of population growth over the last 200 years and the system of land inheritance and subdivision, most plots of land are quite small. Sorensen reported that while some people inherit land near river basins, others are stuck with land in the mountains where barely any soil remains due to deforestation and resulting erosion.[210]Land is normally inherited, bought and sold without official documentation or land titles, but farmers have relative security of their land from informal tenure rules.[211]As discussed in Chapter 3, this land tenure situation alone would be unlikely to deter longer-term land quality investment.

Land degradation

Haiti has a severe deforestation problem. Although the country was once completely forested, less than 2 percent of the country remains forested to this day. This deforestation has caused a high amount of soil erosion, and the country now faces severe land degradation

Figure 23. Deforested, eroding hills in Haiti.

[208] Eric Sorensen. Personal Interview. October 11, 2013.
[209] "Haiti." Everyculture.com. Advameg, Inc. 2013. Web.
[210] Eric Sorensen. Personal Interview. October 11, 2013.
[211] "Haiti." Everyculture.com.

problems that result in decreased agricultural yields and devastating landslides.[212] Sorensen described how community elders recounted the days when Haiti was a jungle. Now, they look to the hills and often see desert or rock due to the deforestation and subsequent erosion (see photo in Figure 23 on the previous page).[213] This has a ripple effect down through the ecosystem. Long droughts and intense rains exacerbated by climate change and irregularity cause intense floods. As a result, nutrients are leached out of the soil and topsoil is washed away.[214]

Only one-third of the Haiti's land is considered suitable for cultivation due to the rugged terrain. However, in 2003, 40 percent of Haiti's land was being used for agriculture (crop production, feed production, pasture).[215] This use of marginal lands further contributes to the degradation and erosion problems the country faces.

Farming and soil management practices

Practices vary in different parts of Haiti, but in the communities that CRI has worked in and visited, Sorensen described that oftentimes nothing in the form of carbon, organic biomass or compost gets deposited back onto the field. While he sometimes saw people leave crop residues on their fields, he explained that, "many of their cultivation practices call for them to take the entire plant off the field." In Sorensen's experience, the average farmer does not use any inputs or irrigation systems.[216]

Social context: Health, economic and environmental concerns of charcoal consumption

Much of rural Haiti lives in extreme poverty. For the past couple decades, the average family income in rural Haiti has sharply declined with an average family of six earning under 500 dollars per year.[217] Women cook their food using wood or charcoal in inefficient stoves that produce harmful emissions, as described in Chapter 3. According to the CRI website, more than 93% of Haitians rely on deforested charcoal as their main energy source. Because of this, Haiti's charcoal prices are very high compared to most

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212 "Country Profile: Haiti." Library of Congress – Federal Research Division. May 2006. Web.
213 Image credit: Trees ForTheFuture via flickr. 2008. Web.
214 Eric Sorensen. Personal Interview. October 11, 2013.
215 "Country Profile: Haiti." Library of Congress – Federal Research Division. Web.
216 Eric Sorensen. Personal Interview. October 11, 2013.
217 "Haiti." Everyculture.com.

developing countries, and "an average Haitian family might spend over 40% of income on cooking fuel."[218] As earlier described, this charcoal use also results in health concerns; rampant deforestation and resulting land degradation; economic costs; time costs; and other environmental concerns. Ultimately, as shown in the loop in Figure 24,[219] charcoal reliance is reinforced.[220] Therefore, charcoal fuel use and poor soil (which results in low agricultural productivity) are interlinked and part of the same problem.

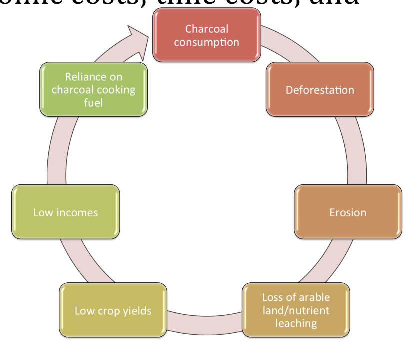

Figure 24. The charcoal consumption loop

Project design: Figure out what problems need to be addressed

CRI went to Haiti to assess local needs and problems, survey solutions, and from that, design a program model based on community needs. Although CRI started their project with a sole focus on agriculture side, they quickly realized they couldn't address the soil and agricultural productivity problem in Haiti without also addressing what they saw as the root cause of it, which was charcoal consumption.[221]

CRI had already had a way to cheaply and efficiently turn agricultural waste into a charcoal dust (biochar), but they did not yet have a way to turn it into fuel. By establishing a partnership and receiving the help of an organization in Uganda called Eco-Fuel Africa, CRI was able to adapt some of their sustainable fuel work that they were doing to the Haitian context while bringing in their own biochar expertise. Through this collaboration, CRI developed a market-based enterprise model called the "Char Social Enterprise model."[222]

Char Social Enterprise

The char social enterprise is CRI's primary project in Haiti, and is known there as the "Chabon Vet" project. It is based in Northern Haiti, where CRI owns a 6-acre production

218 "Green Charcoal." Carbon Roots International Inc. 2013. Web.
219 Figure provided by Eric Sorensen.
220 Eric Sorensen. Personal Interview. October 11, 2013.
221 Eric Sorensen. Personal Interview. October 11, 2013.
222 Eric Sorensen. Personal Interview. October 11, 2013.

center located outside of Cap-Haitien. The enterprise employs a decentralized network of over 60 smallholder farmers and entrepreneurs who produce carbon-rich char from their agricultural waste (such as sugarcane bagasse).[223]

Char producer network

CRI recruits producers by approaching farmers and micro-entrepreneurs who have agricultural processing facilities in Haiti. "We tell them, we have a way that you can make money off of your waste. We will buy it from you and be your customer. Are you interested in that? ...Invariably, people say absolutely, because they want more money. Especially with rural farmers who make one to two dollars a day, the prospect of any extra income proves to be quite attractive to them."[224]CRI trains these entrepreneurs and individual small farmers, building their "char producer network" – a network of char producers who have one to ten biochar ovens, depending on the amount of agricultural waste they generate.

Figure 25. Char production in the TLUD ovens.

CRI makes the ovens locally and from local materials for about $25 each, which covers material, building, transport and delivery costs. The ovens are basic TLUD ovens (described in Chapter 4.2). The farmers and entrepreneurs receive the ovens and gradually pay them off on a lease-to-own basis as they produce char for CRI. Training on how to use them takes a day or less. Then CRI tells the producers, "We're going to come back next week and buy whatever char you've made."[225]

This builds a supply chain for the enterprise. Sorensen reported that CRI has recruited many of these producers – both individuals and entrepreneurs – and the number is growing every month. CRI visits the producers on a weekly basis to purchase whatever char they've made. "A little bit of that goes to pay off the oven, but for the vast majority of it

[223] "Char Social Enterprise." Carbon Roots International Inc. 2013. Web.
[224] Eric Sorensen. Personal Interview. October 11, 2013.
[225] Eric Sorensen. Personal Interview. October 11, 2013.

they get cash." CRI brings the char back to their production center where they produce two products: green charcoal cooking briquettes and biochar.[226]

Green Charcoal

Figure 26. Green charcoal briquettes smolder in a traditional Haitian stove

The green charcoal briquettes are made from the carbonized agricultural waste at CRI's production center, which employs more than a dozen staff members.[227] The briquettes can be used as "drop-in" replacements for traditional charcoal (shown in Figure 26 and 27).[228] According to Sorensen, they burn longer, hotter and cleaner.[229]A green charcoal versus wood charcoal YouTube demonstration showed that the briquettes boil water (approximately 1.5 liters) four minutes faster than the traditional charcoal.[230] Sorensen emphasized that the briquettes require no new stove technologies or changes in cooking methods, which "significantly ameliorates key obstacles that plague new cook stove and alternative fuel technologies."[231] Also, the briquettes, which are sold by a network a women charcoal retailers, are 15-20 percent cheaper than traditional charcoal.

Figure 27. Green charcoal briquettes are laid out to dry at CRI's production center.

80 percent briquettes, 20 percent biochar

CRI uses 80 percent of the charcoal dust (known as "char") bought from the producer network to process into briquettes. The remaining 20 percent of the char is devoted towards biochar (for soil application). There are a few reasons 80 percent of the char gets turned into briquettes. Firstly, biochar does not yet have a ready market in Haiti

226 CRI "Char Social Enterprise."
227 CRI "Char Social Enterprise."
228 Photo credit: Carbon Roots International (via their website).
229 Eric Sorensen. Personal Interview. October 11, 2013.
230 "CRI's green charcoal vs wood charcoal comparison." Carbonroots YouTube Channel. Posted May 17, 2013. Web.
231 CRI "Green Charcoal."

(see discussion below). Because the goal for the enterprise is for it to become financially sustainable, they must sell a product (the briquettes) to make revenue. Also, Sorensen explained, even though the soil problem in Haiti is extremely bad, the charcoal cooking fuel problem (including deforestation, fuel price and health problems) is even an even more acute, pressing need.[232]

Working with Haiti's biochar market

The nonexistent biochar market in Haiti

Sorensen explained that biochar doesn't have a ready market in Haiti for a number of reasons. "The biggest reason is poverty and the fact that people in Haiti really don't spend any money on any soil inputs, so really no fertilizer, whether organic or chemical."[233] Because of this, CRI can't easily sell biochar to strangers. Even if local farmers were interested, many of them live in severe poverty, and according to the poverty traps theory, they would not be able or inclined to spend money on a longer-term, unfamiliar investment. The extreme poverty situation in Haiti definitely presents great challenges to creating demand for biochar; extreme poverty is definitely a potential barrier for the diffusion of biochar systems.

So far, CRI has sold biochar on a limited basis mostly to agricultural NGO projects. However, CRI's long-term goal with biochar is to do more research and lay a foundation for a local biochar market. The biochar work is currently subsidized by the green charcoal production.[234]

Building the biochar market

The 20 percent of the produced char that is devoted to biochar is used for field trials, demonstration plots, and giving biochar back to the original producers so they can put it in their soil. Sorensen explained that this system has many benefits for the project: "One…it's going towards rebuilding their soil. Two, the more biochar we get into the soils of farmers, the more benefits these communities will observe, and that's a potential way to

[232] Eric Sorensen. Personal Interview. October 11, 2013.
[233] Eric Sorensen. Personal Interview. October 11, 2013.
[234] Eric Sorensen. Personal Interview. October 11, 2013.

build a local market for biochar in a long run. Three, once these farmers start having higher agricultural productivity through the use of biochar, it will raise their incomes. They will have more food to sell, and they'll have more agricultural waste to turn into charcoal, which feeds our model."[235]

Field trials and demonstration plots

CRI is currently overseeing many demonstration and test plots. Plots rotate depending on the season, but crops they are testing include tomatoes, sorghum, cassava and peanuts.[236] The peanut trial is especially significant, because they hypothesize that biochar will help mitigate the harmful, high aflatoxin content that many Haitian-grown peanuts have.[237] CRI's test plots in Haitian soils have yielded significant increases in soil fertility, water retention and crop yields. Early adopter local farmers have also planted biochar crops next to crops with no biochar supplementation, showing a visible, favorable difference (as shown in Figure 28).[238] The CRI website notes their biochar trials and demonstration plots as "perhaps the most powerful tool to spur adoption of biochar use among Haiti's smallholder farming communities."[239]

Figure 28. A farmer stands next to his biochar trial which showed a huge difference in yields.

Biochar Workshops

In addition to their main work in their home community, CRI has been holding biochar production and application workshops in many different Haitian communities since 2010. "CRI provides the supplies needed to build several biochar ovens, which are donated to the host communities for use after the demonstration is complete." They often

[235] Eric Sorensen. Personal Interview. October 11, 2013.
[236] "Demonstration Plots." Carbon Roots International Inc. 2013. Web.
[237] "Peanut Field Trials." Carbon Roots International Inc. 2013. Web.
[238] Image credit: Carbon Roots International (via their website).
[239] CRI "Demonstration Plots."

conduct follow-up visits with early adopters.[240]After these workshops, some farmers have indeed produced and applied biochar, which has given them fertility and crop yield increases.

Differences in local compatibility and interest in adopting biochar as a soil amendment

When CRI was focusing mostly on adoption of biochar as a soil amendment, they had different experiences in different regions of Haiti. "We landed in this extremely rural area due to our original connection in Haiti…for the amount of time and energy spent to convince people there to try [biochar] we weren't very successful at getting them on board. Certainly some people in the community and the several communities in that area thought hey, I'll try this, but those are the ones who were early adopters."[241]

However, Sorensen noted that when CRI member Ryan Delaney held biochar workshops in over 20 communities around Haiti, "he received a much more positive response from those communities than the ones in which we were based…Many more people understood biochar and started using it…We got much better feedback and numbers through those workshops."[242]When asked why he thought this difference occurred, Sorensen commented that "most of those rural agricultural communities weren't as cut off as the one we were based in, and I think that made a huge difference. They had some experience with other types of new innovations… and they had access to roads and markets to sell their food and stuff. All those things put together really made the difference as to whether someone would be really interested versus what we kept hearing in our home community: 'This is great, but this is charcoal. Can we cook with it?' So eventually we took that to heart."[243]

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[240] "Biochar Workshops." Carbon Roots International Inc. 2013. Web.
[241] Eric Sorensen. Personal Interview. October 11, 2013.
[242] Eric Sorensen. Personal Interview. October 11, 2013.
[243] Eric Sorensen. Personal Interview. October 11, 2013.

Chapter 5.2: Case Study 2 – Costa Rica (SeaChar)

Background

SeaChar is a non-profit from Washington State, USA. It was founded in 2008 after President and Chairman of the Board Art Donnelly traveled to rural Panama where he witnessed terrible respiratory disease rate, especially among women, due to indoor air pollution from stoves. He had a background in fine arts and metal work, and decided to design a stove that could cook in a cleaner way. Less than a year later he heard about biochar. Donnelly designed a stove that uses biomass for fuel and produces biochar during the cooking process, as described in Chapter 4.[244] Donnelly was interviewed for this case study and provided valuable insight and information.

Evaluating project prospects

Donnelly was invited by a Costa Rican coffee farmer and his organic producers alliance to travel to the Talamanca region of Costa Rica in January, 2010 for a 6-week evaluation of the feasibility of doing a biochar stove project there. The farmers were interested in biochar, and the migrant coffee pickers lived in difficult conditions with poor indoor air quality during the picking season.[245]

By the end of the year, University of Washington and the National University of Costa Rica were involved in the project as well. SeaChar ran a pilot project using a study group of 32 households during the harvest from December to March, and the results looked encouraging due to high client satisfaction reports on surveys (more details below).[246] This was the beginning of SeaChar's main biochar stove project, which is called Estufa Finca ("farm stove," in Spanish). This case study focuses on the current phase of the Estufa Finca project, which is "hosted by a 1200 member organic cacao growers association (APPTA)."[247] SeaChar intends for this development process to continue for at least three years.

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[244] Art Donnelly. Personal Interview. July 31, 2013.
[245] Art Donnelly. Personal Interview. July 31, 2013.
[246] Tom Ternes, Susan Bolton, Art Donnelly. "Estufa Finca—Santos Pilot Project Results Report." April 8, 2011. SeaChar. Web.
[247] "Estufa Finca Project." SeaChar. 2013. Web.

Description and context of project in the Talamanca region of Costa Rica

SeaChar works in rural communities in Talamanca, which is Costa Rica's poorest region. It is a tropical rainforest region in the southeastern part of the country. One of SeaChar's main project locations is the Bribri community of Amubri, an indigenous community where locals speak Bribri and Spanish.

Agricultural history

The Bribri claim to have been cultivating cacao for 3000 years and it has special significance in their culture. Organic cacao, used in the production of premium quality chocolate is the primary cash crop for the Bribri farm families. However, their cacao crops have recently suffered from fungal diseases called monilia and black pod (more info below).[248]

Many of the Bribri practice small-scale agriculture, cultivating several different species of crops. A typical orchard may have 14 different types of fruit and nut trees inter-planted with the cacao.[249] Before the arrival of the Estufa Finca project, charcoal was not recently used in agriculture in the community; however, many elder community members recalled using charcoal on their fields many decades before.[250]Also, the concepts of the importance of soil organic matter and long-term soil sustainability were already familiar the Bribri farmers.[251] Donnelly noted that even though charcoal wasn't (recently) used in local agriculture before the arrival of SeaChar, the local people were quite familiar with charcoal use in general. He stated, "In the community we're working in, the charcoal already had value, one of the reasons being that people cook with it." He noted that the Bribri know charcoal well and use it for other purposes too, such as medicine. "People [there] have all these good associations [with it]."[252]

In Costa Rica in general, many organic farmers already use charcoal in their fertilizer formulations (e.g. the coffee farmer who originally invited SeaChar to Costa Rica).

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[248] Art Donnelly. Personal Interview. July 31, 2013.
[249]"Estufa Finca-Talamanca 2012-13 Part 3." *Art Donnelly* YouTube Channel. Posted January 2, 2013. Web.
[250] Art Donnelly. Personal Interview. July 31, 2013.
[251] Whatley, Neil. "Community Development with the Bribri of Costa Rica." Foundation for the Application and Teaching of the Sciences. 1999. Web.
[252] Art Donnelly. Personal Interview. July 31, 2013.

However, disregarding any recent use of biochar, all of that charcoal is produced using traditional methods, which contribute to deforestation and create harmful emissions.[253]

Social context, traditional cookstoves

In the communities where SeaChar works, most of the families are living in extreme poverty, surviving on less than $3 per day. Interconnected issues that plague these communities are deforestation, poor agricultural productivity, poverty, and health issues.[254] Before SeaChar brought biochar cookstoves to Amubri, most families relied on traditional open-fire stoves to do their cooking. A woman from the community who was interviewed about the traditional stoves, Gloria Torress Buitrago, commented that, "It was hard to look around and just breathe without feeling the smoke burning the eyes or throat."[255] High rates of respiratory problems and disease, especially among women and children, plague the area as they do in many other rural communities that use traditional cookstoves.

Proceeding forward with the project: testing the stoves and the biochar

SeaChar worked on adapting their new stove design to be made from local materials, including a 5-gallon steel paint bucket, some corrugated steel roofing material, and half of a one-gallon tomato sauce can.[256] It is shown in Figure 29.[257] In order to get funding, SeaChar got their stoves emissions tested. They found that SeaChar's stoves burn much more cleanly

Figure 29. The Estufa Finca stove on its setting.

[253] SeaChar "Estufa Finca Project."
[254] "Blog." SeaChar. 2013. Web.
[255] Stacey Schultz. "Biochar Cookstoves Boost Health for People and Crops." January 29, 2013. National Geographic News. Web.
[256] Schultz "Biochar Cookstoves Boost Health for People and Crops."
[257] Photo credit: SeaChar.

than traditional stoves and open cooking fires. Emissions, cook time and fuel reductions are described in Chapter 4.2. SeaChar also had their charcoal samples (from the stoves) tested, which confirmed that the stoves were producing good quality biochar. In terms of boichar yield, on average, families are able to get 1 ½ to 2 kilograms a day of biochar from cooking two meals on an Estufa Finca.[258]The project garnered the attention of National Geographic who gave them a grant to fund the Estufa Finca project.

Project goals and piloting the Estufa Finca

SeaChar established its project goals: To improve air quality to prevent respiratory illness; to reduce deforestation and resulting soil erosion; to create biochar for carbon sequestration and soil improvement; to reduce time required to collect wood; and to support rural women's groups to build stoves and develop sustainable businesses.[259] SeaChar then ran the Estufa Finca Santos Pilot Project from December 2010 through March 2011 in order to evaluate the ability of the stove to meet the goals above. The pilot project included field-testing and monitoring of the stoves, and it took place in the Los Santos coffee producing region of Costa Rica. SeaChar (and others) developed test and survey protocols and built 32 stoves. The stoves were then installed in the homes of migrant coffee pickers and then tested and monitored.[260]

Estufa Finca Santos Pilot project

The pilot project included five main elements: A population demographic and baseline stove survey, a customer satisfaction survey, a controlled cooking test, an end of season follow-up survey, and data analysis.[261] The baseline stove survey, customer satisfaction survey, and controlled cooking test all yielded very positive results for the Estufa Finca stove in comparison to the traditional stoves, and the stove was well received by the recipients. However, the end of season follow-up surveys found that usage had dropped off by the end of the coffee harvest season, as has commonly happened in clean cookstove projects (refer to discussion on the clean cooking sector in Chapter 4.3). Five out

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[258] Art Donnelly. Personal Interview. July 31, 2013.
[259] Ternes, Bolton and Donnelly. "Estufa Finca—Santos Pilot Project Results Report."
[260] Ternes, Bolton and Donnelly. "Estufa Finca—Santos Pilot Project Results Report."
[261] Ternes, Bolton and Donnelly. "Estufa Finca—Santos Pilot Project Results Report."

of 28 remaining study participants had completely stopped using the stoves, and many more (no exact number) were using the stoves incorrectly (more detail below).

Multiple factors contributed to this drop in usage, including:

- Some discontinued use of the stoves due to lack of availability of smaller sized coffee wood trimmings and the additional time required to trim larger wood to allow it to be used in the stove.
- In several cases households were still using the stoves; however, they were using them improperly. "They were allowing larger pieces of firewood to simply burn or smolder with no attempt to regulate the airflow. Evidence of this was soot on the walls above the stoves and the accumulation of ash in the combustion chambers."[262] Because of this, the stove benefits were not being fully delivered.
- Some people were not using the stoves in the morning because we had emphasized lighting them outside and people did not want to go out in the cold and wind to do so.
- It was observed in several households that stove parts were missing.
- In at least one household, a stove ended up in the hands of people who didn't know how to use it.
- In some households, the stoves had been successfully adopted, but were being used to *supplement* the traditional cookstove rather than replacing it.
- Some cooks reported feeling unsafe using the stoves because the surface became very hot.[263]

SeaChar learned many lessons from this project, including the importance of ongoing stove use training and certain stove operational preferences. This feedback helped them to modify the stove and diffusion methods to better fit the needs and habits of local communities. Modification included improvements to both the stove's setting and the stove's coop top. A removable child safety guard was established as a standard feature of the stoves, and the base block (that the stove rests on) was changed from two blocks to one to ensure primary air control. Cook top improvements included allowing for multiple pots, moving the rebar supports to provide a more useful side-board surface, and including a burner accessory for use with smaller diameter pots in the cook top kit.[264] Overall, the pilot program helped them to improve upon their innovation for their longer term Estufa Finca projects with hosts like APPTA.

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[262] Ternes, Bolton and Donnelly. "Estufa Finca—Santos Pilot Project Results Report."
[263] Ternes, Bolton and Donnelly. "Estufa Finca—Santos Pilot Project Results Report."
[264] Ternes, Bolton and Donnelly. "Estufa Finca—Santos Pilot Project Results Report."

The current Estufa Finca project

After gaining lessons and insight from the pilot project, SeaChar developed a program for the community they are continually working in for the longer term. The program includes community meetings, direct community involvement in the stove design, training workshops for the cooks, and an incentive program based on buying the biochar that the stoves produce.[265] The stove now takes a wide variety of fuel types, including wood, garden debris, bamboo, dried animal dung, and food waste material including coconut shells and corncobs.[266] It has also been modified in minor ways to better adapt to local cooking methods.

Fungal disease and biochar

SeaChar has been doing biochar research regarding the fungal diseases (monilia and black pod) that rapidly emerged and spread in the late 1970s and early 1980s. The fungal diseases decimated the previously thriving cacao industry, and the area is still recovering. Some organic cacao production has returned, but the diseases remain a problem and continue to repress production. Donnelly commented, "We have evidence which suggests that the application of charcoal can moderate or mitigate the infection from fungal diseases."[267]

Donnelly speculates that if their results are positive, biochar could play a big role in tropical agriculture regarding fungal infection mitigation.[268] If this becomes true, the locally perceived need of biochar for cacao (and other) production may greatly increase.

Taking root and collaboration

Donnelly identified key steps that helped their project to take hold. They found a strong host community in Costa Rica and started working with an indigenous women's development association, ACOMUITA,[269] in order to reach out to, work with and empower

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[265] "Blog." SeaChar. 2013. Web.
[266] Schultz "Biochar Cookstoves Boost Health for People and Crops."
[267] Art Donnelly. Personal Interview. July 31, 2013.
[268] Art Donnelly. Personal Interview. July 31, 2013.
[269] Asociación Comisión de Mujeres Talamanqueñas. Translation: Association Commission of Talamancan Women

women, who are most directly affected by the stoves due to their high activity in the kitchen. SeaChar also started collaboration with a university, CATIE,[270] that is helping them with agricultural biochar research as well as giving them local credibility and expertise. They are currently hosted by APPTA,[271] a small organic cacao producer cooperative (as mentioned above). They are working together on biochar research and trials.[272]

SeaChar staff made local allies who helped them with things like storage space and transportation. They also developed an affinity for the community. SeaChar hired local staff and got other community members to keep the project going during the times they traveled back to the U.S.

Community outreach

Community outreach is an important part of SeaChar's project in Talamanca. At the beginning, SeaChar hired some local women and trained them to be community promoters and to help advertise community meetings. Generally 30-60 people showed up to community events, where SeaChar staff would do a two-hour presentation about the stoves, as seen in Figure 30.[273] The sacred hot chocolate of the Bribri was cooked on the stoves as a demonstration. SeaChar uses a few different methodologies for teaching about biochar. Donnelly explained, "A lot of people are illiterate, so we have to have very good graphic materials to supplement whatever we did in the presentation, and to leave behind."

Figure 30. Local SeaChar staff lead a stove workshop for women.

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[270] El centro de educacion agricultura y investigacion. Translation: Center of Agriculture Education and Research
[271] Asociación de Pequeños Productores de Talamanca. Translation: Association of Small Producers of Talamanca
[272] SeaChar "Blog."
[273] Photo credit: SeaChar.

By January 2013, SeaChar had already held 18 farmer workshops, community events and demonstrations. They had also already distributed 142 biochar producing cookstoves, and there was a waiting list for people who wanted them.[274]

The presentations shared not only the benefits of the stoves themselves, but also discussed the biochar end product and how people could use it. Donnelly noted that at first, they talked about biochar in terms of just being charcoal to make for more effective communication and understanding. "We called it "bio carbon", kind of like biological charcoal."[275] Donnelly said that the farmers immediately understood the concept quite well because they were familiar with ideas surrounding soil carbon. "People get why biochar is a good idea pretty quickly, but they're farmers so they're conservative."[276]

Incentivizing biochar, the demonstration effect, key farmers, farmer workshops

Donnelly found the best way to incentivize people to use biochar was to stress the money savings involved. "Everybody has fairly short horizons, and the poorer you are, the closer to the edge you are, so you're less likely to take chances. You just have to pitch your talks to the audience."

In order to demonstrate biochar's utility, SeaChar identifies key farmers to get involved with – early adopters. Donnelly commented that working with these opinion makers pulls the attention of other community members. "As soon as we are up producing biochar, we donate charcoal to [early adopters], and then we counsel and educate them as to how to use it, so that their neighbors can see the effects…Word of mouth spreads about it." For the Estufa Finca project, this strategy has been pretty effective so far. They have also gotten involved [and spread biochar] in community garden projects, cacao farms, organic nurseries and standard plot tests. Their scientific trials have verified that their biochar produces beneficial yield results.

In some of SeaChar's workshops (mentioned above), they focus specially on biochar's use in soil. They show farmers how to make biochar and the tools needed to prepare it. An example of activity at a workshop is loading biochar ovens with guayaba

[274] "Estufa Finca-Talamanca 2012-13 Part 3." *Art Donnelly* YouTube Channel.
[275] Art Donnelly. Personal Interview. July 31, 2013.
[276] Art Donnelly. Personal Interview. July 31, 2013.

prunings and pyrolyzing the biomass for 2 hours. When the biochar is ready, everyone gets a chance to help prepare and apply the biochar to garden beds as well as to build a compost pile with "biochar and a microorganism rich molasses solution."[277]

Spurring a biochar market, charcoal buy back program

Seachar is having some success at teaching farmers how to use the charcoal they produce in their stoves, but they also want to spur a local market for the biochar; at this point, not every family can (or wants to) use all the biochar they are producing.

The charcoal buy back program

SeaChar took 32 households in one community and enlisted them into their prototype charcoal buy back program. They did six pick-ups over the course of the year. In six months they picked up 3.5 tons, which was considered extremely successful. Two tons of that went into research and demonstration (including agricultural research, donation to key farmers and putting it into a school garden). They also sold a ton and a half without doing any advertising.

Figure 31. Biochar yield after cooking in an Estufa Finca stove.

Donnelly said that the biochar buy-back program is a great incentive for families to use the stoves. He noted that lots of local families expressed interested in the smoke-free aspect of the stove,[278] but that the real draw is the biochar aspect and in the income it can bring them (Figure 31).[279]

Once the new cooks have their Estufas Fincas for one month, they can join the biochar buy-back program. The promoters make the rounds once a month, buying biochar at approximately 5 U.S. dollars per 8 kilogram sack. Households can earn an extra $15-20 per month by selling the biochar produced by their cookstoves. In January of 2013, there were about 22 households that regularly participated in the buy back program.[280]

[277] "Estufa Finca-Talamanca 2012-13 Part 3." *Art Donnelly* YouTube Channel.
[278] Schultz "Biochar Cookstoves Boost Health for People and Crops."
[279] Photo credit: Art Donnelly (Picasa).
[280] Schultz "Biochar Cookstoves Boost Health for People and Crops."

Selling the bought-back biochar

SeaChar sells the biochar both by word of mouth and at the farmer's markets. Some customers include the ministry of ecology, an organic papaya grower, expatriate farmers and gardeners, and local nurserymen and people who are doing plant starts (often cacao). "It is well known to the nurserymen as being a good soil amendment for building substrata because it holds moisture really well… So we've had people that have been really excited about having a source of agricultural charcoal. "

Donnelly said, "We're finding people buy from us, they have a good experience, and they come back and say 'can we buy a oven off of you guys?' It's the ideal thing to have happen."

Chapter 5.3: Case Study 3 – India (GEO)

Background

Dr. N. Sai Bhaskar Reddy is the CEO of Geoecology Energy Organization (GEO), a "registered Indian public charitable trust which focuses on community capacity building and empowerment, geoecological and natural resources sustainability, climate change (Mitigation and Adaptation) and renewable energy." It was founded in 2006, and it's major projects regard rural energy (e.g. cookstoves) and biochar.[281] Dr. Reddy has been working with biochar for the last 9 years, much of that time with GEO.

Although Reddy has worked on many different projects relating to biochar and charcoal use, this case study will focus mostly on Reddy's work with GEO's Good Stoves and Biochar Community Project (GBCP). However, it will also incorporate some of Dr. Reddy's other activity, experience and ideas surrounding biochar. Reddy was interviewed for this case study and provided valuable insight and ideas.

Good Stoves and Biochar Community Project (GBCP)

GEO is implementing The Good Stoves and Biochar Community Project (GBCP) in semi-arid parts of India, mostly in the Andhra Pradesh State. The project originated in 2009. They are being supported by Action Carbone, a program of the Goodplanet

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281 Reddy, N. Sai Bhaskar. "Good Stoves and Biochar Community Project." Geoecology Energy Organisation (GEO). Web.

Foundation.[282] GBCP is working to promote sustainable biochar production and encourage biochar application while bringing a positive social impact to rural communities. So far, GEO has designed 14 different kinds of "Good Stoves" (biochar-making cook stoves) in order to suit different stove needs in different places.[283]

Description and context:

Land in India

Ownership and tenure

India is made up of mostly small farms cultivated by family labor and livestock. In 1980, around half of the farm holdings in the country were less than 1 hectare, and only 4 percent were more than 10 hectares. Most farmers possess secure rights to the land they work, either as full owners or protected tenants. States oversee tenure security and the establishment of fair rents, so laws vary in different states.[284] The farmers Dr. Reddy works with in Andhra Pradesh have long-term access to their land.

Land degradation

According to India's 2009 State of the Environment report, half of India's total land area is degraded[285] - about 146 million hectares.[286] Since then, the amount has risen. Deforestation is listed as one of the major factors of land degradation, and two of the top five cited causes of India's deforestation are shifting cultivation (due to poor soil fertility) and firewood collection.[287]

Specifically, soil degradation and desertification are a huge problem in certain rural areas in India, one of them being Andhra Pradesh. These problems have been worsening in the last few decades and contributing to the increasing poverty and food insecurity of Indian rural populations.[288] Agricultural productivity continues to decline even as farmers

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[282] "Improved Stoves and Biochar Application in India." Action Carbone. 2010. Web.

[283] Reddy "Good Stoves and Biochar Community Project."

[284] Thakur, A.P. and Sunil Pande. "21st Century India: View and Vision." Global Vision Publishing House. New Delhi, India. 2009. Web.

[285] "State of Environment Report: India 2009" Ministry of Environment & Forests, Government of India. Environmental Information System (ENVIS). Jairam Ramesh. Vijai Sharma. July 20. 2009. Web.

[286] Hectare: A unit of area equal to 10,000 square meters. Equivalent to 2.471 acres

[287] Prasad, Ambika. "5 Major Causes of Deforestation in India." Preserve Articles. 2012. Web.

[288] "Improved Stoves and Biochar Application in India." Action Carbone.

add extra chemicals (such as fertilizers and pesticides) to the soils.[289] The rural population currently lacks power to combat these worsening conditions and their resulting worsening livelihoods. In addition, "an ecological catastrophe threatens to result across India if such problems are not remedied urgently."[290]

Land management practices

Land management practices vary in different locations of India and within Andhra Pradesh. It is common to use fertilizer and pesticides, and increasing dependence on these chemical inputs has been cited as a large problem in the area.[291] However, traditional agricultural methods such as slash and burn agriculture are used in many places as well. Reddy described that in some of the places the GBCP brought stoves to, farmers used burning for soil management. A rice farmer's practices are described: After harvesting rice and plowing the muddy plots, farmers "burn the waste from their rice plants, making lots of thick, polluting smoke and a little ash to fertilize the soil."[292]

Social context: Health, economic and environmental concerns

Dr. Reddy works with "very poor people in rural communities." They live mostly in remote areas with little access to resources. Reddy commented that their livelihoods are difficult.

Many of the farmers who Reddy works with were already putting charcoal in their soil. He sees many other traditional uses of charcoal in medicine, cleaning, building, craft, animal husbandry and livestock, among others.

Most of the farmers Dr. Reddy works with are dependent on "inefficient, three stone stoves," which are essentially wood/charcoal fires with stones to rest pots on. These highly polluting stoves present the common social, economic, health and environmental problems faced by many around the world, as earlier discussed. The food security and livelihoods of rural farmers in India are also threatened by the land degradation issues they face.

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[289] Reddy "Good Stoves and Biochar Community Project."
[290] "Improved Stoves and Biochar Application in India." Action Carbone.
[291] Marten, Gerry. "Escaping the Pesticide Trap: Non-Pesticide Management for Agricultural Pests (Andhra Pradesh, India)" EcoTipping Point Project. June 2005. Web.
[292] "CNN Biochar - GSBC Project, Peddamaduru village, Jangaon." Andhra Pradesh, India. Uploaded May 31, 2011. Video Clip. Web.

Approach to problem solving and project design

The Good Stoves and Biochar Community Project includes the establishment of the commercialization chain of highly-efficient biochar-making cookstoves, the diffusion of improved small-scale ovens, the pyrolysis of agricultural residues that are burnt otherwise, the soil fertility's enhancement and the long-term carbon sequestration through biochar application in soils. The aim of the project is to "enhance the living conditions of rural families, counteract deforestation, protect biodiversity, increase crop production, improve agricultural waste management and remove carbon from the atmosphere as a carbon-negative strategy to fight global warming."[293]

Figure 32 (above). The top two pictures show a local woman with her smoky traditional stove and then with her new, clean-burning biochar stove.

Figure 33 (below) shows Dr. Reddy giving a stove workshop to local women.

Starting in 2009, the project set out to test their innovations. The project includes four main aspects: Distributing 5000 improved cooking stoves (Figures 32 and 33),[294] producing natural biochar fertilizer by carbonizing biomass, creating local production and sales industries for biomass carbon, and doing pilot experimentation with the aid of volunteer farmers to test links between biochar application and increases in soil fertility.

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[293] Reddy "Good Stoves and Biochar Community Project."
[294] Photo Credit: N. Sai Bhaskar Reddy (Picasa).

Piloting, refining and selling the stoves

Since the beginning of this project, GEO has been testing various types of stoves to find a solution to fit with local cooking methods. GEO originally distributed one stove model (CM-Magh) to 35 families. Weeks of testing as well as evaluation of users' comments helped GEO to redesign the ergonomics of the model and produce a newer model (CM-Laxmi) that is easier to use. "This has been approved by users because of its lower wood consumption, greater ease of use and higher quality in slow-cooking methods." It is also able to take any kind of biomass as fuel. This stove costs about $6. Over the years, GEO has designed over 20 stove models to fit different contexts and purposes. They take different feedstocks (some models can take any feedstock) and some can heat as many as three pots at once.[295]

Farmer test plots, Research and Development Centre

GEO has been working with volunteer farmers to apply biochar to their own plots of land, and they have shown encouraging productivity gains following application. They also built a Research and Development Centre in the village of Peddramaduru, in the Warangal district of Andhra Pradesh in order to increase the involvement of local communities. Now more than 2,000 people, including "local farmers, NGOs, women's groups and students have been aiding GEO with conferences, workshops and training programs in the use of biochar and improved stoves."[296]

Biochar's chain of values

Dr. Reddy stresses that biomass is always a valuable resource and it is important not to waste it. The open burning he sees happening in farmers' fields is both wasteful and environmentally harmful, and he wants that biomass to be used more efficiently, including for cooking and for soil carbon. He explains that ultimately biochar reaches the soil, but it can have many uses in the process that make it more valuable than putting it directly into

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[295] Reddy, N. Sai Bhaskar. "Good Stove." GEO. No date. Web.
[296] "Improved Stoves and Biochar Application in India." Action Carbone.

the soil. He encourages integrating many uses into biochar, especially traditional charcoal uses if they are sustainable.

Dr. Reddy's approach

Introducing biochar to farmers

Dr. Reddy said it is important to keep the approach to diffusion simple and non-commercial. He believes in empowering the people to do what they want with the biochar. Dr. Reddy told the story of bringing biochar technology to a community that was unfamiliar with using charcoal as a soil amendment.

He went to the farmers in a community, showed them biochar, and showed them potted plants with and without biochar in their soil. The one with biochar was bigger and greener. He then started to build up communication with the farmers about biochar by explaining the properties of biochar – "how light it is, how much surface area there is within it, and how it is an excellent habitat for soil microbes..." Dr. Reddy explained that the community then helped him by explaining their different local uses for charcoal. He continued communication with them and learned about their specific livelihoods and traditions.

Demonstration trials in farmers' fields

Reddy wanted to make the results of biochar application observable to the community – he knew it wouldn't work to simply come in and tell people to do something to their farm. He built up a relationship with three farmers (early adopters) and convinced them to apply biochar to their fields. The fields they applied the biochar to were no longer being used because they were no longer fertile. The farmers followed Dr. Reddy's instructions for applying the biochar, and the results were amazing. "You could see that they reclaimed the field," explained Reddy.

Observability makes a difference

Not only did Reddy and the farmers see that the fields were revitalized and growing crops – the entire village noticed the visual difference. The people of the village understood the result and all of the farmers began using biochar to revitalize their dying fields. "Still today they are cultivating the fields without leaving them fallow," Dr. Reddy explained.

Application and inoculation

Dr. Reddy noted that most of the farmers he worked with easily understood the concept of biochar, but that they sometimes misunderstood the processes surrounding it. Because of this, he said, it is important to create a methodology of making biochar compost based on the locally available material and traditions. In terms of application, he believes in encouraging "initially point application because it is a low cost method, then line application, then spread application." Point application is applying biochar to the specific plant locations, line application is applying lines of biochar under a row of crops, and spread application is applying biochar to an entire field.

Inoculation: Geo Spirit centers

Through his work with biochar, Dr. Reddy has felt spirituality for the earth, which led to the development of a unique inoculation strategy. He calls it "Geo Spirit Centers." After trying it himself, he explained, "I started encouraging the farmers to declare some portion of their land where they will not touch any kind of plant in order to let the local biodiversity flourish." He explained that this is giving them access to their own local microbial life for the inoculation of their biochar and their fields. As a result, local microbes are integrated into the local soil, improving its health and fertility. Also, the biodiversity in the land patch brings different species of birds and insects, natural predators that control pests. "Like that, you will help to protect your own field, you can always inoculate your agricultural fields with local microbes, and you are helping the local biodiversity to thrive. And for the future you are creating this new spirit center." Reddy noted that many farmers he has worked with have gotten kind of used to reserving such a place in their fields.

Looking at local traditions and resources

Dr. Reddy commented that when bringing biochar technology to communities, he always looks at the local traditional rituals, festivals, cultures and other things (Figure

34).[297] Dr. Reddy said there are always multiple festivals per year. He discussed one festival in his region that happens after the rains. The festival includes the spilling of sacrificial animal blood, rice, other food items, and leaves – all onto the soil. The next day they collect this material and throw it into the fields and around the village, especially covering farmlands. This mixture causes a boom of soil microbes, and the farmers get a better crop. Dr. Reddy explained to the community the value in adding some charcoal to the mixture as part of the festival, and biochar has now been incorporated. Every time the festival happens, some biochar is introduced to the soil during a microbe boom.

Figure 34. This image shows local women dancing around and celebrating their new clean burning biochar cookstoves

Reddy also addressed the different resources and skills that are found in different places. He believes that, "based on the skills of the local people and the local materials, we can always teach communities how to convert the biomass into biochar in a cheap and efficient way with fewer emissions."

Learning more about traditional agricultural charcoal use

In addition to performing many other biochar-related experiments, Dr. Reddy has been visiting remote places in India with traditional charcoal use in soil. He believes that the study of traditional biochar/*terra preta* practices in different parts of the world is important, and that "we need to find ways to improve these existing practices for sustainability and adoption."[298] Learning about how biochar-like practices traditionally fit in to different rural cultures can provide valuable insight into how they might fit into many more in the future.

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[297] Photo Credit: Reddy (Picasa).
[298] Reddy, N. Sai Bhaskar. "Sustainability of Biochar Systems in Developing Countries." GEO. No date. Web.

Information dissemination

Dr. Reddy has taken a multipronged approach in sharing his work and other information about biochar. He commented that, "most people write papers, but papers don't show pictures. They only do data and analysis." On his website, he shows many pictures and diagrams. He stresses the importance of having information that is attractive, understandable and available to everyone.

He also emphasizes the importance of making biochar technologies and research open source, so that interested communities and potential adopters are more likely to be able to find information that can apply to their specific situations. "Because of the complexity of biomass (types, values, size, shape, density, etc.), converting it into biochar is difficult by any single design, so there is a need for many different biochar production designs that are suited to specific feedstocks and project circumstances."[299]

Chapter 5.4: Analysis of Hypotheses

Now that we have examined three different case studies of biochar-related diffusion projects in different developing world smallholder areas, we can analyze the hypotheses by looking at and applying relevant details from the different case studies.

Compatibility Hypotheses

1. Adapting a biochar system to fit in with community traditions and values is likely to increase the success of diffusion.

India

This hypothesis is supported by the case of biochar system diffusion in India and Dr. Reddy's strategy in approaching communities. After arriving in a new community and showing and explaining biochar to local farmers, he communicates extensively with the farmers in order to figure out how biochar can fit in with the local traditions and values of the community. He asks the farmers all about how they use charcoal, and, he described, "the community helps me by explaining how they use the char for different means

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[299] Reddy "Sustainability of Biochar Systems in Developing Countries."

locally."[300] This builds up the communication between Dr. Reddy and the farmers, and allows for the incorporation of charcoal's local traditional values into the biochar use. Examples of other local uses include cleaning, sanitation (Reddy suggests biochar urinals), filtration, medicine, and animal husbandry. After various traditional and incorporated uses, the biochar ultimately goes into the soil. Even if a community was not originally familiar with biochar soil application, many of the values of the system are already familiar and traditional to them, making adoption much more attractive and likely. Further, the strengthened communication channels and mutual respect between Reddy and the farmers builds up trust, and farmers are more likely to give biochar soil application a try.

Dr. Reddy doesn't stop there with fitting biochar in with community values. For example, during certain festivals biochar is now spread on farmlands along with a mixture of other things, as described in the case study.

Finding parts of the culture, traditions and values where biochar fits right in is key to Reddy's strategy of encouraging farmers to use it. He has found that integrating its application to soil as part of the culture is an effective way to get it in the ground. It also increases the value of the biochar itself. "It integrates the values of biochar not only for soil but also many other ways," he notes.[301] It must also be noted that his spiritual approach to biochar inoculation – the Geo Spirit Centers – has been much more successfully adopted than other recommended inoculation methods. Perhaps this is because it incorporates and corresponds with spiritual values. It must be noted that these methods are careful not to discount the indigenous knowledge systems mentioned in the diffusion of innovation theory.

Reddy has also gone to lengths to make sure his cookstoves fit with community traditions and values. He has developed over twenty models that work for various different purposes and are compatible with local cooking traditions. His stoves website displays some designs that can heat three pots at once.[302] Accommodating several pots is makes it possible to cook for large events or family gatherings.

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[300] Dr. N. Sai Bhaskar Reddy. Personal Interview. October 23, 2013.

[301] Dr. N. Sai Bhaskar Reddy. Personal Interview. October 23, 2013.

[302] Reddy "Good Stove."

Overall, the adaptation and inclusion of biochar systems to community values and traditions has proven valuable to its acceptance and diffusion in communities in Andhra Pradesh.

Costa Rica

The project in Talamanca, Costa Rica uses the incorporation of community values and traditions as a way to lure people in to their innovation. At the community meetings held by SeaChar, they make hot chocolate on the biochar cook stoves because hot chocolate is sacred to the Bribri. This draws peoples' interest and also created good associations with the project. This embrace of local traditions and values has likely been an important factor in their success thus far of drawing local attention to their innovation and convincing people to try out the biochar cook stoves.

The results of SeaChar's Estufa Finca-Santos Pilot project showed that at first, the stoves didn't completely fit with the local cooking traditions. While the reasons some people stopped using the stoves were mostly due to fuel preparation difficulties, many people continued to cook with their smoky, traditional stoves in addition to the biochar stoves, because the new stoves weren't meshing very well with their cooking traditions. In the pilot project report, SeaChar wrote that one of their lessons learned was that "stove settings and cook top designs need to take into account differences among cultures…foods, meal preparation, pot types and sizes…"[303] SeaChar came in without a strong grasp on the local cooking traditions and that negatively affected diffusion. However, the pilot project served its purpose by informing SeaChar about how to make the stoves more compatible to local cooking traditions. They have since made (and are continuing to work on) improvements to the stove setting and cook top to make it more compatible to the local cooking traditions. These include allowing for multiple pots, allowing for primary air control (so the heat can be adjusted), making a better sideboard surface, and adding a burner accessory for smaller pots to the cook top kit.

Now that the modified stoves better fit the local cooking habits and traditions, diffusion has been more successful, along with continued stove use in SeaChar's home

[303] Ternes, Bolton and Donnelly. "Estufa Finca—Santos Pilot Project Results Report."

community. Seeking and acting on community feedback about cooking traditions has helped SeaChar continually make improvements to increase the stoves' compatibility.

Haiti

The project in Haiti originally focused on charcoal as a soil amendment (biochar) and did not have much success in their home community. People did not value charcoal as a soil input, and they did not belief charcoal was for that purpose. They did, however, value charcoal as a fuel, which is a central part of their lives. This is one of the reasons why diffusion of CRI's green charcoal cooking briquettes is so much more successful.

It is also worth comparing the charcoal briquettes to biochar cookstoves as a means of improving indoor air pollution, reducing cook time, and reducing fuel costs. Because the briquettes are a drop-in replacement for traditional charcoal, now new stove technologies or alterations in cooking methods are needed. In terms of compatibility with local traditions and values, the briquettes are superior to the biochar cookstoves because no traditions or habits are altered with briquette use. Consequently, briquette diffusion has been a simple, faster, and more successful process.

These examples from the India and Costa Rica case studies support the hypothesis that adapting an innovation to local community traditions and values is an important part of the diffusion process. Incompatibility with traditions (such as cooking) can lower diffusion or bring unintended consequences (such as continuation of use of the old, smoky stove along with the new stove).

2. Diffusion of biochar systems is more successful if there is a history of similar practices, such as applying charcoal or ash to soil. Systems or system components that are less locally familiar and compatible will have less successful diffusion.

India

The India case study provides an example of a situation where new biochar systems were brought to communities that traditionally applied ash or charcoal to soil in one way or another. Practices varied in different locations. Some farmers did open air burns of their crop residues (such as rice husks), and others made char in trench mounds before working it back into the soil. The farmers who used these traditional practices had a good understanding of the concept of soil carbon, so they understood the significance of biochar. The introduction of "new" biochar systems (including the biochar ovens and cook stoves) is compatible with their previous beliefs and values regarding agriculture, so it is more about the adoption of a new, better technology to continue an old idea (with the added clean cook stove benefits as well). This makes diffusion of biochar application to soil much easier and more likely compared to a community without prior experience with charcoal application. This example compared to the biochar case in Haiti (discussed directly below) illustrates the contrast between diffusion of an innovation/practice to people who are familiar versus unfamiliar with the concepts and benefits behind it.

Haiti

The case of CRI's experience with biochar diffusion in Haiti contrasts with the case of biochar diffusion in parts of India where charcoal or ash application to soil is a familiar concept. In CRI's home community in Haiti, there is no traditional practice of using charcoal as a soil amendment, so it is a new concept to the farmers.[304] Furthermore, Sorensen described that most farmers do not put any sort of input – organic or not – back into their soil. "Many of their cultivation practices call for them to take the entire plant off the field."[305] These local practices suggest that biochar application is not consistent with their traditional agricultural values. To the local farmers, the concept of the importance of soil carbon is foreign and practices similar to biochar application are unfamiliar. Therefore, they have no reason to believe biochar will help. "What we kept hearing in our home community was, 'This is great, but this is charcoal…Can we cook with it?'"[306]

In contrast to the biochar aspect of the Haiti project, the concepts behind the green charcoal briquettes were very familiar upon introduction, and have therefore been much more compatible. As stated on CRI's website,

[304] Eric Sorensen interview. 2013.
[305] Eric Sorensen interview. 2013.
[306] Eric Sorensen interview. 2013.

> Consumers in Haiti and other regions of the developing world are proving extremely receptive to switching to green charcoal briquettes. Because the briquettes function the same, and switching to green charcoal saves money and prevents deforestation, Haitians have begun to embrace green charcoal as a viable alternative to wood and wood-based charcoal.[307]

The briquettes make sense to the local citizens because the concept is in line with the fuel practices they already use, yet they are seen as advantageous because they provide for the need of a cheaper and cleaner fuel source. Because the briquettes are a drop-in substitute for the normally used charcoal, no training or change in practices is needed. Users can apply their old experiences and habits to the technology. Cooking and heating practices are not altered, so this change is quite culturally viable.

Overall, the green charcoal briquettes have high compatibility for rural Haitian smallholder communities because of the already-existing similar practices, while the biochar application to soil component has lower familiarity and consistency with existing values, and therefore lower compatibility. Consistent with the hypothesis, the briquettes have diffused much more successfully than the agricultural biochar application, even though they both bring high relative advantages.

Costa Rica

Although the Costa Rica project has not been hugely successful so far in getting local farmers to adopt biochar application, Donnelly reported that they understand well the concept of soil carbon and the organic matter application, and therefore understand the significance of biochar. Because of this, prospects for future adoption of biochar as a soil amendment look better than in Haiti.

Even though biochar is not yet widely used locally, SeaChar has been successful in selling the bought-back biochar (produced in the stoves) to other Costa Rican customers including organic farmers and nurserymen, who were already familiar with the advantages and use of agricultural charcoal prior to their introduction to SeaChar's biochar. Their historical practices of using agricultural charcoal made a transition to biochar extremely compatible with both their beliefs and their routines, which is why many of them became

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[307] CRI "Green Charcoal."

interested customers. One specific example is the coffee farmer that Donnelly met and collaborated with. He had originally been using agricultural charcoal and was excited to use biochar in its place – he had already witnessed the benefits agricultural charcoal could bring, so biochar fit perfectly with his prior agricultural experiences and practices. For the farmers who had histories of practices similar to biochar use, a demand for buying the stove-made biochar was very easy to create, feeding the system as a whole.

The introduction of biochar cookstoves has required some adjustments in order to maintain their usage after initial adoption. After the first round of stove trials in Costa Rica, customer satisfaction was high, but eventually stove usage dropped off. This was mostly due to changes in characteristics in the new stoves from the old, traditional stoves. Changes in practices, such as the need to prepare small fuel and not knowing well enough how to work and maintain the stove, caused many to return to their old, familiar practices, as has been a problem with many clean cookstove projects in the past (such as the Hanna, Duflo and Greenstone paper mentioned previously).[308] SeaChar has since been addressing this problem by directly involving the community in stove design. However, it illustrates difficulties with maintaining previously unfamiliar practices, in contrast to the briquettes, which require barely any changes in practice. The above phenomena and outcomes remain consistent with the hypothesis.

3. Diffusion of biochar systems is more difficult in extremely rural communities than in less rural communities that have more experience with the outside world and with introduced innovations.

Haiti

Sorensen described that the extremely rural location of CRI's main project has proven to be a hurdle, and that CRI's efforts (especially workshops) have proven more fruitful in slightly less rural areas. He speculated that this may be due to the fact that less

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[308] Hanna, Duflo and Greenstone. "Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves."

rural communities have more prior experience with new introduced technologies and ideas.

When CRI was focusing mostly on adoption of biochar as a soil amendment, they spent a lot of time in their extremely rural home community, which did not have much access or exposure to the outside world. They had an extremely difficult time trying to convince people to try biochar and the only people who would even try it were early adopters.

However, when CRI traveled around Haiti and did biochar workshops in several different rural communities, they received a much better response. The communities they traveled to for workshops were rural smallholder communities, but they were less cut off from the outside world than CRI's home community. The more positive response to biochar experienced in the more "connected" communities is likely due to higher compatibility, probably because these communities had more past experience with new innovations.

Costa Rica

The case of biochar use and sales in the Costa Rica project supports this hypothesis as well. While not much biochar adoption is happening in the very-rural home community, many people who have more exposure to the outside world and with introduced innovations are buying biochar (such as the NGOs, nursery men, organic coffee farmers collective). SeaChar has also successfully sold some biochar at the farmers market, where the consumers are less isolated than in their home community.

4. A biochar system that addresses a variety of perceived needs of the community is likely to increase the success of diffusion.

Haiti

As earlier discussed, the diffusion of the green charcoal briquettes has proved more successful than the diffusion of biochar as a soil amendment. Another contributing factor to this difference is that the local perceived need for a cheaper, cleaner fuel source (than their traditional wood and charcoal) is more acute than their perceived need for a soil amendment. This is illustrated in the previously shared quote, '"This is great, but this is charcoal. Can we cook with it?'" Realizing that the community's perceived needs were stronger for cooking charcoal, CRI changed their focus (as previously discussed) and diffusion was more successful. Stronger perceived needs for cooking charcoal make the demand for the briquettes much higher than for biochar.

In CRI's char social enterprise model, the small business owners were attracted to the biochar oven technology because it was a way for them to make extra money while getting rid of their agricultural waste. It is compatible with their perceived need of earning more income without having to significantly change their business operations. Making biochar from their waste is a convenient addition to their businesses that addresses their perceived needs for higher income. It is a built-in incentive.

Costa Rica

SeaChar's pilot project (discussed above) also helped them to adjust the stove design to better address perceived cooking needs. This overlaps somewhat with cooking traditions, because cooking traditions can create perceived needs. The pilot project showed that the biochar stoves were not meeting all perceived needs – notably child safety and also the need for capacity to heat multiple pots. Some people were unwilling to prepare the small fuel from the coffee plant cuttings, suggesting that these specific users' needs could be better fit with a stove that takes larger or different fuel. SeaChar was able to address some of the needs, such as child safety and creating a more variable cooking surface, and this made the stoves more compatible and adoptable for the people in their current home community.

The incentive to make money by producing biochar as a byproduct of cooking on the biochar cookstoves follows the same concept as the char social enterprise model described above. The perceived need of higher income is fulfilled with the adoption and use of a new biochar cookstove, incentivizing community members not only to adopt, but to continue using it.

Although the biochar buy-back program may be the strongest incentive to adopt, cited statements by a local woman suggest that prior to the project, there was a perceived need for a solution to the indoor air pollution caused by the old stoves and a reduction of time and money required for fuel collection. The biochar stoves meet these perceived needs, which encourages their adoption among community members and meanwhile introduces biochar familiarity to the community and making efforts to create perceived needs for biochar in the future.

Because of the agricultural charcoal practices that already exist for some farmers in Costa Rica, selling the biochar has been successful because of perceived needs (for agricultural charcoal) of nurserymen and some organic farmers.

SeaChar is currently working towards the already perceived need of mitigating fungal disease in cacao plants by using biochar. If their field trials continue to be successful in using biochar to mitigate fungal disease, this is likely to increase local biochar adoption based due to an increased perceived need for biochar by Costa Rican (especially Bribri) farmers. This is because local farmers will perceive a greater need for biochar if it can play a key role in keeping their cacao (and possibly other crops) healthy.

India

Dr. Reddy has taken a different approach to meeting perceived needs, and it has proven very successful. He has designed over 20 biochar-producing stove variations so that different stoves can meet different needs. Different stoves take different biomass feedstocks, so people in different locations or situations can adopt stoves to fit their specific feedstock choice. The model mentioned in the case study is able to take any type of biomass as fuel. Different models have different features and sizes. Some models can accommodate three pots, and have been reported by users to work well when cooking for many people. This is a great need in some places, especially if families are large. In general, the biochar stoves can suit a variety of different needs so adopters have fewer compromises to make when switching stoves.

Reddy has been able to create perceived needs for biochar application in some cases, such as the case described to support the observability hypothesis (next section). Reddy strategically used farmer plots to make biochar's benefits visible to the community. When they saw what biochar could do, they felt like they needed it and so adopted. The need for biochar also created a greater perceived need for biochar-producing stoves – and a greater incentive to use them. The successful adoption rates of multiple different kinds of stoves show that the different stoves are meeting the different needs of people.

An interesting and useful study would compare stove usage among adopters 4 years after adoption of biochar producing stoves with buy-back programs, biochar producing stoves without buy-back programs, and non-biochar-producing clean cookstoves. This could provide some valuable insight into the difference monetary incentives, biochar incentives, or no incentives makes on continuing cookstove use. Needing an extra income source or a biochar source for the vegetable garden could be enough incentive to maintain biochar cookstove use over the long-term, but this needs to be studied. Evidence from the Costa Rica biochar buy-back program indicates the incentive may make a longer term difference in cookstove use.

Observability hypothesis:

Identifying and working with key community members (i.e. early adopters) will increase observability of biochar system benefits. This increased observability will lead to increased adoption rate of the project technologies.

India

Dr. Reddy told the story of bringing biochar technology to a community that was unfamiliar with using charcoal as a soil amendment. Reddy wanted to make the results of biochar application observable to the community – he knew it doesn't work to simply come in and tell people to do something to their farm. He built up a relationship with three farmers (early adopters) and convinced them to apply biochar to their fields.

Not only did Reddy and the farmers see that the fields were revitalized and growing crops – the entire village noticed the visual difference. The people of the village understood the result and all of the farmers began using biochar to revitalize their dying fields. Without those key farmers, other community members would not have been able to observe the benefits of biochar for themselves, and Dr. Reddy likely would not have been able to convince them to try it. This story illustrates not only the importance of observability but also the role community members can play to make beneficial results visible to community members, convincing them to try the new innovation.

Developing relationships with community members was also important to incorporating biochar into the festival described above (in the compatibility with traditions and values section). Reddy incorporated biochar and stoves into community events with the help of community members, and these events acted like advertisements for the new technologies – increasing their observability and encouraging adoption.

Costa Rica

Observability has played a key roll in the Talamanca project as well. Since the beginning of the project, SeaChar has used communication channels in order to make the benefits of their system more visible. Donnelly explained how this helped with the diffusion of the cookstoves, especially at the beginning of the project. SeaChar hired some local women to be community promoters and advertise for community meetings. Because the women are well connected and relatable to many community members, many people showed up to the events (usually 30-60). They were held in public, exposed areas, so people would walk by, stop and observe out of curiosity. The stoves were always displayed and in use – cooking the sacred hot chocolate of the Bribri. SeaChar staff did presentations about the stoves during the events. They showed how they worked, their beneficial qualities, and that they made biochar. This process was visible to community members – they could see it happening and see the end result. Charcoal already had value and good associations in the community, and the demonstrations made this valuable result (as well as the other desirable stove properties) visible to community members. In this case, holding public events to make the biochar stoves visible was key to helping community members observe the workings of the stoves and decide to adopt them. The local community promoters were key in making these events visible and attractive to the community.

To increase the observability of biochar's effects in soil, SeaChar gets involved with local community garden projects. They also identify "key farmers" – early adopters – who they can recruit, offering them free biochar as well as instruction in how to use it.

Neighbors have indeed noticed the beneficial effects of biochar: "Word of mouth spreads about it. That's been pretty effective so far."[309]

Haiti

CRI uses observability as a technique to try to increase the diffusion of biochar application to soil. The effects of biochar are made observable through CRI's demonstration plots. CRI also identifies early adopters and encourages them to do farmer trials, giving them free biochar and helping them through the process. Many of the farmer trials have planted the same crop "with biochar" and "without biochar" next to each other, and the differences in health and volume of the crops with and without biochar are very noticeable. This has been very encouraging for the farmers using it and for CRI. However, even with observable differences on the farms, a market for biochar hasn't really caught on locally yet. Sorensen explained, "right now we're in the market creation stage, we want to just get it into the soils so people see what it does and they start demanding it and there's a demand for it."

In all three case studies, community members – often early adopters and other times people who are involved in community events – have been identified and used to make the biochar systems and their benefits more visible to the general community. In most cases, this has proven useful in increasing the success of diffusion. In CRI's case, they believe that more observability is needed to build up a local biochar market.

Conclusion of Analysis

This analysis highlights significant evidence from the case studies that supports the previously stated hypotheses regarding compatibility and observability in the diffusion of biochar systems to rural smallholder communities. To increase the probability of success in biochar system diffusion, important questions to consider include:

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[309] Art Donnelly. Personal Interview. July 31, 2013.

- *Can the system be adapted or implemented in a way that makes it fit in with community traditions and values?*
- *Is there a history of practices that have similarities to the biochar system that will be implemented?*
- *To what extent has the proposed community been exposed to outside innovations?*
- *Does the proposed biochar system address needs perceived by the community?*
- *Would it be feasible to identify and work with key community members in order to increase the observability of benefits from the biochar system?*

While the questions above are important to ask in the approach to diffusing a biochar system, many other factors must be considered. These factors include other components of the process of diffusing innovations (as discussed in Chapter 4.3) as well as certain other considerations that apply to the complex process of designing and implementing biochar systems. Although these considerations will not be discussed in detail in this paper, a few important ones will be mentioned in the next chapter.

Chapter 6: Additional Considerations for Biochar Diffusion Projects

Although the case study analysis focused mainly on compatibility and observability, there are many other important considerations that must be taken into account when designing and implementing biochar related projects. A few more of the important lessons arise from the case studies and are presented below.

Taking an integrative approach

"Biochar should not be viewed as a specialized product for soil amendment alone…the scope of biochar is manifold. The broad areas of biochar use include soil management, livestock, biomass energy, water purification, green habitats, sanitation, health... The value of biochar increases due to its reuse and integration with the above aspects. For example, biochar used in sanitation can then be re-used as fertilizer." – Dr. N. Sai Bhaskar Reddy[310]

It is important to take an integrative approach when designing biochar projects and systems for smallholder communities. Technologies involving biochar are capable of addressing many issues, and as previously discussed, smallholder communities face many interlocking problems. It is important to keep all local issues and values in mind and address them when possible with the available tools – this often means incorporating other functions besides soil remediation into the system. It should also be emphasized that biochar production and application to soil does not have to be the central element and goal of a biochar system diffusion project. The ultimate goal for these projects is to bring as much benefit as possible to smallholder communities, and that will come in different forms and balances in different places – each system must be continually adjusted to fit the needs and context of a local community. Striving to make biochar systems integrative and comprehensive will bring greater and more universal benefits to communities. It will also likely to make adoption (of a biochar system) more attractive, therefore increasing diffusion success.

[310] Reddy. "Sustainability of Biochar Systems in Developing Countries."

Suggestions for incorporation

There are many things that can be integrated into biochar systems, and as Dr. Reddy noted, the more uses the char has before it reaches the soil, the more value it has. When incorporating other elements into a biochar system, it is important that there is a need for these elements and that they are culturally compatible, otherwise their diffusion won't be successful, and their inclusion could negatively affect the diffusion of the entire biochar system. Oftentimes, however, the incorporated elements other than biochar *help* the diffusion of a biochar system. Some examples of technologies and ideas that can be incorporated into biochar systems are as follows:

- Biochar cook stoves – improve indoor air quality and health, among other things.
- Green charcoal briquettes – Cleaner, cheaper, more sustainable than traditional fuel in many places.
- Biochar urinals – Used to improve local sanitation; automatically charges the biochar.[311]
- Biochar water filtration – Creates access to clean water.
- Pyrolysis of invasive plant biomass to make biochar – Helps restore native ecosystem, provides feedstock.
- Incorporation of biochar into local traditions, rituals, festivals, cultures etc.

Incentives

"So you want people to try something? Pay them." – Art Donnelly[312]

Incentives are often an effective way to get people to try or adopt a new technology. Both CRI and SeaChar successfully use incentivizing through their buy-back programs. It works – people are getting paid to use SeaChar's clean biochar cookstoves because they are getting paid for the biochar that they produce. People are getting paid to dispose of their agricultural waste (through pyrolysis) because they are getting paid for the biochar that they produce from it. Without these incentives to adopt, diffusion of these systems would be unlikely to occur, especially because of the high poverty context. Regarding incentives, Eric Sorensen elaborated, "'I don't grow a lot of food,' is not an incentive to change…A

[311] Dr. N. Sai Bhaskar Reddy. Personal Interview. October 23, 2013.
[312] Art Donnelly. Personal Interview. July 31, 2013.

successful model is going to figure out how to pay people…We buy [the biochar] back from [the biochar entrepreneurs] so there's a direct financial incentive for them to make it."[313]

Identifying/using early adopters

As discussed in the diffusion of innovations literature, a common diffusion technique is to identify early adopters and target them for adoption first. The hope is that that they will adopt and then other community members will follow their lead. A successful case of this was described in the analysis of the observability hypothesis. Art Donnelly emphasized the importance of this strategy. "If you're working in a development situation, you've got to indentify key players, opinion makers, influential people in their communities…People model their behavior off of other people…Find some of those people and concentrate on them. It'll pull other people in to see and look what's going on."[314] All three case studies used this method to some degree, and it has proven useful.

Communication

Communication with the local community is extremely important both in designing the project and during diffusion. It is important to get a lot of feedback and input from community members and also to have community members on the team, so that a local point of view is taken into account and so there is always someone present in the local community to continue the project. Learning about the community, relating to the local people and gaining their trust is an important step in diffusion. It is important to speak about the biochar system in language that is understandable, relatable and attractive to the local people. Dr. Reddy noted that using jargon is a mistake, and that it is important to put explanations into layman's terms.[315]

Social context

It is important to take social context into account, especially for the diffusion of biochar as a soil amendment. If people don't have solid land tenure, it is unlikely they will

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[313] Eric Sorensen. Personal Interview. October 11, 2013.
[314] Art Donnelly. Personal Interview. July 31, 2013.
[315] Dr. N. Sai Bhaskar Reddy. Personal Interview. October 23, 2013.

want to make a long-term investment in the land they are currently working on. Change agents should be aware of local beliefs, cultural norms, and taboos in order to align the system and its diffusion with the local culture and avoid offending people.

Scalability

When designing a biochar technology or system, it is important to think about scale. For example, producing biochar using only one family cookstove will not yield enough biochar in a reasonable time scale for a farm. If a family faithfully uses their stove for every meal every and yields an average of 1.75 kg per day (the Estufa Finca average), a year's yields will only be about 70 percent of one ton, and standard biochar application rates (mentioned in Chapter 4) start around two tons per hectare, although more biochar brings better results (to a point). Accumulating a minimum amount of biochar for one hectare would take 3 years!

Buyback programs such as SeaChar's can help cookstove biochar accumulate faster, but if the biochar stays within the community but there is no other source, few people would be able to adopt biochar application at a time and there would be long waits due to low supply. For this reason, cookstove biochar production is not very scalable and best used for buy-back programs or vegetable gardens.

Scaling it up

Because biochar cookstoves are extremely small-scale in terms of biochar production, stove projects usually incorporate other technologies that are more scalable, such as TLUDs. A standard 55-gallon TLUD produces about 8 to 12 kilograms of biochar per batch[316] and TLUDs are extremely cheap and easy to make. Batches can also take as short as one hour. If you have 15 people make 5 batches of biochar in one day, you can have a ton right there. If one person makes one batch per day, they could have almost 5 tons within one year. TLUD ovens are reasonably scalable because they are so cheap and operating time is relatively short. There are also newer, larger oven, retort and hybrid designs that can produce larger amounts of char in one run.

[316] "Biochar Production Units." *International Biochar Initiative*. International Biochar Initiative, 2013. Web.

Feedstock

Feedstock source and availability is an important consideration, especially when looking to scale up production. There is an extremely wide variation in feedstocks and crop yields, so the amount of land that producing one ton of biochar would require (by using that land's agriculture waste) varies greatly. For an example of what one agricultural waste feedstock would yield we can look at coffee prunings (which are used as fuel in the Estufa Finca). A 1981 study found fuel wood yields from coffee prunings in Costa Rica:[317]

Coffee density (plants per hectare): 3895
Oven dry firewood: (kilograms per hectare): 1111
Pruned branches (number per hectare): 4308
Mean oven dry weight per branch (kilograms): .24
Mean oven dry firewood weight/plant (kilograms): .28

If biochar production technologies like the TLUD generally yield a 20-30% biochar mass of the original (dry) feedstock, we can calculate how much biochar one hectare of coffee prunings would yield. 25% biochar yield multiplied by 1111 kilograms/hectare of oven dry firewood equals approximately 278 kilograms of biochar. Relying on these prunings alone as a feedstock would not be very scalable, because it would take 6.5 years to get 2 tons of biochar. However, luckily there are often other feedstock sources as well, such invasive plants (discussed below). Also, these pruning yields could be drastically different from other farms and especially from other feedstocks.

Scalability is a critical factor in biochar systems and must be assessed with each individual project.

Sustainability

"The main challenges [for biochar] are the availability of sustainable sources of biomass and the accessibility of efficient biomass-to-biochar conversion technologies." – Dr. N. Sai Bhaskar Reddy[318]

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[317] Romijn, M., and E. Wilderink. *Fuelwood yield from coffee prunings in the Turrialba Valley.* CATIE, 1981. Web.
[318]Reddy. "Sustainability of Biochar Systems in Developing Countries."

Sustainability is an incredibly important factor that must be addressed in every biochar project. There are many subtopics within sustainability that need to be considered. These challenges must be acknowledged and fully addressed, because if they aren't, biochar diffusion could do more harm than good.

Sustainable feedstock source

It is imperative that biochar feedstock demand does not lead to the unsustainable harvest of forest resources or to harmful land-use decisions (such as land-grabbing). Dr. Reddy wrote, "The approach of having captive lands for biomass production for large scale commercial production of biochar should not be encouraged, because this approach competes with the limited land resources."[319] In locations that do not have much available biomass waste, sustainable biochar systems may not be feasible. Feedstock sources for biochar should come from biomass that would otherwise be "waste," such as agricultural waste, or food waste. Donnelly mentioned that coconut shell, which is abundant in Costa Rica, makes a good biochar.[320] Another good feedstock source is invasive plants. Reddy suggests using the *prosopis juliflora,* an abundant, invasive plant in India,[321] and Donnelly suggests using bamboo and other invasive plants in Costa Rica.[322]

Emphasize sustainability during diffusion

The importance of using sustainable feedstock sources must be stressed by all change agents – it is their responsibility that the system they diffuse remains sustainable. Change agents should also emphasize and encourage other sustainable agricultural practices.

Project and system lifecycle

The overall emissions lifecycle (including transportation emissions, etc.) of project implementation and of an ongoing biochar system should be considered and assessed if

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[319] Reddy. "Sustainability of Biochar Systems in Developing Countries."
[320] Art Donnelly. Personal Interview. July 31, 2013.
[321] Dr. N. Sai Bhaskar Reddy. Personal Interview. October 23, 2013.
[322] Art Donnelly. Personal Interview. July 31, 2013.

possible. The carbon footprint should remain low if it is not negative (due to the biochar's offset/reduction in deforestation and emissions).

Emissions and efficiency

Emissions of the biochar technologies should be tested and kept low. No open burning of biomass should occur, and charcoal should be made using low-emissions technology. The traditional methods of making charcoal have much higher emissions and should not be encouraged. In addition to having low emissions, biochar systems should strive for high biomass-to-biochar efficiencies. Efficiencies vary depending on technologies and other factors, but most technologies should be able to get above a 20 percent yield of biochar by weight.

Biochar testing

Biochars should be locally tested and field trials should always be performed to make sure the particular biochar being used brings worthy benefits to the local soil. Inoculation and charging should be practiced in field trials and in diffusion.

Conclusion

Biochar-related technologies that are appropriate for the rural smallholder context do exist, and designing integrative biochar systems for diffusion in this context has the potential to bring long term social, economic and environmental benefit to smallholder communities. Rural smallholder farmers make up a large proportion of the world's population, and collectively, diffusion of biochar systems to many of these communities around the world could have a great global environmental impact that aids in agricultural sustainability, land conservation, and forest conservation in addition to remedying significant local issues.

However, widespread diffusion to the developing world smallholder context is a long way away. The modern biochar field is young, and the smallholder-biochar-system-diffusion field is in its infancy. At this point, every on-the-ground biochar diffusion project brings valuable new experience, insight and innovation to the field, and it is important that these projects are shared and learned from.

Focusing on diffusion technique and system design is just as important as improving technologies and expanding field and lab research; if biochar systems for the smallholder context don't diffuse well, there will be little benefit, wasted resources and regret.

In analyzing biochar diffusion case studies, I focused only on compatibility and the role of community members in observability because these aspects deserved full attention rather than getting lost in a sea of the many important aspects of diffusion (which are also worth exploring further with respect to small scale biochar systems). The case studies showed not only that compatibility is important, but also that it can and should be approached in many different ways. Causing a biochar system to be perceived as compatible by a local community is a dynamic process that takes and deserves time, effort, creativity and flexibility. The same goes for forming trusting relationships with local community members, who are vital to the diffusion process for many reasons including their influence on observability.

So, can convincing someone to sprinkle charcoal during a festival change the world? It may seem like a silly proposition but its greater significance is worth acknowledging and contemplating. Smallholder issues are world issues that affect every human increasingly so as time goes on. Biochar-related technologies and knowledge can have a positive impact, but these remedies will take hold only if they are compatible with and beneficial to the body that receives them.

If biochar systems are tailored to be compatible with the specific communities to which they are introduced, there is a better chance that those communities will persist in using them for the long term and that adoption will spread. These biochar systems may be small-scale (for good reasons), but that doesn't mean they don't have a large potential.

One of the most valuable things I learned from my personal interviews with Eric Sorensen, Art Donnelly, and Sai Bhaskar Reddy is that diffusion projects like these require tremendous commitment from their supporters and staff. The projects I studied and the people I talked to have given me reason to hope that the energy, devotion and passion that they are putting into these projects will pay off for as long as biochar remains in the soil, and that the payoff will spread and multiply like microbes that encounter biochar.

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