


The Beauty of BIOCHAR

An eBook by Soil Reef LLC

The Beauty of Biochar

Authored by

Soil Reef LLC

A Field Guide for Gardeners and Farmers

ConteNtS

While this Revision provides many up-dates, and additions much of the original 2010 work appropriately remains unchanged. The general result of all this "new" work further supports the value, growth, and new applications of biochar. Like biochar itself, the basics remain while the "understanding" expands.

We hope this book will inform and encourage people who have an interest in, and can benefit from, biochar. The primary focus this eBook is for its use in soils. It is not written for scientists, but might sound that way on occasion as we describe properties that make biochar unique and so beneficial. This book is for everyone who understands soil is the foundation for human health, economic security and climate stability. In short, life.

Bits of Biochar *Photo: Hawaii Biochar Products*

In 1851, Andrew Jackson Dowling, a renowned landscape designer, horticulturist and writer of his time wrote:

> *"Canals and railroads wrote a one-way ticket for soil fertility. They bring from the West millions of bushels of grain, and send not one fertilizing atom back to restore the land. And in this way we shall by-and-by make the fertile prairies as barren as some of the worn out farms of Virginia."*

This quote was a prelude to the Dust Bowl, though not meant as a prediction at the time.

Biochar is a lightweight, highly porous charcoal—designed to use in soil: farms, gardens, horticulture, landscaping Photo: Hawaii Biochar Products

BIOCHAR – WHAT IS IT?

Biochar is a special form of highly porous charcoal ... then what is highly porous charcoal? It is charred carbon made by heating biomass – commonly waste wood – without oxygen. One of the great things about biochar is it can be made from any biomass waste – materials we have no better use for at a given time and place. Biochar is an excellent way of turning waste material into a long-term beneficial product.

Biochar, however, is not made to be burned as fuel, as charcoal typically is. Instead, biochar is intended to be put in soil, where it causes physical, chemical and biological transformations to promote sustainable and long-term soil fertility in nutrient poor or infertile soils. In soils that are already well cared for and fertile, biochar helps build a resilient soil that is better able to maintain its normal functions under unusual conditions. Such unusual conditions include heavy, prolonged rain and dry spells, both of which are expected to be more frequent as a result of climate change.

Properly made, biochar also produces renewable energy during its manufacturing process.

Properly used, biochar can allow crops to grow with exceptional health, yield and nutrition.

Properly applied, biochar can have major impacts for environmental uses and needs.

Properly implemented, biochar systems sequester carbon to mitigate climate change.

PICTURING BIOCHAR

Imagine holding a piece of a charred log from a freshly extinguished campfire where it didn't have a chance to fully burn into ash. This lightweight, dusty, blackened wood is simple, natural biochar. Drop the char on the ground and crush it into the soil with your foot. You just added biochar to soil to enliven and enrich it.

High temperatures have transformed carbohydrates made by plants into lightweight, brittle, black char. Controlled pyrolysis captures up to half of the biomass carbon as char, instead of incineration to ash, gas and heat which leaves only small amounts of carbon behind. The black biochar residue, after activation, has been used for a very long time to filter many materials – from water to gases. Many of us have water from our refrigerators or pitchers which filter water with activated carbon. Biochar is the precursor to making activated carbon.

Biochar changes soil in ways we can see, feel and smell. Biochar-amended soils gain in tilth, look darker, feel damper, smell sweeter.

NATURE'S NANOTECHNOLOGY

The key to this transformation by pyrolysis is found at microscopic and sub – microscopic – or "nano" scales. Throughout this book we will discuss the relationship between biochar's structure and its effects in soil. Biochar contains pores that range over a tremendously wide scale, from nanometers to tens of micrometers. Although such sizes are all very small from a human point of view, they represent a large variety of different spaces for biochar to interact with soil. Depending on the size of pores, different mechanisms can take place inside them. Biochar's retention of water and nutrients in simple forms (those that plants take up directly) occurs largely in nanopores which are too small for even small bacteria to fit in. Bacteria and fungi can fit into larger biochar pores and find a suitable habitat to grow and reproduce.

Biochar Field Trials in Honduras *Photo: Dr. Julie Major*

Note sparkles –Sunlight glinting from biochar
Photo: Hawaii Biochar Products

In short, while biochar has a "nano-structure" which gives it beneficial properties in soil, it is more than that: it is also organized in pores at a "micro" scale that can provide a "refuge" for microbes to inhabit. At an even larger scale, it can interact with other soil constituents to modify soil structure. In the next pages you will learn more about how this works and why it's important.

HISTORY OF BIOCHAR

Scientists are still learning actually *how* biochar builds better soils. But biochar isn't a new discovery. In fact, charcoal use in soil has ancient roots, and our predecessors have long known that biochar can do good in soil.

Fire and the formation of some biochar are central factors in the maintenance of many natural ecosystems. Also, for thousands of years the application of biochar to soils has been part of routine farming practice in many parts of the world. Adding biochar to soil was reported in the 19th century as having "significant increases in farm revenues." "Fire Manure" is a 17th century Japanese description of biochar.

The earliest and best-known example of ancient use of biochar in soil is from South America's Amazon region, where the use of biochar dates back over 6,000 years. Indigenous communities began creating Terra Preta (Portuguese for "black earth"), a rich, loamy, fertile soil.

Most nutrients in the rainforest are stored in the lush plant life above and below ground. If the forest is removed, heavy tropical rains quickly leach nutrients from soil, and year-round hot, humid conditions lead to the quick decomposition of organic matter, leaving behind acidic, reddish or yellowish clay.

Terra Preta soils formed where villagers accumulated household refuse, much of which contributed nutrients, such as fish and animal bones contributing calcium and phosphorus. Charcoal was also incorporated along with other wastes, perhaps from on-site burns, or as residues from cooking or clay baking fires. Basically, Terra Preta soils formed under village trash piles which included charcoal and plant-nutrient containing residues. This "midden" origin of Terra Preta is quite obvious still today, because these soils are usually full of broken pieces of pottery.

Give biochar a try in your garden and watch changes develop in your soil & plant roots: the images on the right show Terra Preta soil which was made by humans, hundreds to thousands of years ago, in the Amazon Region, by adding biochar and other materials to soil. On the left you see the typical soils of the Amazon basin. The top pictures were taken at sites 200 meters apart.

Photo Top: pictures by Dr. Julie Major, bottom pictures by Bruno Glaser

This lighter, fertile, carbon-rich soil most likely allowed them to grow more nutrient demanding crops in small amounts near dwellings, while staples such as bitter manioc were grown in larger, more distant plots on soils which were also managed with biochar, but are nowhere near as fertile as actual Terra Preta.

Early observers believed this rich, dark soil was the result of natural geological processes, for example volcanic activity of sedimentation in ancient lakes. But by 1992, scientists realized these soils are not natural, but were made by the indigenous tribes.

Section 2

BIOCHAR BASICS

Before learning how biochar works to support soil and life, it helps to see what biochar is and where it comes from.

A small handful of biochar like this can be mixed with the soil when planting each tomato plant
Photo: Michael Cleary

Typically, the best Biochar begins as organic biomass. By photosynthesis, living plants capture sunlight to unite carbon dioxide (CO_2) with water to create carbohydrates. Plants combine solar energy, CO_2, water, and minerals into sugars and an array of other essential molecules, and build their tissues from sugar modified into fibers.

Pyrolysis is used to transform this biological matter—mostly plant, but animal manure can also be made into biochar. If biological matter can be dried and burned, it can be made into biochar.

Charring creates biochar's soil-improving chemical and physical properties. It also transforms carbon that was in an easily degradable form into carbon that can be sequestered in the soil on the very long term.

Biochar was applied at a rate of 10 tons per acre in rows behind a proud subsistence farmer in Cameroon.
Photo: Lawrence Rodemaker – Biochar.org

Charcoal is commonly made for fuel from wood or wood by-products. Yet grass, leaves, straw, hay, cornstalks, husks, nutshells, manures, and any natural waste can also be pyrolyzed to make biochar. Biochar made from biomass waste which has no other use is actually a great way of turning this waste into a valuable product ... vs. sending it to a landfill.

Depending on what it is made from and how it is made, biochar has different characteristics. For example, the maximum temperature reached during pyrolysis is important in determining the characteristics of the biochar.

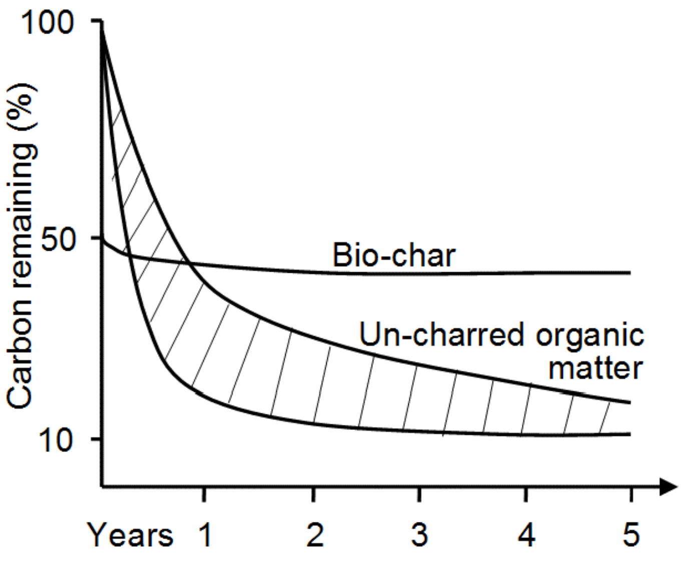
Chemically, biochar is mostly carbon, with embedded minerals and other constituents such as hydrogen and oxygen. In many productive soils, black carbon from naturally charred biomass constitutes up to a third of total organic carbon. Black carbon is a key, natural part of soil—closely linked to other forms of (uncharred) organic matter and nutrient cycles.

Biochar has the potential to expand our planet's supply of arable, productive land.

Biochar brings more than high-carbon richness to soil. Its carbon bonds strongly, resist

weathering, decay and decomposition. Biochar's stability in soil is one of its best long-term virtues.

"Ordinary" organic matter such as compost, mulch and manure decompose relatively rapidly in soil. Five years after a compost application, roughly 85 to 90 percent of the carbon returns to the air following decomposition into carbon dioxide (CO_2). (*See diagram below*)



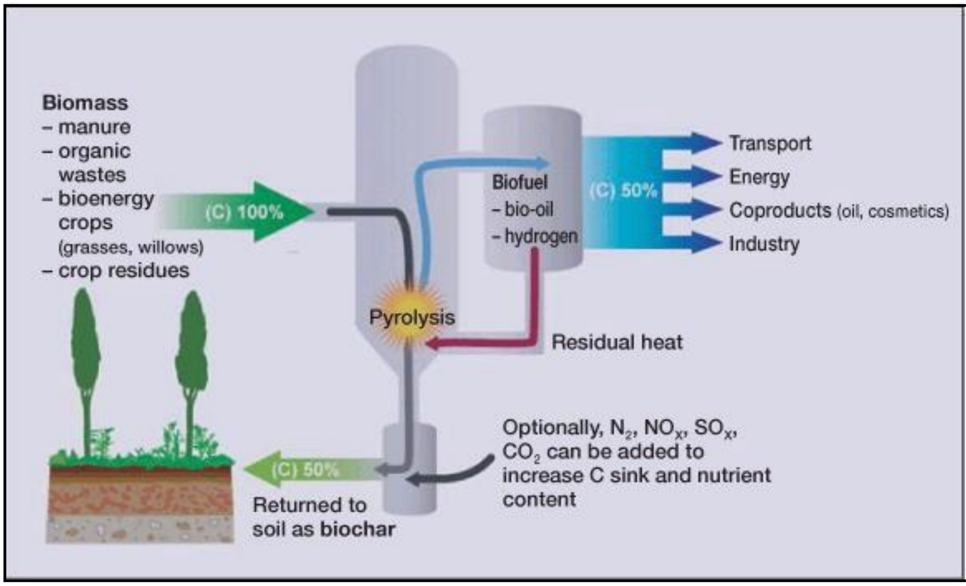
Strategies for Global Change

Figure from Professor Johannes Lehmann et al, 2006, Mitigation and Adaptation

During pyrolysis, roughly half the biomass carbon is captured as char, while the other half escapes as CO_2 while renewable energy is generated. Once created and applied to soil, a small amount of biochar carbon - the "mobile" fraction - is lost as CO_2 over a period of months to a year or more.

After this "mobile" carbon fraction is lost the stable, "resident" part of biochar remains. So once biochar is added to soil, the bulk of it is extremely stable and doesn't disappear, staying in the soil for hundreds to thousands of years. This carbon is measurable and verifiable, and could qualify for carbon offset credits when the necessary methodologies are completed and approved. The worldwide potential of arable land, including marginal land, to soak up carbon is large and significant. Using household, landscaping, farming, and forestry wastes to make biochar is simply our best, most natural strategy to suck CO_2 out of earth's atmosphere and store it in safe, stable, solid forms ... in our soils, where it also improves soil quality.

Globally, in the last century, soils that sustain our food supply lost an average of at least half their carbon due to farming practices. Biochar can help restore these soils.

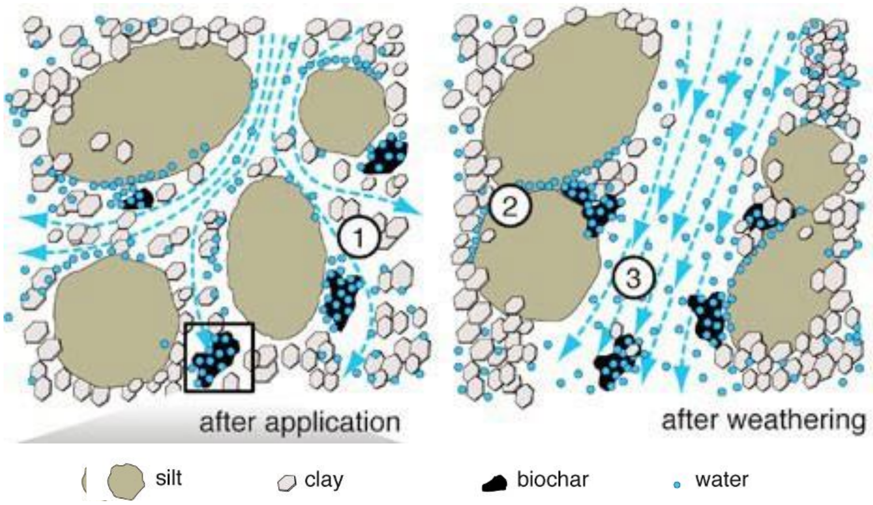


Biochar can be carbon-negative. Biomass subjected to pyrolysis forms biochar, which is a tool for carbon sequestration in soil. Energy is also produced in the pyrolysis process, and can be captured to displace fossil fuels. Biofuel systems are carbon-neutral at best; biochar systems have the potential to be carbon-negative.

Image from Lehmann et al. (2007), Frontiers in Ecology and the Environment

BIOCHAR PROPERTIES AND SOIL

Biochar's unique physical and chemical properties have the potential to permanently improve soil structure, enhance water circulation, improve nutrient availability and enhance beneficial microbial interactions with plants. Biochar can change the soil's structure to allow compacted soil to breathe, and create homes for microbes. Its durable, stable nature continues to maintain soil quality for centuries. Simply put, biochar can build better soils.



Biochar and soil structure (1) soon after application to soil, the high porosity of biochar means it can retain large amounts of water; (2) after weathering, the biochar helps the formation of soil aggregates, which include biochar and other mineral and organic particles in soil; (3) this allows a higher flow of water and air through the soil.
Image courtesy of J. Major

Adding biochar to a field or garden has the potential to increase soil quality, cut input costs and improve the nutritional quality of crops grown on poor soil. While biochar has many different effects on soil chemistry and biology, only some of its physical effects are easy to see. In soils with poor structure, a lighter, more crumbly soil is the most obvious.

Biochar can improve soil structure by attracting and binding particles into larger structures—known as "aggregates". Soils with better aggregation are properly aerated, are better able to let rainwater infiltrate and are less prone to erosion. In short, soils with better aggregation have better tilth. Such an effect is, however, unlikely to be visible in the short term – biochar needs time to interact with other soil constituents and its effect improves over several years after application.

Biochar Field Trials with James Madison University Shenandoah Valley, VA
Three rows of 5%, 10%, 20% biochar by volume blended with the soil.
Photos: Erich Knight

Early June 2009

Mid-August 2009

Soon after being added to soil, biochar can have an impact on the pore space within soil. Biochar itself is more than three-quarters empty space. These hollow cavities can store air, water, nutrients and beneficial bacteria and fungi.

Biochar does not decompose like compost or manure, which disappear from soil within a few years, creating a steady need for annual re-application. Years after being incorporated into your soil, biochar keeps on working and some of its effects improve with time. As biochar matures to improve aeration, drainage, nutrient retention capacity and tilth, it fosters beneficial soil microbes that perform key roles in nutrient cycling. Biochar builds a permanent healthy soil.

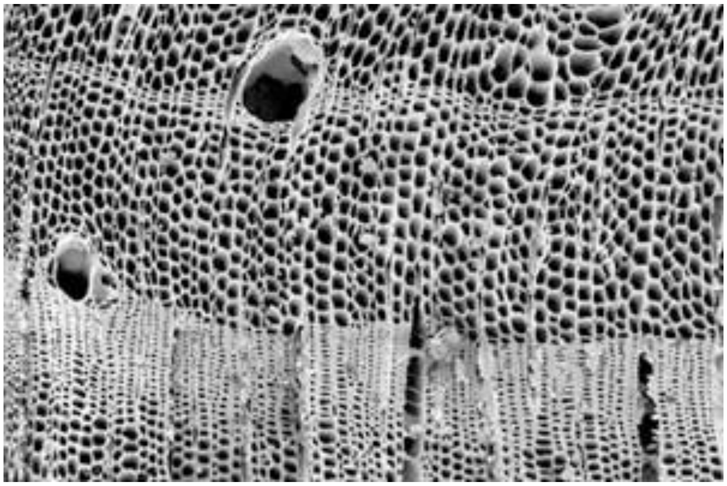
All these traits mean biochar combines the qualities of sand, clay, silt, humus, manure, compost and plant litter—all important components of a healthy, productive soil. Good biochar contributes more soil-improving properties than any of these components taken separately, but without negative effects from too much of any one component. Biochar does not work alone but in conjunction with all of these other soil components.

Biochar's beneficial effects arise from its interactions with water, air and soil. Researchers are still learning exactly how biochar's unique properties interact with each other and the environment. To understand how biochar produces its many benefits, let's examine what we currently know about biochar from four perspectives: fire, water, the air and soil.

BIOCHAR AND FIRE

Charring is a fascinating process. A progression of chemical reactions occurs as biomass is heated through drying and torrefaction phases and past the charring point. Temperature, type of biomass and duration of heating—all strongly affect chemical properties of the resulting biochar.

Different charring techniques create very different biochars with different effects in soil. Low-tech methods to produce biochar retain one-third to one-fifth of



Biochar's internal structure – magnified. Biochar consists of cavities that retain water & nutrients that are released when plants need them. What can be seen here are the larger pores of biochar, it also has pores that are too small to be visible. Photo: Hugh McLaughlin

Biochar enhanced soil (right) grows larger plants which give higher yields Photo: Kanso Technology

the carbon from the original biomass, which otherwise goes up into the air as carbon dioxide and methane, to a lesser extent. Modern, improved production of biochar is optimized to capture up to half the carbon as char—before it can return to the air, and minimize smoke and the emissions of greenhouse gases such as methane. Such improved techniques can be simple – for example, home-made cooking stoves – or more high tech, like industrial plants.

"Pyrolysis" and "gasification" are technical terms for processes that create biochar. They heat biomass past the charring point, but with little or no oxygen. Since not

Biomass Combusted Forest & prairie fires produce only 1% char due to the open-air environment that fuels it. *Photo: Dept of Conservation & Natural Resources*

Wood chips charring inside the BiG Char rotary hearth kiln. *Photo: Hawaii Biochar Products*

enough oxygen is present, the biomass isn't burned completely to ash. Instead, it is thermally disassembled and converted into water vapor, gases, liquids, oils, tar, and biochar.

In an oxygen-rich burn, only ashes remain after total combustion of biomass. But forest fires and wildfires also generate natural biochar. Low temperature smoldering fires are a natural charring process in prairie and forest ecology. Pyrolysis develops wherever low- or no-oxygen conditions occur in fire's uncontrolled chaos.

Modern pyrolysis uses a closed container to control the process, restrict air flow and convert biomass to biochar. High-tech systems can also extract useful energy and chemicals. These technologies are much cleaner and produce minimal emissions compared to traditional, smoky charcoal production.While pyrolysis and gasification can be industrial scale, they are also useful to home gardeners and large and small farmers everywhere. Biochar is an option for anyone—from large-scale growers to diversified organic farmers. Biochar can provide benefits at every scale—from corporate agriculture to orchards, vineyards, small farms,

The first generation Biochar 1000 unit from Biochar Engineering, LLC is a mobile pyrolysis unit to produce biochar, circa 2014 *Photo: Hawaii Biochar Products* vegetable plots, suburban backyard gardens, backyard landscaping, and your houseplants.

This kiln has pipes for burning the smoke, to greatly reduce emissions from the process.

*Nature's Nano Technology – the least material to create the greatest **surface area*** Photo: David Yarrow

BIOCHAR AND WATER

Biochar can have dramatic effects on water retention in sandy soils, which by nature are poorly able to retain moisture. Biochar's porous structure and reactive chemistry can both strongly affect water. Yet, right after exiting a pyrolysis unit where it was heated to 500 ˚C, biochar is bone dry and tends to repel water. After it is exposed to humidity in the air or "quenched" by wetting, its relationship to water dramatically changes from "phobia" to "philia". This means that after an initial wetting of "unwilling" biochar, it easily sorbs large amounts of water.

*Biochar has hundreds of thousands of square feet of surface area in each ounce – greater than our human **lungs*** Photo: Dr. High McLaughlin

Chemically, plants are mostly water—up to 90 percent. So plants consist largely of plumbing to move water from roots to leaves—bundles of tubes, pipes and veins. Thus, plant matter is mostly hollow inside. Properly made, biochar preserves this microscopic structure of the original biomass.

Biochar itself is more than three-quarters empty space—protected internal micropores that store air and water to support efficient nutrient cycling. This increases aeration and drainage, and may reduce the likelihood of water logging.

When there is plenty of water in soil, water moves into biochar's pores. As the soil dries up after a rain event, some of the water retained inside biochar pores slowly moves toward the edges of a biochar particle, and into plant roots. This and the fact that biochar holds large amounts of water, means it may be able to supply water to plants more effectively than sandy soil can.

Although these effects have not been demonstrated yet, the characteristics of biochar indicate that biochar-amended soils are likely to be more resistant to desiccation (dehydration) through water storage in an extensive pore structure. This is most likely to occur in soils that have a poor ability to retain moisture. In soils that have a poor ability to drain, like poorly aggregated clays, a biochar amendment has the potential to reduce water logging and oxygen-depletion or souring through better aggregation and aeration. However, it is not known how long it takes for these effects to develop.

BIOCHAR AND AIR

Biochar can improve aeration and gas exchange in poorly aggregated soils, as it improves soil structure over time. Biochar is very lightweight—less than 20% of the weight of sand. This extremely low density makes it great to build a lighter soil.

Biochar brings air into soil by its own porosity—it is essentially 85% hollow—and also by causing aggregation of soil particles, which adds more airspace (pore volume) to soil. Proper soil aeration is crucial to a healthy balance of nutrient-cycling microbes.

Biochar can also reduce the emission of greenhouse gases from soil. Several researchers documented reductions in nitrous oxide emissions from biochar-amended soil. This is relevant because nitrous oxide is 298 times more potent a greenhouse gas than is CO_2. Biochar can also help reduce ammonia losses from manures and compost, and has historically been used to reduce odors in these materials.

Biochar can keep more nitrogen in soil and available for plants. Often, a significant portion of applied nitrogen fertilizer is lost by leaching and through gaseous losses. Biochar keeps more nitrogen in soil, in a plant-available form, and out of the atmosphere and waterbodies. Plants may obtain more nitrogen, over a longer duration, in biochar-amended soils.

Rootball with Biochar & Compost For size comparison, the larger square chunk of Biochar in the foreground is ¾"
Photo: Josiah Hunt

Moss thriving on 1-year-old biochar
Photo: David Yarrow

BIOCHAR AND SOIL

We've learned that biochar can improve soil structure over time, making soil more resilient and carbon-rich. It also allows soil to become alive, and we'll explain how in the next few pages.

Mycorrhizae on Biochar hyphae and geminating spores
Photo: Dr. Paul Hepperly

Agro-chemical run off into our streams, rivers and watersheds creates unnatural algae blooms in our water systems, which in turn, consume much of the oxygen in the water, creating an environment that shellfish and fish cannot survive in, called "dead zones"
Photo: Michael Cleary

The soil's ability to hold positively charged nutrients (cations, "cat-eye-ons") such as potassium and calcium, is measured by the "Cation Exchange Capacity" or CEC. CEC may be the least understood of the values given on a soil analysis report, but it helps to remember that cations are nutrients with positive charges, including ammonium which is a positively charged form of plant-available nitrogen.

Biochar has the potential to improve the soil's CEC, in other words, to directly retain many plant nutrients on its surfaces, thereby preventing these from being washed away through soil after heavy rainfall events. This happens because biochar surfaces develop negative charges over time thus retaining more cations for future plant use, since negative charges attract positive charges.

Biochar has also been shown to sorb and reduce the mobility of several agrochemicals such as herbicides and insecticides. Biochar in soil can thus reduce leaching of fertilizers, agrochemicals, and nutrients from our gardens, turf, wood lots, forests and fields. Biochar amendments can protect our streams, rivers, lakes, watersheds—even distant fisheries—from run-off of agro-chemicals, fertilizers and manures . This in turn would reduce lake eutrophication, red tides, harmful algal blooms, and oxygen-deprived "dead zones" in water bodies. The retention capacity of biochar can also reduce pollution of groundwater in private and public wells.

These nutrients that biochar retains are known to remain available to plants. Biochar surfaces become locations for plant roots to easily obtain needed nutrients. Plant root hairs can grow inside the larger pores of biochar, and remain attached if the plant is pulled from the soil.

Incorporating organic matter is a common way to raise the soil's CEC. This can acidify the soil as the compost rapidly decomposes. Biochar, on the other hand, may raise soil CEC and it does so on the long term, since it decomposes on century or millennial time scales. This slow decomposition also means it won't acidify soil.

Roots growing in the biochar
Photo: Hawaii Biochar Products

BIOCHAR AND LIVING SOIL ORGANISMS

Dr. Nardi, a University of Illinois scientist, writes in his book "Life in the Soil," that a square meter of healthy garden soil is home to 10 trillion bacteria, 10 billion protozoa, 5 million nematodes, 100,000 mites, 50,000 springtails, 10,000 creatures called rotifers and tardigrades, 5,000 insects and arachnids, 3,000 worms and 100 snails and slugs. Throw in the occasional mammal such as a chipmunk or a mole, and a salamander or two, and you get the idea that you don't have to travel to the Brazilian rainforest to luxuriate in the biodiversity at our feet.

In addition to storing water and nutrients, the healthiest soils support a diversity of beneficial microorganisms: bacteria, fungi, protozoa, and other micro, meso and macro fauna. These beneficial organisms transform and cycle nutrients—processes that build richness, conserve nutrients, and support sustainable productivity. The primary goal of biological agriculture is to make soil come alive with stable, diversified, intimately organized microbial communities.

In E. O. Wilson's 2002 book, "The Future of Life," he opens with a letter to Henry David Thoreau updating him on our current understanding of the nature of the ecology of the soils at Walden Pond.

> *"These arthropods are the giants of the microcosm (if you will allow me to continue what has turned into a short lecture). Creatures their size are present in dozens-hundreds, if an ant or termite colony is present. But these are comparatively trivial numbers. If you focus down by a power of ten in size, enough to pick out animals barely visible to the naked eye, the numbers jump to thousands. Nematode and enchytraied pot worms, mites, springtails, pauropods, diplurans, symphylans and tardigrades seethe in the underground. Scattered out on a white ground cloth, each crawling speck becomes a full-blown animal. Together they are far more striking and diverse in appearance than snakes, mice, sparrows, and all the other vertebrates hereabouts combined. Their home is a labyrinth of miniature caves and walls of rotting vegetable debris cross-strung with ten yards of fungal threads. And they are just the surface of the fauna and flora at our feet. Keep going, keep magnifying until the eye penetrates microscopic water films on grains of sand, and there you will find ten billion bacteria in a thimbleful of soil and grass. You will have reached the energy base of the decomposer world as we understand it 150 years after your sojourn in Walden Woods."*

Soil conditions in overworked, degraded, or naturally poor soils are unfavorable to the activity of beneficial bacteria and fungi to cycle nutrients.

Such soils are not as productive, and can foster disease-promoting conditions. Biochar can sustain nutrient cycling by supporting communities of microbes that are beneficial. Biochar's honeycomb micropores become filled with bacteria and fungi. Its vast internal areas are spaces for microscopic creatures to inhabit.

Biochar can be seen as one of the nicest foundations a bacterium could ask for. Once added to soil, biochar becomes a perpetually moist microhabitat where bacteria are nourished, and well-protected from predators.

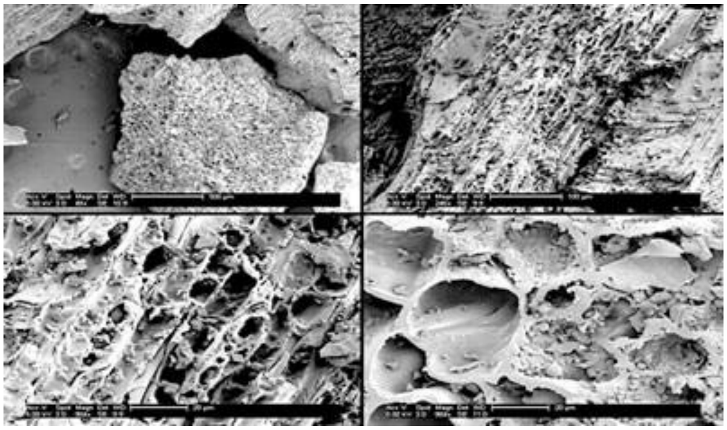
These pores provide seemingly endless internal spaces that become like luxury condominiums for soil's beneficial bacteria and fungi. These residential refuges promote biodiversity for more complete and efficient nutrient cycling.

Biochar restores activity and diversity to bacterial and fungal communities needed to build healthy, productive soil. Its porous structure, its jumble of biologically active surfaces, make it ideal habitat for nutrient-cycling bacteria and soil-building fungi.

Scientist studying Terra Preta in South American rainforest describe its teeming microbial communities as a "microbial reef." Like a coral reef does for sea-life, biochar does for the soil, supplying food and shelter. Instead of sheltering marine life, biochar supports an underground ecosystem of fungi, bacteria and other organisms—the base of the soil food chain. When times are lean, biochar is a reservoir storing bioavailable nutrients. When times are full, biochar is a platform for microbes to launch a biological bloom of soil-enriching activities.

National Geographic called biochar a "soil within the soil." At plant scale, roots search the soil for water and nutrients. At a microbial scale, bacteria and their buddies eat molecules retained in biochar pores to convert them into nutrients for plant roots. Biochar promotes resilience and diversity in this network of nutrient cycles.

A gardener can let this "microbial reef" do the work of growing strong plants, while biochar helps to buffer changing rainfall and water, unusual weather and fluctuations common to garden soil.



Carbon Condominiums: Utilities Included, fungi & bacteria wanted. Increasingly magnified biochar

As a Coral Reef is to Marine Life, Biochar is to Soil Life, creating a healthy environment where many beneficial species thrive.

Gardeners should see themselves as microscopic zookeepers—raising and sustaining vibrant communities of soil microbes. Growers should see soil as a complex living system—to be stewards of living microbial ecology.

Nitrogen is a primary nutrient crucial to soil balance and plant health. How plants use this element that is present mostly as an atmospheric gas is an instructive example of interactions between microbes and biochar. The entire nitrogen cycle in soil is driven by microbes, and seems to work better with biochar.

Bag of Soil Reef Biochar. See SoilReef.com for Availability Photo: Soil Reef LLC Product

In the soil, nitrogen can be in organic form, or be present as an anion (nitrate, $NO3^{-}$) or cation (ammonium, $NH4^{+}$). Biochar has been shown to reduce the leaching of both nitrate and ammonium from soil. Thus, biochar soaks up excess nitrogen and later releases it when plant demands increase.

On this planet, the vast majority of the nitrogen is in the air. This nitrogen is in a very stable form that cannot directly be used by any living organisms. To produce the nitrogen fertilizers which agriculture today so strongly depends on, large amounts of fossil fuel energy are required. However, nature has its own elegant ways of "fixing" atmospheric nitrogen, in other words to transform nitrogen from the air into compounds that living organisms can use. This transformation is done mostly by microbes living in the soil and oceans. Many types of bacteria fix nitrogen in soil. Best known are Rhizobia, which live in symbiosis with legume plants such as beans, peas, alfalfa, clover and some trees. The bacteria are allowed inside small root structures called nodules, following very complex communication with the plants. Once the nodules are formed, Rhizobia provide the plants with nitrogen they can use, and the plant provides the Rhizobia with the sugars they need for energy.

Biochar has been shown to stimulate nitrogen fixation through rhizobial symbioses in legumes growing in poor soil. Also, on the biochar-rich Terra Preta, nitrogen–fixing legumes are often found to be more prevalent than on adjacent, "normal" soils.

Arbuscular Mycorrhizal Fungi (AMF) are beneficial "root-enhancing" fungi. They also live in symbiosis with plants, help build quality soil, and provide essential nutrient cycling services to plants. As in the case

of symbiotic nitrogen fixation, plants usually provide the fungus with sugar made from sunshine through photosynthesis. Mycorrhizae supply plants with water, key nutrients such as phosphorus and zinc and protection from disease.

Fungal Hyphae spread over leaves, beginning digestion

An AMF fungal spore germinates and grows out into a dense profusion of thin, white threads. Each white whisker—called "hyphae"— searches soil, sucks up water and minerals which it then trades for sugar from plant roots. This network of hyphae greatly expands the volume of soil which a plant can explore using only its own roots, helps ensure steadier nutrient supplies, and improves drought resistance.

When soil is amended with biochar, interactions between plants and mycorrhizae have been observed to be enhanced. Biochar's mycorrhizae-promoting effect has not yet been fully studied, but researchers think that changes in nutrient availability, effects on other soil microbes and soil chemicals, and the fact that biochar can provide mycorrhizae with a refuge from predators could be important.

Those hyphae—the threads piping water and nutrients through soil—secrete a glycoprotein residue called "glomalin"- a sticky substance that binds soil particles together to increase aggregation.

Glomalin is a carbon-containing molecule which decomposes a lot more slowly than other organic matter in soil, so more mycorrhizae mean more glomalin and thus more carbon buildup in the soil. Biochar can help catalyze this.

Mycorrhizal interactions are a well-known symbiosis between plant roots and fungi. These mutual relationships are pervasive throughout Nature, including our gardens, farm lands and forest soils. We have much to benefit from these symbioses, if we promote them.

BIOCHAR IN THE GARDEN

"*Chicken Soup for the Soil*" is one way gardeners can view biochar.

Biochar brings fire's benefit back to the garden, without fire's disadvantages. Restoring fire's by-products to soil will go a long way to restore natural quality to soil. Gardeners can do a lot to revive soil's natural fertility by simply, properly adding appropriate biochar, Nature's nano-technology.

Biochar is not a fertilizer. The bulk of it is not eaten by microorganisms. Biochar provides many services to soil. As a soil builder and stabilizer, biochar can increase productivity, and the gardener may save of manufactured NPK fertilizer. This is your typical fertilizer found in a garden supply store, for example 8-12-6 which contains 8% nitrogen (N), 12% P_2O_5 (5% phosphorus (P), and 6% K_2O (5% potassium (K).

Biochar can improve soil's physical structure and chemistry, but also soil biological factors, because biochar supports beneficial microbes that promote overall soil health. 20th century thinking used *chemistry* to supply nutrients and help achieve higher crop yields. 21st century food production focuses on soil *biology*, with "probiotic" strategies to strengthen the soil food web and sustainably improve and maintain soil quality and resilience.

For land managers concerned about the carbon cycle in the balance of Nature, biochar is a way to take carbon dioxide out of air by changing it into a very stable material and returning it to soil to remain sequestered for centuries.

Currently, the most difficult thing about using biochar is simply to get some. This potentially carbon-negative technology is so new that few businesses, equipment and technologies exist to supply large amounts of cleanly made, appropriate biochar for broad-scale land application.

Biochar enthusiasts are still learning how to best use biochar in different gardening situations. Here we provide guidelines for you to consider and experiment with. Always start small when working with biochar for the first time in a given situation, as you would with any new technique. Keep in mind that biochar is not a single material – depending on what it is made from and how it is made, biochar can have beneficial, neutral or detrimental effects in a given soil and cropping situation. Even different biochar batches from a small backyard pyrolysis unit can be very different. So be cautious until you have mastered your own biochar making process, or you have found a supply of good, consistent biochar and know it works for you. Remember that once biochar is in your soil, you cannot get it back out. The International Biochar Initiative provides a free technical bulletin (IBI Technical Bulletin #101, available in several languages) outlining simple tests to ensure a biochar is safe before applying it to soil.

BIOCHAR ON THE FARM

The link below will take the reader to an article that focuses on the "bulk" application of biochar on a "working" farm. Beginning in 2015, it covers, in some detail, the "why", the "how", and the "results" of this bulk biochar application. This is one of the early large-farm examples, and is joined today by an ever-larger group of farmers recognizing the soil/ economic benefits of biochar.
https://rockdustlocal.com/uploads/3/4/3/4/34349856/downthewormhole.pdf

BIOCHAR TRIALS

Left: No biochar was used for the control
Photos: Hawaii Biochar Products

Right: Biochar used within the soil blend.
Photos: Hawaii Biochar Products

PREPARING BIOCHAR FOR SOIL

Biochar's capacity to absorb nutrients makes it a potentially optimum delivery substrate for plant nutrients. These prime nutrients will be held on biochar surfaces, with little chance to leach, easily available to microbes and roots. Blending biochar with fertilizers, compost, manures and inoculants is a wise approach to efficient and effective use of resources. Many biochar materials tend to be quite dusty. Avoid breathing charcoal dust as this can represent a health hazard. Mixing biochar with other, wet amendments such as manure or compost will help control dust. Simply wetting biochar with water will also control dust, although you should make sure you weigh biochar before wetting it, if need be. Always wear a dust mask when handling biochar. A simple paper mask used against flu germs works fine.

BIOCHAR PARTICLE SIZE FOR GARDENING

To microbes, the best part of biochar is the smaller bits. Over time, biochar will break into smaller particle sizes (but not decompose) which increase the surface area of any given piece. In soil, the most precious part are these finer particles, which eventually "aggregate" soil particles into larger clumps needed for open pore space and aeration. In the nanometer world of microbes and molecules, a thumb-size piece of char is a massive metropolis like Los Angeles.

James Madison University Summer 2009
Left Side Control Strip – No Biochar
Right with Biochar – Crops performed better, had better color & higher yields
Photo: Erich Knight

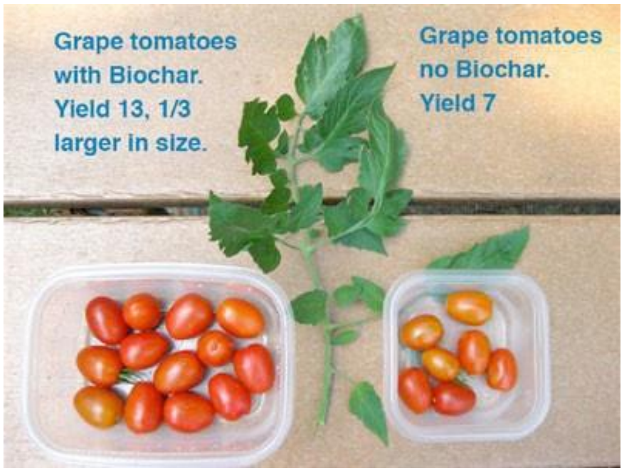
Biochar is very brittle and shatters easily. It's easy to crush or grind into pea and coffee bean size, before working/tilling into the top 4-6 inches of your soil. Moistening biochar before crushing will go a long way to keep dust down. You can also crush it inside a bag or sack to help control dust.

Remember to always use a dust mask when crushing biochar.

Sift out precious powder to use for special purposes, such as seed starter mix, or adding to compost tea. You can also add fine biochar to water, shake and use to water your house or outdoor plants. Larger size pieces up to 1.5" can be used for soil mixes or tilled right into the soil for larger gardens as well as farms, to potentially substitute peat moss, vermiculite, perlite, or zeolite.

INOCULATION WITH MICROORGANISMS

In soil, microorganisms play key roles in cycling nutrients, and biochar can stimulate these functions. Biochar fresh from a pyrolyzer is devoid of life and gradually becomes colonized by microbes after it is added to soil. Inoculating biochar with nutrients and microbes may provide beneficial results in a shorter time frame. Alternatively, one can certainly just put biochar directly into the soil and wait for Nature to take over.



First Harvest – Head to Head Test
All future harvests outperformed the "No Biochar" Test Cell.
Perform your own trials
Photo: Michael Cleary

Many strategies and substances are available to activate biochar and inoculate it with beneficial microbes, including compost, compost tea, biodynamic preparations, EM (effective microorganisms), mycorrhizal inoculum, bacterial sprays and earthworm castings.

The easiest way to inoculate is to blend biochar with compost, for example in a 50/50 ratio, then let it "age" at least two weeks with adequate warmth and water. This "primes" the biochar to preload it with freshly released nutrients and microbes. The aging period allows time for microbes to physically inhabit biochar. During this time, biochar's color changes from shiny black to lusterless gray.

APPLICATION RATES & METHODS

Gardeners and landscapers can manually incorporate biochar into soil by hand at the time of planting—or any time thereafter. Larger applications are possible with a wide array of tools and equipment to spread biochar on the soil and mix it/till it safely into the root zone of the plants you are planting.

Biochar is very lightweight, so a given volume weighs less than most soil ingredients—20% of sand, for example. A general rule of thumb is up to one pound per square foot. This maximum rate has not often been tested, so it should be considered to be on the high end. You should start on a small scale with smaller rates, for example a third of a pound per square foot. When adding biochar to mixes, the rate of one pound per square foot roughly corresponds to 2.5% by weight. This value requires assumptions to be made on the density of the biochar and of the rest of the mixture, and these densities can vary considerably. In short, consider these to be rules of thumb and run your own experiments, conservatively to begin with.

Gardeners need to be especially wary of applying too much biochar when using biochar made from manure. Biochar from manure can contain lots of ash (which is basically salt) and unless this ash is washed out by abundant water before seeds are sown or seedlings transplanted, it can cause salt stress and even kill plants if a high application rate is used.

Gardeners should strive to maintain their soil's carbon level at a minimum level of 5 percent, and ideally at 10 percent. Depending on the availability of biochar, you may consider splitting applications into several smaller amounts applied over a few growing seasons, rather than one single large treatment. However, note that in research done to date biochar was always applied at one single time, and positive results were usually observed.

BIOCHAR TEST APPLICATION RATE

0% Biochar | *20% Biochar* | *10% Biochar* | *5% Biochar*

Landscape Ecology – Hawaii – note the higher application rate of 20% didn't increase growth any more than the 10% test rate

Photo: Josiah Hunt

One potentially effective way to spread biochar, as we mentioned before, is to add it to compost. This moistens the biochar, makes it easy to handle, and minimizes wind losses of the fine particles at the bottom of the bag or bucket. If applied directly to the soil's surface, biochar should be tilled into the root zone as soon as possible. Remember that the very fine biochar powder is also precious; don't let wind blow it away ... keep it out of the air by moistening and till it into the soil.

Biochar can make better compost. It reduces odors and gaseous losses, soaks up nutrients so they don't leach out the bottom of the pile, and provides stable habitat for composting microbes. This can shorten composting time, and yield a higher quality product.

DO YOUR OWN RESEARCH

Biochar research is ongoing—by soil scientists at leading agricultural universities, the US Department of Agriculture and Agronomists at many private and public companies. Research is also being conducted in backyard garden and on farm test plots. Do your own biochar testing. Cultivate crops with raw biochar, "inoculated" biochar and without biochar, to serve as a "control" plot and see for yourself what happens. To make sure you experiment with treatments that will allow you to fairly compare the effect of biochar to other practices, consult the International Biochar Initiative's *Guide to Biochar Field Trials* and/or talk to people around you who have experience with testing agronomic inputs, for example local cooperative extension staff.

Educate yourself. Many websites and online communities worldwide are devoted to learning to make and use different types of biochar. Email lists allow you to join the discussion of biochar experimenters. News articles and research reports emerge weekly now. Businesses and organizations offer information and services.

Tell others about this new technology. Explain this new carbon–sequestering strategy for planetary health and sustainability to other gardeners, landscapers and farmers to stimulate their interest and participation.

Become an advocate. Talk to your local nursery, university and politician about this new paradigm for personal health, food security, economic prosperity, and renewable energy independence. Spread the word how this "new" 6,000-year-old method can sustainably sequester carbon and grow better food.

FARMING AND BIOCHAR

Biochar offers farmers the potential to reduce input costs, increase yield and improve soil quality. Applied only once, biochar can permanently improve arability and reduce future costs for fertilizers and soil treatments. The permanence of biochar and the fact that its beneficial effects improve after application should be accounted for when comparing the costs and benefits of biochar application. Doing this can be difficult, since very little information is available for farmers to use in their calculations. This is another reason why we encourage you to experiment with biochar on a small scale and generate numbers for your farming conditions, and to share that information with others.

As biochar matures and becomes intimately linked to other soil constituents, it continues

At left, 4 tons biochar/acre and at right, 6 tons biochar/acre in 2009 field trials at JMU Shenandoah Valley, VA

Photo: Erich Knight

to improve aeration, drainage, and the soil's ability to hold nutrients through a greater CEC.

As discussed previously, biochar is not a replacement for fertilizer. Biochar is not a food for plants or microbes. Fertilizer, compost and/or manure should be used with biochar. Since biochar's beneficial effects build up over time, greater fertility improvements immediately after soil application may be observed if biochar is pre-treated, formulated or inoculated with soil microbes. As a soil builder and quality enhancer, it only requires incorporation into soil. Biochar can maintain soil productivity with less fallowing, rotation or other down-cycles, over generations—as in the case of Terra Preta. No other soil amendment can provide such benefits. Biochar however is not a panacea. Just as Terra Preta soils can become degraded by overuse, biochar must be a tool in a broader strategy to properly manage soil.

Most biochar has a liming effect on soil, neutralizing acids that occur naturally or build up with cropping and fertilizing. Biochar can reduce the need to apply liming materials. Biochar promotes soil particle "aggregation" to increase aeration, rain infiltration and drainage within soils—all essential to minimize desiccation or souring.

Biochar compost application at Loeffler Farms in Pepe'ekeo, HI where soils are poor and land scarce.
Photo: Josiah Hunt

Cape Cod, MA turnips on Biochar
2 – 3 times the size of typical turnips grown there … and still delicious Proudly grown by Bob Wells
Photo: David Yarrow

Biochar has many different properties and a multitude of effects. As stated above, yield increases are associated with biochar applied at rates of 30-40 cubic yards per acre. This large range comes from research carried out using many different soils and crops, and optimal rates for any given soil/crop combination cannot be given at this time. You should experiment to determine which rates are best in your situation. Again, beware of high application rates especially when working with high-ash biochars such as those made from manures.

Productivity gains are likely to be greatest, at least in the short term, if biochar is thoroughly mixed into the root zone. Banded or broadcast surface application will benefit soil as biochar works its way into soil, but soil quality and crop yield benefits may take longer to be observed.

Moistened biochar should apply well with any equipment used to spread manure, compost or lime. Pneumatic systems designed for granular materials like seed, or some fertilizers should be used after adjustment to the equipment or careful sieving of the biochar to assure regular flow patterns.

Uniform topsoil mixing—disking or plowing biochar into surface soil—is ideal, but low-till or no-till operations can add biochar between rows, into repairs and new plantings, or mix with compost and mulch around plants or trees as top dressing. Users of biochar must be aware that dry biochar left on the surface can rather easily be blown away by wind or transported by heavy rainfall. Therefore whenever biochar is left on or near the soil's surface, care should be taken to protect biochar from erosion by using cover crops, for example.

Beans at 1 week without Biochar

Beans at 1 week with Biochar

Beans at 5 weeks without Biochar

Beans at 5 weeks with Biochar

Photos: Hawaii Landscape Products

Mixing biochar with other amendments can make application easier. Creative suggestions to get biochar into soil include coating seeds with biochar. Another is to add biochar to animal feed and let the animals deposit it. Research in several countries documents biochar's benefits to animal digestion, health and productivity.

While the production of biochar for soil application is still in its infancy, researchers speak of "designer biochars", which would be optimized for producing the best results on given soil types and given cropping systems. Biochar makers can change the biomass feedstock they use and modify pyrolysis conditions, such as maximum temperature, duration and oxygen level, to create biochars with different properties. Depending on production conditions, biochar can be made with high or low pH, thereby reducing acidity or alkalinity after application to soil. Biochar can also be designed to be high in certain nutrients—such as potassium or phosphorus—depending on the feedstock used.

For the typical farmer, an application rate of a minimum of 2 metric tons per acre may be a good place to start. Even though biochar is a one-time soil enhancer, it might not be possible for a farmer with several hundred or several thousand acres to finance the application of this or a larger rate of biochar to a large area. Starting with a smaller test plot on 1/4 to 1 acre, at application rates of 2 metric tons per acre is more economical and can be followed by small incremental applications until you find the right percentage for your soil. In order to appropriately design a biochar experiment. No matter the scale, plan ahead and get help. You can consult the International Biochar Initiative's *Guide to Biochar Field Trials* or talk to people around you who have experience with testing agronomic inputs, for example local cooperative extension staff.

Biochar holds many opportunities for benefits greater than just gains from increased productivity. Biochar in soil is a form of sequestered carbon, so biochar application may be a way to earn "carbon credits" that can be sold for additional income.

Opportunities to minimize costs to produce and distribute biochar are best realized by local associations, businesses or farm cooperatives. Subsidies may be an option in the future for local governments and civic organizations to support biochar projects to promote economic development while improving air and water quality, soil resilience and productivity.

One way to create businesses and employment is supporting projects to manage forests by making biochar out of beetle-killed trees, and material removed to reduce the amount of fuel for forest fires. Also, invasive tree & plant species removal projects will benefit from the incentive of markets for biochar and bio-fuels. In all cases, project proponents should strive to realize the full potential of biochar as a tool for sustainable land management and climate change mitigation. Not all biomass can and should be made into biochar, at all times and in all places. Environmental impact assessments of biomass removal should be carried out whenever relevant.

Collection and processing of biomass to make biochar must develop into local businesses and regional industries that create employment and careers to produce, design, assay, and distribute biochar—and associated bio-fuels. The development of a biochar industry will be most sustainable if it is undertaken locally to solve local problems, and taking the local environmental and social reality into consideration.

CONCLUSION

Properly designed and implemented biochar systems have the potential to conserve and protect our natural resources while improving our well-being and prosperity. Technologies to produce biochar can be scaled from simple home-made methods to farming systems and industrial processes that co- produce gas, bio-oil and heat energy.

Biochar production benefits both individuals and our overall society, and can create jobs, build careers, develop businesses and initiate industries for its production and use. Biochar rewards us with increased crop productivity while it enriches soil, and thus our food. We need to take advantage of these potential opportunities – simple, ethical choices with far-reaching benefits, such as energy-producing biochar systems.

Sally Brown, an eminent commentator for Bio-cycle Magazine: "... bring the char, but also bring the no till, compost, cover crops, limestone and a range of other options to restore function and health to your soils." Further, specific biochars are likely very good for specific things under specific circumstances, like binding metals on contaminated sites. They might also be important for reducing odors during composting. Finding the char that is right for its use will certainly be the focus of much of the scientific research moving forward."

A key part of "Nature's Nanotechnology" might be the best way to describe biochar and its host of unique properties.

Finally, there are expanding applications for biochar in various environmental areas beyond soil reclamation and remediation, particularly in dealing with water issues. Information in these areas are available on the web or by contacting us at Char-Help@SoilReef.com. The focus of this material has been educational in regards to biochar and its soil application for plants.

WEB RESOURCES – SOME USEFUL LINKS:

- **United States Biochar Initiative:** www.biochar-us.org
- **International Biochar Initiative:** www.biochar-international.org
- **Terra Preta BioEnergy Lists:** www.terrapreta.bioenergylists.org
- **Field Applications of Biochar:** www.biochar-international.org/wp-content/uploads/2018/04/IBI_Biochar_Application.pdf
- **Biochar Particle Size & Water Properties:** https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0179079
- **Biochar & Prepping it for Soil:** http://www.ecofarmingdaily.com/biochar-prepping-soil/

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