

Carbon-Negative Farming Using Biochar in Soil

by David Yarrow, December 2010

Wood, Fire & Wire

IN MAY 2010, A CATTLE FARMER NEAR JAFFREY, New Hampshire told me about an unusual fly ash by-product. A NH utility has eight plants burning certified wood chips to generate electricity. One plant has a technical limit that prevents complete combustion of the wood, and yields fly ash that's 60% carbon.

The farmer explained a recycling company sells fly ash from the eight utility burners to farmers. Since these plants only burn wood from trees, their ash is a registered NH Dept. of Agriculture soil amendment. Feedstock is forest-grown wood, so the ash contains the same balance of elements needed to grow plants, and unlikely to contain excess toxic metals and heavy elements. Thus, fly ash from these eight incinerators is considered safe for soil use. However, this fully oxidized ash is very alkaline (11.0), and must be used lightly and intelligently.

The one unique burner operates in a carbon-capture mode, retains a lot of Carbon as charred wood, rather than spew all the Carbon up its exhaust flue as CO₂.

The beef farmer asked: Can this 60% carbon fly ash be suitable in soil as biochar? This certified biological matter undergoes restrained combustion to leave most Carbon un-ignited. Can this fly ash be classed as "biochar"? Can it sequester Carbon?

Carbon, Climate & Farming

Carbon, third most abundant element of life, is the backbone atom of biology. Carbon forms four bonds to other atoms (*figure 3*). Carbon's 4-armed, 3-sided, tetrahedral geometry (*figure 2*) can build chains, rings, sheets, and spirals—and more elaborate architectures. Organic Chemistry—the science of Carbon—identified tens of thousands of biological molecules.

Carbon is usually black. Carbon absorbs all colors, radiates none. Diamond—crystal clear Carbon—is a notable exception.

Black expresses Carbon's absorbing nature. Carbon attracts and holds any energy it encounters. In circuits, Carbon absorbs electrons to resist current flow. In water, Carbon adsorbs ions to filter them from solution. In cell biology, Carbon surrounds ions to enclose and insulate strong electric charges. In compost and soil, Carbon is sponge to absorb water, minerals and odors. The first nuclear reactor had graphite (carbon) rods to absorb neutrons and restrain a chain reaction.

Carbon is very mobile—always moving, changing location, form and function. Thousands of biological molecules are formed from Carbon—chains and rings. Sugar, protein, fat, oil, enzyme, hormone, DNA, RNA, membrane, shell, bone, skeleton—all built with a Carbon backbone. Carbon is the signature element of life.

Carbon is so mobile, science sees it as a **Carbon Cycle**, and tracks its movements through the biosphere in various geological and biological forms. Of Carbon on land, 75% is **Soil Organic Carbon (SOC)**. Very little Carbon was in Earth's atmosphere—until recently.

Carbon in the air now challenges our human future. Deforestation, desertification and annual tillage



figure 1: **Wood Pellet Biochar**
carbon char ready to be sequestered

release Carbon from soil into sky—burning out SOC. Fossil fuels—coal and oil, ancient geological Carbon—accelerate biomass Carbon emission. Methane—Carbon with four hydrogens (*figure 2*)—is rising, too. Earth's greenhouse gas load is rising sharply—exponentially.

Carbon's capacity to absorb energy causes air to heat up. The "greenhouse effect" has raised Earth surface temperature enough to disturb weather and seasons. In 2010, all across the Northeast, spring blooms began two weeks early.

Climate Changed

WELCOME TO A NEW GEOPHYSICAL ERA. 2010 reached a critical tipping point. I doubt we'll dial this biological clock back. Not any time soon.

Climate scientists globally calculate 350 ppm is a safe maximum for atmospheric Carbon. Carbon is currently 390 parts per million (ppm)—and rising. So, we are already 40 ppm over the safe limit. We not only need to quickly curb our Carbon emissions, we must develop technologies to remove Carbon from the air and lower the Carbon level.

At 390+ ppm, *carbon-neutral* isn't enough to avert a climate crash. Agriculture and industry must re-structure to remove carbon from air, and store it in stable, solid forms. We must lower Carbon levels to return to ecological safety and sanity.

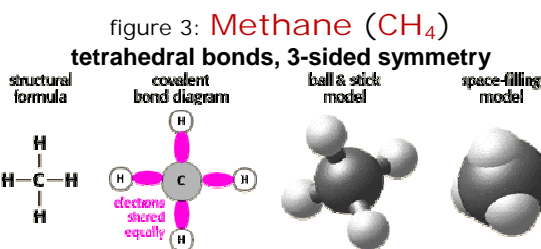
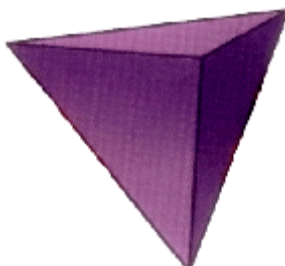
Carbon Farming—in the red zone

Current agriculture has huge Carbon footprints to grow food, feed and fiber. Farming's big-foot Carbon contribution is estimated 17 to 30% of total man-made emissions. A lot is out-gas from plowed, fertilized fields as fertilizers oxidize volatile Carbon and Nitrogen. Machines and constant tillage use fossil fuels, burn more Carbon. Fertilizers—especially Nitrogen and Phosphorus, major soil anions—use lots of fossil fuels, including 50% of US hydrogen. Food transport and processing are energy intensive carbon emitters.

Our daily bread is big greenhouse gas source. Meats and animal foods carry bigger Carbon price tags. Many calories of fossil fuel are used to put one food calorie on our plate. We are eating our way to climate calamity.

FIVE ONE-GALLON BAGS OF HIGH-CARBON FLY ASH ARRIVED

fig. 2: **Tetrahedron**
4-direction bonding



in early June at Saratoga Apple, a 200-acre farm on upper Hudson Valley west slopes in northeast Saratoga County. Owner Nate Darrow is changing his farm to biological agriculture methods and materials to grow nutrient-dense fruits and vegetables. The farm has dense, heavy clays—tight, impermeable, needing calcium, sulfur, phosphorus, boron, copper, manganese, trace minerals—and especially carbon.

Five ziplock bags, bulging with fluffy, black powder—from rice grains to dust (figure 4). I recall Nate, his hand in this high-carbon fly ash, rubbing it in his fingers. The light powder isn't dusty or greasy—a smooth, soft, silky texture. Eyes wide, face softened in surprise, Nate lifted a handful of black dust, almost smiled, said how this likely can improve his thick, sticky soil. He felt it, too.

Lettuce Seedling Trial

Summer solstice, I returned from a trip home with half a dozen Accelerator™ trays for a lettuce seedling trial—a basic toxicity test. A simple sprout test can quickly reveal any benefits to growth. A 1-year-old pile of chicken manure sat near Nate's greenhouse, so I mixed soil for three trays: compost only, 4:1 compost+ flyash, 8:1 compost+ flyash.

Nate chided me for not adding soil to my blends, so the next day I made a fourth tray with 50/50 chicken compost and soil.

Results were dramatic (figure 6). A month later, 50/50 soil mix had uneven, weak growth. Compost only sprouted an ambitious bouquet of healthy leaves, and 4:1 compost with fly ash was a bit more lively. But, to my surprise, 8:1 compost with fly ash was a green volcano of vigorous leaves erupting from the tray—twice the size of 4:1. The enthusiasm of the crowded lettuce seedlings was obvious.

I'm not sure this NH flyash should or can be classed as "biochar." I'm not convinced it's ecological or moral to incinerate trees to make electrons dance in wires. But I'm certain this charred Carbon enhances soil fertility and plant growth—higher nutrient density and better plant health.

What is Biochar?

BIOCHAR IS A NEW WORD CREATED IN 2008 to describe charcoal prepared properly to add to soil. And since these soils

Figure 6: **First Lettuce Seedling Trial**



figure 4: **High-Carbon Fly Ash**
light, smooth, fluffy, silky powder

water purification.

What is new is the idea to put charcoal in soil. Before a few months ago, the idea was unknown. Farmers never heard of it; blacksmiths insist it's a waste of fuel. The NH utility loses energy (and money) as unburned carbon from their burner.

Yet, charcoal in soil initiates a transformation to shift how soil functions—and how we define productive capacity—our system of soil fertility. My poorly planned lettuce test clearly showed this.

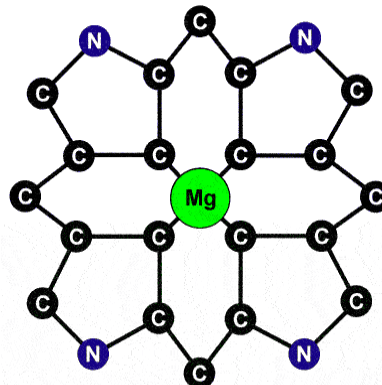


fig. 5: **Chlorophyll**
20 carbons in 8 rings

This new use for an old substance is getting high level attention in Washington—at the USDA, White House, DOE, EPA, NSF. Already, three USDA PhD soil scientists are teaching this strategy to growers and foresters, and support federal research funding. At the first North American Biochar Conference in August 2009 at University of Colorado Boulder, USDA Secretary Vilsack explained President Obama's policy priority to empower rural communities to benefit from the emerging Carbon economy.

Many professional scientists and resource ecologists now recognize the multiple values biochar offers a society headed off an exponential cliff. Word is spreading fast.

Ancient Indigenous Legacy

Putting charcoal in soil startles modern farmers and scientists. Yet, the method was used for 6000 years in South America's Amazon Basin. Early European explorers reported patchworks of fertile, productive soils—three or more times the yield of adjacent clay. Their black color named them "terra preta"—"dark earth" in Portuguese—in clear contrast with light-colored rainforest clays—weak, acid, tight, infertile (figure 7).

Forty years ago, science showed their darkness and fertility is due to Carbon—lots of Carbon—up to 10%, even 20%. Mostly charred Carbon—charcoal deliberately added by indigenous tribes. *Terra preta* aren't odd geological deposits but man-made, by invention and intention.

Two decades of aerial photos and canopy-penetrating radar revealed thousands of acres of man-made, high-Carbon soils. Far more than suspected—enough productive, fertile land to feed five million—likely more.

The presence of these extra-ordinary soils is scientific fact, but questions remain about their creation. The method began in west Andes foothills, and spread by 4000 years ago to the Amazon mouth. By Christ's birth, the practice spread all across Amazonia. In all, agricultural areas covered 10 per cent of land—an area the size of France.

Scientists on the ground and in labs worldwide study *terra preta* to unravel mysteries of how indigenous tribes

will grow our food and feed, extra high standards must be set to identify charcoal for such special service.

Biochar isn't just a physical substance. The name also identifies a strategy to sequester carbon to mitigate global warming—to address the largest single issue humans face.

Charcoal is nothing new. Charcoal was made for centuries by hundreds of methods on every continent. Charcoal is still the principal cooking fuel in a third of household kitchens. Charcoal is first choice media for fluid filtration and

made these soils. Scientists puzzle how these soils sustain abundant nutrients and soft, absorbent texture, even in intensive production. National Science Foundation funded millions to research how this can help temperate climate soils and crops.

Carbon Farming—in the black

EVERY FARMER IS A CARBON FARMER. Growing plants and animals is producing carbohydrates, proteins, oils—simply, carbon management. Yet, until recently, Carbon got scant recognition as an agent of soil fertility. SOC stocks were squandered by farmers focused on a few fertilizer chemicals and antibiotic management.

However, 21st Century growers must reverse farming's huge Carbon footprint, and take quantum leaps into new insights, materials and methods. A new generation of growers must lead the way to sequester carbon in soil—to begin a long, slow path to lower Carbon levels.

First step back from the exponential edge of our climate change cliff is to cut emissions and stop adding to our troubles. Sharp decreases in fossil fuel use, machinery and tillage, smaller farm size, and growing numbers of growers. Changing fertilizers and soil management can cut Carbon & Nitrogen soil emissions. Local infrastructures to grow and distribute food must be rebuilt.

But our current excess of 40ppm CO₂ demands added strategy to suck CO₂ out of sky into soil. Reduced emissions must be augmented by accelerated removal.

Carbon-Negative

Carbon-negative is a new word for ways to remove Carbon from the air. We can't just reduce our Carbon footprint—we need to reverse our Carbon impact on Earth. If we cut emissions and develop ways to remove Carbon, we start to dial down Carbon.

Plants are among Earth's greatest carbon fixers. Plants, by **photosynthesis**, fix Carbon to build their bodies and fire their metabolism. With sunshine caught by **Chlorophyll** (figure 5), plants remove Carbon from air, bond it with water in rings called **carbohydrates**—sugar (figure 8). Plants use these sweet Carbon rings to spin threads, coil cables, weave webs, and pleat sheets to build their cellulose bodies.

Farmers must lead the way to sequester Carbon from the air by restoring it to soils. Certainly soil can sequester vast volumes of Carbon. Soil is where much of the Carbon came from, due to deforestation and tillage. Our true question is: How fast can Nature put Carbon back in its proper place in the Carbon Cycle? Are we ready? Committed to help?

Organic certification standards mandate 4-5% SOC. Time to go beyond organic and consider this a minimum. Farmers must manage soils to capture Carbon and increase SOC to more than minimum levels. Realistic level is 9-10%.

Controlled Combustion

If we burn biomass and exclude Oxygen, up to half the Carbon can be captured as charcoal—almost pure, super-stable Carbon—not oxidized to gas, but reduced to char. If we recycle this Carbon into soil, it remains there—not just

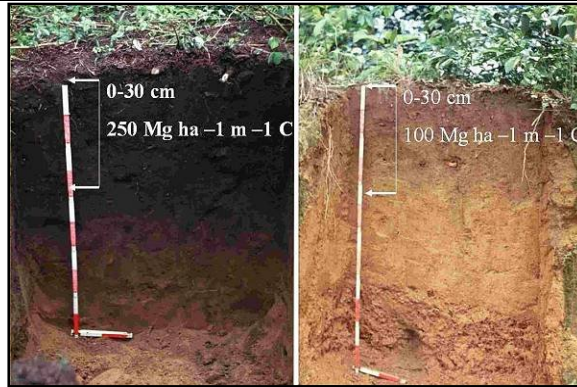


figure 7: Terra Preta Amazon clay

months or years, but centuries—sequestered—invested in long-term fertility.

If, each year, we divert a small percent of plant-fixed Carbon into stable soil stores, then each year after growing year, significant CO₂ can be sucked out of air into soil. James Hansen, America's leading climate scientist, studied this soil sequestration strategy. His 2008 climate simulations agree that in 50 years, this can begin to lower CO₂.

Common sense says farmers need financial rewards for this carbon

sequestration service.

I PONDERED THE DRAMATIC EFFECT NH FLYASH HAD ON SEEDLING GROWTH. My reasoning focused on the ash—oxidized, soluble elements—very alkali (pH 11.0). Its minerals are easily, quickly available to microbe and plant, to stimulate germination and growth. Made from woody biomass, ash has optimum ratios of elements plants need to grow: Calcium, Potassium, Phosphorus.

Second Seedling Trial

I prepared three new trays to compare three types of biochar:

- 1) NH 60% carbon, fly ash "biochar"
- 2) Biochar, maplewood homemade in sealed retort (no ash)
- 3) Rhizochar: commercial biochar, mineralized & inoculated

Fly ash and retort biochar were blended with organic potting soil at 1:4, 1:7 and 1:10 ratios. Each blend filled four rows of a tray. Tray three had four rows blended with Rhizochar; four with potting mix only (control), four with greenhouse soil (control). Trays were carefully filled and precision-seeded with lettuce.

Again, results were unexpected (figure 9). By second leaf emergence, differences in seedling growth were obvious. Any cell with biochar grew better than controls—1:7 and 1:10 more than 1:4. Little difference was seen between the three biochars. Retort biochar—fresh, with no soluble, mineral oxide, alkali ash—grew plants a little larger than mineralized, inoculated Rhizochar.

Again, biochar triggered a burst of healthy, vigorous growth. But retort char success suggests a cause other than soluble ash.

NATURE MAKES CHARCOAL IN EVERY SMOLDERING PRAIRIE OR FOREST FIRE. Ecologists only recently recognized Carbon char residue in soil, to question how it got there and

figure 9: **Second Lettuce Seedling Trial**



affects soil structure and function.

Is Biochar a Fertilizer?

The answer, oddly, is “No.”

In soil, biochar hardly breaks down, doesn't weather or chemically react. Up to 50% of biomass carbon can be captured as char (figure 12). In five years, char loses only 3-5% more mass—mostly tar and resin residues consumed by bacteria. Beyond five years, the line is nearly flat. So, nothing eats it. It's not nutrient, or fertilizer replacement.

Yet, documented science shows charred biomass—properly made and put to rest in soil—delivers several immediate benefits:

- increase porosity, lower density, better tilth
- improve soil fertility
- higher CEC—and AEC
- greater nutrient density
- faster nutrient cycling
- better fertilizer efficiency
- enliven soil biology and diversity
- sequester carbon 1000 years

Substantial data confirms char in soil also improves water filtration, reduces leaching and curbs volatile out-gases.

Here are six unusual, useful services biochar provides to soil:

Insulate

First: Carbon insulates electric charges in cells and soil.

In Basic Electricity, I learned Carbon is a *resistor*. Carbon's four half-empty orbitals absorb electrons to retard their movement—a *semi-conductor* that *impedes* electric current flow in a circuit.

In soil, Carbon's first service is to surround ions to isolate their strong electric charge. Tiny char fragments arrange themselves in clusters around ions—much like *chelation*. Or **Chlorophyll**—20 Carbons in 8 rings around a Magnesium ion to capture photons for *photosynthesis* (figure 5).

At larger scale, Carbon surrounds soil particles to separate their strong electric charges. Char inserts itself between soil granules to insulate their electric attraction. This isolates electrons to curtail stickiness and counteract tight, dense structure. Soil can open, soften, with looser tilth, texture, air flow, water penetration.

Absorb

Second: Char is a sponge to soak up water.

Plants are mostly water—at least 75%. Plant structures are mostly plumbing to move water around. In a microscope, plants look like bundles of pipes and tubes (figure 10). Properly charred, these microscopic pores are preserved (figure 11). Char is very light because it's mostly empty. It's full of holes, and

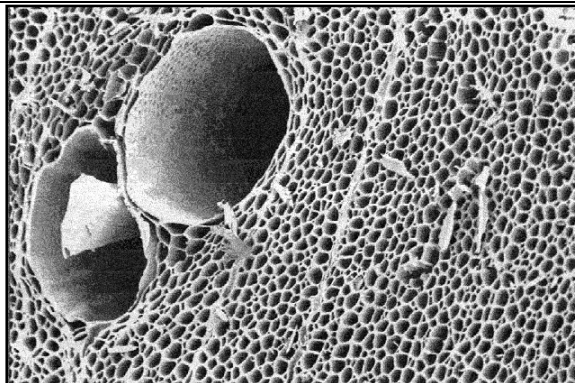


figure 10: Cellulose Nanotubes plumbing to move water inside a plant

increases hollow spaces in soil. Thus, char weighs one-sixth as much as the same volume of sand.

Char's micropores are sponges to soak up water, holding up to six times its weight out of soil circulation. This captive capillary water is slowly released back to soil. Biochar boosts soil capacity to absorb and digest water, resist drying out.

Adsorp

Third: Char attracts ions out of solution. This slight electric attraction is “*adsorption*.” Atoms don't bond, but their electric polarity attracts them into intimate relations.

Char, like humus (figure 14), has broken rings and embedded mineral ions that are areas of electric charge. Char's charges attract ions with opposite charge, pulls them out of solution, loosely held by char.

Char's vast inner micropores are hundreds of times more adsorption area than particles like clay. Char added in modest amounts—5 to 10%—sharply boosts CEC.

Char's huge ion adsorption capacity is ideal to filter water. In soil, ions aren't pollutants, but nutrients—cations, anions, and larger biological molecules, such as starch and protein. Like a magnet, char attracts ions out of soil solution to retain them securely within its micropores. Char becomes a storehouse of

loosely-held nutrient ions, ready to exchange with microbe or root.

But char also has positive charge sites. Char not only collects cations, but also attracts anions—Nitrogen (N) and Phosphorus (P). This gives char an **Anion Exchange Capacity (AEC)** to complement and augment its large **CEC**. Thus, char stores ions of both polarities. *Terra preta's* unusual **AEC** capacity caught the attention of soil scientists. **AEC** assures high fertilizer efficiency, reduced nitrate leaching, curbs nitrous out-gas, makes

Phosphorus available at any soil pH.

Amazing what Nature does with subtle electric attraction between atoms. But it gets far better.

Substrate: habitat for biology

Four: char is now ready for a final preparation: **inoculation**.

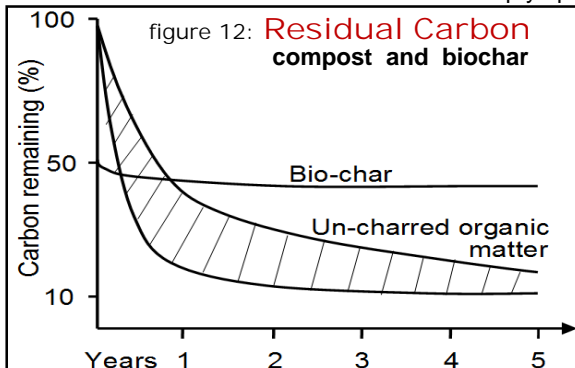
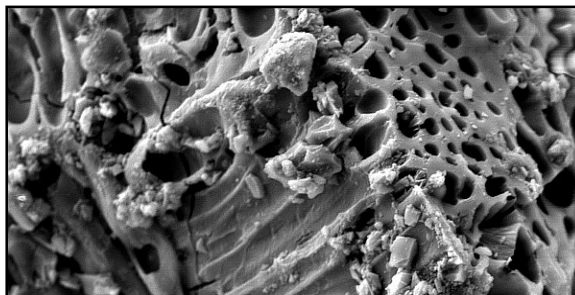
Char fresh from a burner is bone dry and sterile, having been heated to 500+ degrees C. Fresh char is truly an inert ingredient.

But char is empty spaces, filled with water and ions. Microbes quickly move into the vacancies to become residents. We don't eat our houses; microbes don't consume char. They live in empty tubes and cell holes, share water, store food.

Char isn't annual fertilizer, but non-consumable infrastructure. Char's empty space is condominium housing for soil biology. Micropores are a residential refuge from predators roaming soil.

So, in soil, char comes to life.

figure 11: Char Micropores charcoal in a microscope: hollow structures



Some microbes—notably fungi—send threads through soil to search for nutrients. In untilled soil, these networks extend hundreds of feet moving nutrients around. Char gathers scavenged nutrients from these networks—microbial equivalent to supermarkets and shopping malls.

Proper preparation of char for soil includes intelligent inoculation with a full spectrum diversity of microbes. This can be simple as blending with compost, or elaborate methods to take full advantage of char's properties and microbial diversity. Char can also be sprayed with compost tea, biodynamic preparation or EM culture. Depending on particle size, microbes can colonize char in days, or a week.

Questions arise of compost versus char. Actually, the two processes complement, not compete. Compost cooks best with wet biomass, while char “cokes” best with dry. Char needs compost to inoculate its empty micropores. Compost benefits from char's super-stable matrix to house microbes, transfer cultures, and supply minerals and metabolites.

WHEN BIOMASS DECAYS, MOST CARBON OXIDIZES to return to air—full circle in the Carbon Cycle. In photosynthesis, solar energy caught by chlorophyll is harnessed to fix CO₂ with water into sugar. This carbohydrate energy powers most of Earth biology.

Digestion releases this energy to microbes, who share it with soil biology and roots. Slowly, plant and animal residues revert to CO₂, water and energy, feeding the soil biology. In five years, even woody biomass is digested. Large logs left in living soil vanish in a decade or two.

Humus: carbon indigestion

But a small percent of biomass is indigestible. Depending on biomass, moisture, soil, temperature, microbial diversity, and more factors, 10 to 15% remains (figure 12). Mostly, this residue is Carbon. Lignins, fats, celluloses, waxes, chitins resist chemical and microbial breakdown, so a small fraction remains as dark, crumbly, soft, spongy *humus*.

Humus has chemical and biological stability—amorphous dark matter left from microbial decay. Humus persists for decades, even a century, as a soil conditioner, nutrient reservoir and microbial habitat.

Humus, like biochar, is huge, complex mega-molecules—chains and rings—from 50 carbons, up to thousands (figure 14). Like biochar, only 5% transforms lifeless rockdust into rich loam. It can both bind sand and granulate clay. Humic and fulvic acids are acid and alkali extracts of lighter, smaller, soluble fractions.

Humus science isn't much older than biochar, but clearly the two types

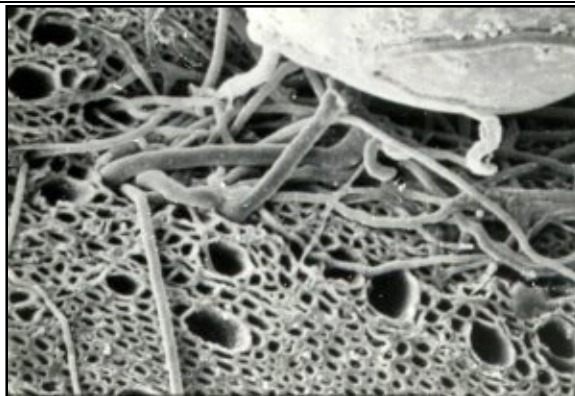


figure 13: Fungus enters Char fungal threads investigate inside

of recalcitrant carbon interact to build soil structure and supra-structure, supply microbial habitat, store food. While they share functions, they also specialize. Stable, healthy, functional soil benefits from a balance of both.

Char and humus are similar, not identical, or interchangeable. They have functional differences. One is humus has oxygen (figure 14); char has none. Biochar is burned without oxygen; any oxygen in its carbon matrix is stripped out. So, char is more inert, but also more brittle.

Agriculture mines humus, humates, peat, and other organic carbon, and burns them out of soil. Like any mined mineral, these resources will be exhausted.

But biochar is renewable.

Community: soil food webs

Five: Char develops fully diverse microbial communities.

Char is super-stable. Burned at 500+ degrees C, this reduced residual carbon is stripped of energy and oxygen, with none to offer enzyme or organism. It barely breaks down; nothing eats it. Science calculates its soil life is 1628 years.

Since char is super-stable, microbes get long-term leases—not a few years, or decades, but centuries. With stability, safety and continuity, they populate char with complex, multi-function colonies. Char allows microbes to blossom into a full function **Soil Food Web**. Dr. Elaine Ingham at Oregon State pioneered insight, science and strategy to collaborate with this soil biology.

Soil microbes are among Earth's most ancient organisms. They form complex communities with interactive, inter-dependent, functional cultures. A teaspoon of living soil has thousands of species—from simple bacteria, lacto-bacteria, up to fungi, protozoa, algae, nematodes, and more. Extreme diversity and broad specialty assure wide adaptation to changing soil and climate.

NITROGEN CYCLE BACTERIA ARE A KEY CONCERN to inoculate soil and char. Nitrogen, fourth organic element, key nutrient needed in huge quantities by current crop production, highly mobile, changing form and energy in complex, dynamic cycles.

The farmer's choice: buy it by bag or bottle, or grow your own.

Nitrogen Cycle: nitrate, ammonia, amino acid

The **Nitrogen Cycle** begins by fixing N₂ gas into NO₃ nitrates. The entire N Cycle is driven by bacteria. These least of all organisms regulate this key biological nutrient in soil.

We know *Rhizobia*, a N-fixing bacteria, lives in legume root nodules, and uses trace element Molybdenum in a special enzyme to create nitrate from air. Inoculating legume seed

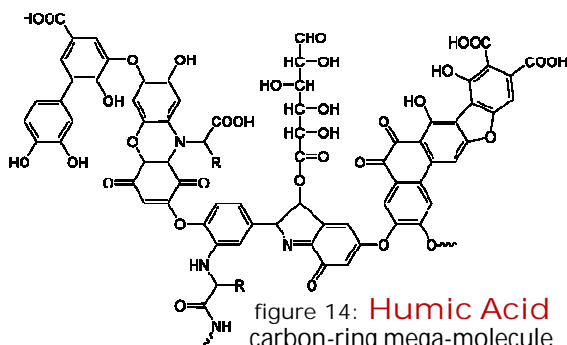


figure 14: Humic Acid carbon-ring mega-molecule

fig. 15: Another Kind of Carbon Ring PHOTO: BiGchar™ Black is Green Pty Ltd Australia



with N-fixing bacteria is established agricultural practice.

But *Rhizobia* is only one of many families of N-fixing bacteria, each specialized in specific host, climate, enzyme, trace element, and ecology. Scientists believe *terra preta* has rich stores of N due to several strains of N-fixing bacteria living in char. Char not only adsorbs N ions out of solution, its resident microbes suck N₂ out of air into solid substance. This opens additional enzyme pathways to fix more N, and to increase soil's N-fixing potential.

Scientists search for N-fixing bacteria to live in biochar in our changing temperate climate soils.

The Nitrogen Cycle undergoes further changes. Bacteria convert Oxide to Hydride—NO₃ to NH₄ ammonia—acid to alkali. Other bacteria convert ammonia back to nitrate. Fertile soil and healthy growth need reserves of both forms of N. Char adsorbs both ion polarities, and N-cycle bacteria change one to the other.

Nitrogen forms oxides (NO, NO₂) that out-gas from soil, and are 250 times more potent than CO₂ as greenhouse gas. Char's anion adsorption (AEC), with N-cycle bacteria to boost soil's metabolic efficiency, curtails NO_x emissions 50 to 80%. By similar adsorption and metabolism, char reduces nitrate leaching.

Biochar's high AEC is augmented by N-cycle bacteria. Char stores N as mineral ions, but also as living biomass—cell bodies and protoplasm of microbes and soil biology. Their presence enhances char's capacity to store N, and convert it to any form soil needs.

Can a full array of N-cycle bacteria live in char?

NEXT, BIOLOGY COMBINES NITROGEN WITH SUGAR TO MAKE AMINO ACIDS, which chain together to make proteins. Three-leaf legumes convert bacterial NO₃ into biological protein—a key gateway to transform geology into biology—plant to animal.

Symbiotic Synergy: microbial economy

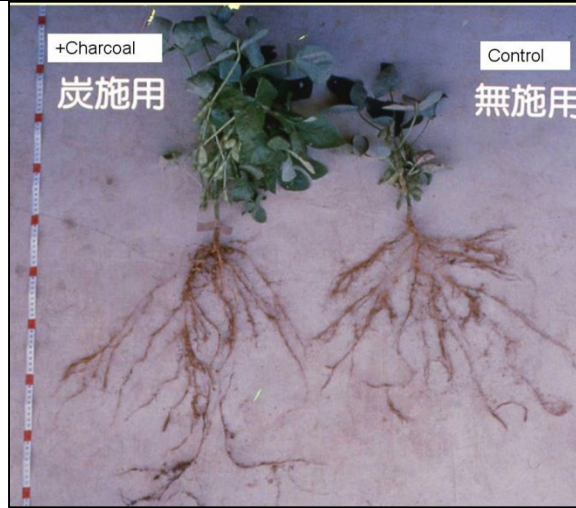
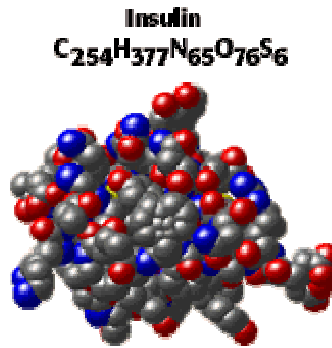


figure 16: **Soybean Nodules**
longer roots, stronger nodules, higher N fixation



Carbon fixed by plants leaks from roots into soil. The loss is no accident, but a deliberate deal for fungi, who accept solar sweetness in exchange for water, minerals and metabolites. Trade in a soil food web economy simplifies a plant's search for soil's solid substances.

This nectar-for-nutrient exchange economy is why soil is best close around roots. It's why the root mass in figure 18 is large and black—roots grew into and grabbed bits of char.

Symbiotic interactions like nectar-for-nutrient trading are widespread throughout the microbial universe. Microbes form networks to share energy, nutrients and information. Living soil is millions of individual organisms in intimate cooperative relationships for mutual benefit.

The whole is greater than the sum of its parts. Myriad cell metabolisms have functional unity that unleashes an astonishing synergy of symbiosis. When all elements are present in balanced ratios, and the soil community develops its full diversity and unity, then growth and health are optimized. Distress and disease vanish as plants reach full genetic potential.

Microbes do more than scavenge water and ions from soil to spoonfeed plants in a swap for sugar. Many key biomolecules are synthesized by simpler soil organisms, then traded with roots. B vitamins are all made by microbes—a yeast. Even "vegetarian" vitamin B₁₂—believed only found in animal foods—is built by a bacteria with trace element Cobalt. In evolution's eons, microbes and plants formed many intimate metabolic partnerships.

Like electrons in a circuit, biology finds paths of least resistance and optimum result. Bacterial biomass and fungal networks initiate catalytic cascades of interactive metabolic accelerants. The effect is **syntrophy**—an organizing energy to counteract the inevitable entrophy of purely physical science. Biological intelligence organizes physical matter into systems and structures that are anti-entrophic, and achieve higher energy, organization and unity.

Insulin—a human hormone—illustrates this molecular, metabolic synergy in complexity. This 254-carbon, multi-ring protein molecule (figure 17)

figure 18: **Corn Shoots & Roots enhanced growth with biochar**

Pot 1: control soil only	Pot 3: soil with 0.74% NPK + 2% char plants grew 38% higher
Pot 2: soil with 0.75% liquid NPK plants grew 11% higher	Pot 4: soil with 0.68% NPK + 5% char plants grew 41% higher

PHOTOS: BiGchar™ Black is Green Pty Ltd Australia

has amplified effects on sugar metabolism in cells, liver and blood. Blood sugar is our body's baseline energy supply.

This reveals biology's power over geology. Soil contains the biological intelligence to optimize conditions for larger life forms.

Mycorrhizae: fungal networks

Mycorrhizae are a family of fungi recognized by science as effective ally—new tool in biological agriculture. This fungi forms intimate associations with plant roots, even grow inside a root—well-researched case of microbe-plant symbiosis. This new insight is well-established science, with an international society.

Dr. Makato Ogawa's 25 years of research in Japan clearly show char is preferred habitat for this friendly fungi. Mycorrhizal spores germinate best on char, and rapidly inhabit char (fig. 19). They send *hyphae*—fine, white, fuzzy, fungal threads—through soil (fig. 20) searching for food. Each thin white whisker is a tiny tube to pipe water and food to fungi.

Roots don't scavenge ions from soil, but grow into char to exchange nutrients with microbes. Fungal threads and char become extensions of plant feeding networks. Much of the root mass in Fig. 18 is char grabbed and held by rootlets.

Glomalin: missing carbon

Fungal threads are *glycoprotein*—sugar plus amino acid. When fungi die, their hyphae decay into sticky stuff that glues soil particles together, creating supra-structures to open and loosen soil, breathe air, circulate water. Soil lightens, loosens, easier to work—less horsepower to till.

Glomalin is a Carbon residue from hyphae of *Glomus* mycorrhizae. A few years ago, this gummy organic carbon was invisible to soil science. Glomalin is now known to be a large fraction of "missing" SOC—estimated up to 30% of SOC, with a lifetime of 50 years, maybe a century.

One example of many microbial symbioses set in motion by char, properly stocked with nutrients, inoculated and inhabited. Each unit of sequestered char supports many times more units of Carbon stored as soil biomass—living, dying, decaying.

Another example how soil can sequester stable carbon.

BIOCHAR CLEARLY ENHANCES PLANT GROWTH. This effect can accelerate production in Nate Darrow's new greenhouses. But, more seedling tests are needed to learn by observation and serendipity to develop precise rates and results for profitable greenhouse operation.

Third Seedling Trial

I had eight types of biochar from a range of feedstocks: dense applewood, light, crumbly straw, NH fly ash powder, inoculated Rhizochar. Lightest was black locust bark char.

Char was blended with organic potting soil at three rates:

4:1 (20%); 9:1 (10%), 19:1 (5%).

I had eight fertilizers—fossil clay, igneous crystal, sea

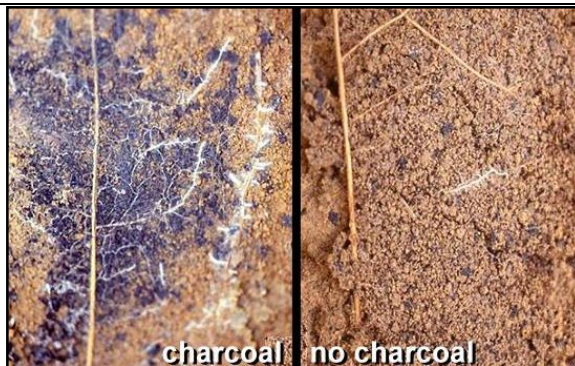


figure 19: **Mycorrhizae**

fungal threads spread quickly in charcoal

minerals, paramagnetic, poultry manure, inoculated Nutrient Density mix spiced with kelp and trace elements, Leonardite humates—geological carbon—dense, greasy, acid.

Late in October, I prepared a new set of trays, seeded with assorted winter hardy greens, mostly spinach and lettuce. The initial 12 trays tested one material—one biochar, or one fertilizer. Later, I blended biochar with fertilizer to see their interactions.

This totals over 2000 seedlings in 20 trays (figure 21), prepared 3 or 4 per group. Last trays were seeded in early November to grow hardy before solstice slowdown. Results will be ready by mid-winter.

THROUGHOUT GEOLOGICAL EVOLUTION, MICROBES IN SOIL AND SEA COOPERATED to optimize conditions for life. By simple respiration, they created the planet's atmosphere, and sustained the balance of gases for nearly two billion years. These least of all life forms delivered uncounted other services to allow larger, complex organisms to evolve and thrive.



figure 20: **Hyphae**

fungal threads form feeding networks

Ancestral Wisdom

Earth's most ancient communities are complex, interactive, inter-dependent, functional cultures. A patch of sod—cut open by tool or toxin—slowly grows successive layers of plants to "re-cover" itself. Collective cultures of microbes optimize fertility to support larger, more advanced life forms, vegetation and trees. Primary service of these unseen soil communities is to build, balance and manage nutrients, and feed larger, younger cousins.

The intelligence of ancient biotic life is ignored and under-rated. In public mind, microbiology is mostly medical and monetary enemy, not ally. Yet, in eons of evolution, biology had to invent, collect and coordinate multiple layers of control systems. Earth's remarkably stable atmosphere in a billion years is sure sign of *homeostasis*—intervention of self-correcting, self-stable intelligence.

The real revolution isn't to add Carbon to soil—only a first step in a larger task to nurse these microbial communities. Properly prepared and deployed, biochar isn't mere inert carbon. It's alive! It embodies a 21st Century shift from chemistry to biology.

figure 21: **Third Seedling Trial**
2000 seedlings, 8 biochars, 8 mineral fertilizers



20th century Green Revolution used chemicals, machines, cheap fuel, and big scale. Society's sudden shift to biological agriculture and technology promises a new Green Revolution—a quantum leap into a 21st Century perspective—to refocus fertility from chemicals to biological insights of soil as interactive, intelligent community.

21st Century farmers are, first of all, soil stewards—caretakers of soil food web biology—this living tissue that is the skin of the land. Biological farmers bring true culture back to agriculture by learning to regenerate these intelligent communities to continue their billion year successful service in evolution:

to create fertile soil and favorable atmosphere.

It begins by restoring soil Carbon.

Carbon Negative Farming

In the face of climate change, a farmer's duty—after feeding the community—is to sequester carbon—to reverse farming's carbon-positive footprint, and pump carbon back into soil. Plants fix Carbon by photosynthesis into sugar—energy and structure to build their bodies. If we convert plant carbon to soil-stable forms, and manage soil to optimize carbon capture and retention, farming has one carbon-negative foot on the ground.

Soil carbon is the foundation for soil biology, and thus sustainable fertility. Biochar isn't one-shot, one-year fertilizer, but remains in soil decades, delivering a multitude of increasing benefits as soil food webs develop habitat and networks. Adding biocarbon is long-term investment in sustainable fertility. A cost/benefit analysis must weigh expenses to buy and apply biochar against benefits that continue a decade—likely longer.

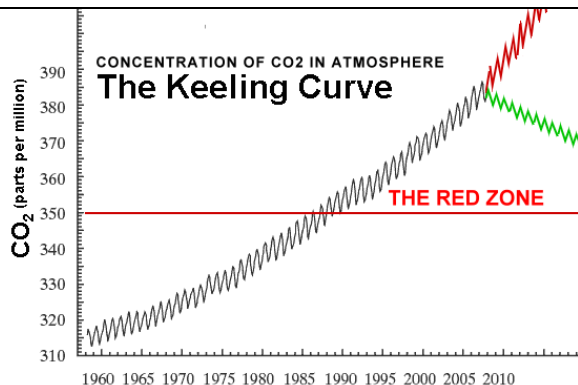
Agriculture's ancient icon—the plow—is obsolete. Tillage burns fossil fuel and SOC, and rips up microbial networks like Katrina over New Orleans. Cultivation is still a useful tool, used sparingly. Farming must shift to no-till, minimum till, green manure, mowing, and grazing as annual agriculture transitions toward permaculture, agroforestry, and perennial diversity integrated with annual crops.

Expanded conservation grasslands increase carbon sinks and ecosystem reservoirs. Mixed perennial savannas that once graced American heartland are carbon sinks that are being restored. Already, hundreds of livestock farms raise grass-fed, range-run beef. Mob grazing—releasing herds onto fresh, mature pasture in constant rapid rotation—promises quick store of SOC.

Food Circle in the Carbon Cycle

The hope of *terra preta* is to expand arable land and increase food production. The urgency of human population growth may be met by this way to turn infertile clay into productive soil. Solid evidence shows this works with sandy soils, too. Carbon, minerals and microbes can revive exhausted, infertile land, even as ancient Amazon tribes transformed acid clay.

To sequester carbon and expand sustainable farmland is a win-win-win for our future.



a lifestyle—new ways to be green by going black.

What do you call a carbon-negative barbecue?

A charbeque.

Energy Descent

The Keeling Curve (fig. 22) depicts a steady upturn of CO₂, measured hourly for 60 years atop Mt. Mauna Loa in Hawaii. CO₂ rises and falls in annual rhythm due to plant respiration in the northern hemisphere—collective in-and-out breath of vegetation between spring and fall. Total volume of Carbon moved is huge.

If we sequester a fraction of this annual Carbon migration as increased SOC, the Keeling Curve can begin descent. Curbing emissions flattens the Curve. But sequestration turns it down, to move our planet toward safety. Each year, collaborating with plants and microbes, CO₂ steps down (green).



Dr. James Hansen wrote in his 2009 paper: *"Carbon sequestration in soil has significant potential. Biochar, produced in pyrolysis of crop residues, forestry wastes and animal manures, can restore soil fertility while storing carbon for centuries to millennia. Biochar helps soil retain nutrients and fertilizers, reducing emissions of greenhouse gases such as N₂O. Replacing slash-and-burn agriculture with slash-and-char, using agriculture and forestry wastes for biochar production can provide CO₂ drawdown of ~8 ppm or more in half a century."*

Higher carbon in living soils improves plant growth, to fix more carbon as biomass, sequester more carbon as char, increase productivity, decrease fertilizers, leaching and out-gas, improve fertilizer efficiency. This reduces annual addiction to fertilizers, and sets in motion many positive feedbacks to inch us back from the exponential edge of a climate change cliff.

Not mere mechanism, reaction path or metabolic cycle. This is partnership with other living intelligence.

Most of all, a shift in heart and psyche is needed for true change to go forward, making choices, aware of our partners, committed to intelligent stewardship. This will be hard to hold to in bankrupt wreck and ruin of centuries of industrial empires.

Renewable Energy & Biofuels

Biochar can also power us through the transition to sustainable society. A common confusion is that biochar production consumes energy and emits carbon. Can this be carbon-negative?

Energy production and sale is industry, not agriculture, and needs a 9th page.

PHOTO: BiGchar™ Black is Green Pty Ltd Australia

