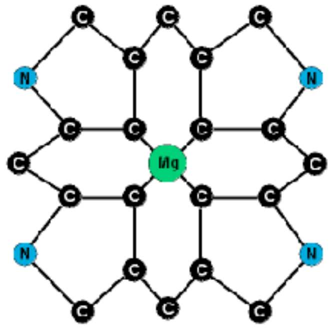
The 4 M's

Preparing Biochar for Use in Soil

David Yarrow, Winter 2013



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We are the Whirled

We can convert agriculture, forestry and landscaping wastes into biochar, a powerful soil enhancer that boosts food security, discourages deforestation, and preserves cropland diversity. Biochar enhances soil structure, sequesters carbon, holds water, and makes soils more fertile. Soils with low rainfall or nutrient-poor see the greatest impact from adding biochar. But this form of charred biomass improves productivity and nutrient density of almost any soil. Scientific research in several countries confirms biochar benefits that include:

- Increase CEC to improve crop growth
- Create AEC to retain Phosphorus, Sulfur and other anions
- Moderate soil pH, increase acidity, lower alkalinity
- Increase water capture and retention
- Improve drought tolerance of crops
- Increase beneficial soil microbes
- Reduce leaching of nitrates and phosphates
- Reduce emissions of nitrous oxide

Biochar use can reverse farmland degradation, support sustainable food production and create renewable biofuels, especially areas with severely depleted soils, scarce organic resources, inadequate water, and poor fertilizer supplies. Biochar makes farmlands fertile for long periods of time to discourage deforestation. Low-cost, small-scale biochar production improves garden, farm and forest productivity, while it provides energy to cook food, dry grain or heat a greenhouse. With an engine or turbine, biochar production can grind grain or make electricity.

This strategy to add charred biomass to soil was first documented in the Amazon by scientists studying unusual black, high carbon rain forest soils, or "*terra preta*," which means "dark earth" in Portuguese. But *terra preta* wasn't made with just char. Clearly, char initiates a process that transforms soil, and this requires an extended period of months. Other ingredients are needed to create *terra preta*. Scientists studying Amazon village "middens know indigenous people added all kinds of "cultural debris" to soil, including garden debris, kitchen wastes, building material, clothing—even urine, feces and kid toys. In a culture with no metal, plastic or synthetic substances, everything is organic, and fully compostable.

Ultimately, *terra preta* is highly fertile, not due to Carbon, but microbes. So, while microbial populations initially grow, diversify and become well-established in fresh char, nutrients are delivered to microbes, and aren't available to plant roots. But once char is fully inhabited and soil biology is fully alive, productivity rises each year to soon surpass chemical fertilizers. Multitudes of symbiosis in fully functional microbial culture take over the feeding of plants

Preparing Biochar for Soil

In November 2007, scientists at USDA National Laboratory for Agriculture and the Environment (NLAE) in Ames, Iowa, began multi-year field trials to assess biochar effects on crop productivity and soil quality. Scientists amended almost eight acres with biochar made from hardwood. Twelve plots got four tons per acre; twelve got eight tons per acre.

They found no significant difference in the 3-year average grain yield from either treatment. Other USDA field and laboratory studies in Idaho, Kentucky, Minnesota, South Carolina, and Texas showed hardwood biochar can improve soil structure and increase sandy soils ability to retain water. But soil fertility response was more variable.

USDA scientists violated four key principles for biochar use:

1) bulk char, in one large load,
2) raw, uncharged char,
3) sterile, uninoculated char, with only a tad of microbial life,
4) synthetic salt fertilizer, tillage and other antibiotic practices.

After all, soil may get 25 or more inches of rain a year, but not all at once in a single event. Biochar, like water, is best added in a series of small doses so soil has adequate time to distribute and digest it. We already know from Amazon research that dumping five, ten, even 20 tons of raw char all at once into poor soil retards plant growth for one year, maybe two. But after that, plants erupt in impressive, vigorous growth.

But a dip in yield isn't acceptable for production agriculture. Farmers can't wait a year or two to harvest a profitable crop. Professional growers need fast response and strong stimulus to growth. Economics and handling logistics require convenience and low cost, with vigorous growth from minimal applied material.

Fortunately, we are learning how to prepare char for optimum effects in soil and on crops. Biochar research in America is hardly ten years old, but solid research shows that properly prepared, intelligently applied biochar has dramatic effects on soil structure and plant growth at as little as 500 pounds an acre.

To prepare biochar for optimum effective use in soil, there

What is Biochar?

International Biochar Initiative

www.biochar-international.org

Biochar is fine-grained charcoal, high in organic carbon, largely resistant to decomposition, produced from pyrolysis of plant and waste feedstocks. As soil amendment, **biochar** creates a recalcitrant soil carbon pool that's *carbon-negative*—a net withdrawal of atmospheric carbon. The enhanced nutrient retention capacity of biochar-amended soil reduces total fertilizer requirements, and also the climate and environmental impact of croplands.

are four fundamental steps—**The 4 M's**:

Moisten, **M**ineralize, **M**icronize, **M**icrobial inoculation.

Moisten: first ingredient of life

First step is to add enough water to moisten char without becoming waterlogged.

Fresh from a production burner, char is bone dry. It's heated to over 500 degrees C, and hardly has a molecule of water in it.

But water is the first ingredient to cook up biological life. Without water, even earthworms avoid char. But properly moist, worms like char mixed with their food, and microbes rapidly move in to colonize the char.

Fresh char isn't just dry, It's hydrophobic. It actually resists water penetration. Residues of tar and resin left in the char are oily hydrocarbons, and repel water. Until thin films and beads of tar are etched out of char, it won't accept water.

However, char left lying on soil a few months loses those black beads of resin, and its color shifts from sparkly black to lusterless gray. Microbes inhabiting char see those hydrocarbon residues as food. Carbon chains and rings contain electrons and energy, so bacteria and other organisms eat it like candy.

Without water, char is very dusty. Fresh char is weak, brittle and shatters easily. So, dry char easily sheds fine black dust that hovers around like a dark cloud. This dust is hard to handle, easily airborne, not healthy to inhale, and blows away in a wind. And yet, that very fine dust is the most precious portion to add to soil and transform its structure because it most widely and intimately inserts itself between soil particles.

In normal production, water is used to kill the fire that makes the char—to cool it down and stop the charcoal fire. People beginning to make char are surprised how much water is needed to extinguish a charcoal fire. A lot of heat is held in char, and char's micropores soak up lots of water. Often engineers quench fresh, hot char by dumping it in water. However, too much water yields char that is soggy, sticky and heavy, which makes handling messy, and screening for particle size difficult. And water-logged char is anaerobic, and poor habitat for beneficial microbes.

But, with careful attention and proper protocol, a minimum of water will put out a fire, yielding lightweight char that's easy to process. With the right moisture, char isn't dusty, but cohesive enough to hold together in soft clumps that are easy and safe to handle, and don't disappear in a wind. And with just enough water, char is suitable media for strong colonies of microbes, and earthworms are attracted to it.

Micronize: intimate relations

Second step is to reduce particle size.

Smaller particles disappear into soil quicker, mixing more thoroughly and intimately with soil particles and organisms. Thus, crushing, grinding and screening char are valuable to increase char's dispersal throughout soil, and optimize its effects on soil structure, ion adsorption and microbial colonization.

The first benefit of smaller particle size is increased surface area. For water, ions and microbes to penetrate char, they must enter at an exterior surface. Smaller bits have more total surface available for absorption and adsorption. A one-inch chunk has a surface area of—at best—six square inches. The same chunk shattered in a thousand fragments has thousands times more surface area. Due to extremely fine microporosity, one gram of biochar has over 4000 square feet of surface area, and 12,000 is achievable. Water, nutrients and microbes quickly get inside smaller particles, and access interior spaces.

Smaller particle sizes also distribute in soil more widely, more intimately. Dust—the smallest particles—smaller than most soil particles—inserts itself between soil particles. Carbon isolates soil granules, insulating their electric charges. Thus, clay is less sticky, while sand has more cohesive body.

Smaller particles hold water better, because water penetrates more easily and quickly into char's sponge-like micropores. Large chunks of char have difficulty drawing water into its deepest recesses, and do so slowly.

Similarly, smaller particles allow ions better penetration into the char's sponge-like internal micropore matrix. A large chunk of char has difficulty drawing ions into its deepest interior spaces.

Ultimately, think like a microbe. What size micropores are fit for bacteria? What size will satisfy a fungi? Rice grain kernels of char are large enough to house thousands of microbes. A 1-inch chunk of char is a microbial metropolis—millions of denizens inhabit and share such a charred Carbon matrix.

Because char performs an assortment of services to soil, a variety of particle sizes seem best. Rice grain size char is large enough for large microbial communities. Powdered char provides condominiums for microbes. Fine dust is most effective to separate soil particles and shift soil structure and tilth.

One advantage of weedy biomass is its char easily crushes to dust in your hand. Minimal effort and machinery is needed to create extra fine, fluffy char, and such char seems to further enhance soil structure and boost its CEC and AEC. After a few years of field trials, we may decide weedy char is better than woody for many agricultural soils and crops.

One fascinating facet is water-soluble complex Carbons. Tiny bits of char—the finest dust, with up to 100 Carbons—are small and light enough to suspend in water. These extremely small Carbon molecules can be harvested by rinsing fresh, dusty char with water. They disappear in water, making it slightly dark. The micro-particles are useful in foliar and other sprays, where minerals ions and nutrients are packaged in these ultra-light Carbons. Such nutrients are more easily and efficiently assimilated through leaf pores. And inside a plant, the Carbons strengthen plant structure and energy.

Mineralize: charge the soil battery

Blending Biochar with Compost

We have no hard numbers on biochar-to-compost ratio. Farmers I work with use 5 parts compost to one part biochar (crushed, average size 3mm, like coarse sand) by volume with good anecdotal results. We don't have replicated, statistically valid trials at this point.

—**Wayne S. Teel**, James Madison University

Most compost we see is done with wood char, but biochar from grass and manure will work. We don't see much char from grass except energy crops like switchgrass. In Germany, bio-activation is done primarily by wood char with manure.

Two operations find poultry litter char composted with dairy manure is a great combination. Carbonized poultry litter provides compost with nutrients removed in the dairy flush.

Pyrolysis is in the absence air. Gasifiers are slightly oxidizing, as is staged combustion (e.g. high carbon boiler ash).

Particle size is highly variable. Lots of theories; no rules. Depends on porosity of other material in compost, and what is the bulking agent. Aeration is an important attribute of char in compost.

In Germany, Spain and Japan, compost is up to 50% by weight (w/w), mostly 5%-25% by volume (v/v). We blend 1:2 (v/v) biochar:organics (municipal yard waste) to end with 1:1 compost-biochar blend to use in stormwater bioretention trials.

When composting grasses, your hands get black at 15% biochar: 85% organics by volume (1:6 v/v). If organics lose half their volume, the end is 1:3, 25% v/v (about 12% biochar by weight). That works well for tree nursery growing media.

As little as 5% biochar by volume is beneficial in compost. We put that much in kitchen compost (food scraps), and worms love it!

— **Tom Miles**

Third step is to add minerals to biochar.

Soil is a battery that stores electric charge. Electrons and ions are electric charges that adsorp onto soil particles, especially SOM and biochar. The ability of soils to capture and hold these charges—both positive (CEC) and negative (AEC)—creates a fundamental electric storage capacity—like the electric potential, or ampere-hours, of a battery. Beyond simple quantity, it's important to also examine how soils can easily and quickly make these electric charges available to organisms.

Both SOM and biochar have remarkable capacity to gather and store both negative (electron) and positive (proton = H+) charges, and are highly efficient to hold and deliver ionized minerals and their electrons to cells. Soil Carbon's large, complex molecules, with their embedded minerals and multiple surface charges, are especially effective to capture and hold free electrons. The more electric charges char can store, the more energy soil has to deliver to growing microbes and plants.

Charging this biological battery begins by adding ionized and ionizing minerals. Cations, although they have a positive charge, contribute electrons to the soil battery by giving up their valence electrons, and thus deliver these fundamental mobile charges to power cell biology. Meanwhile, anions are electron receptors (or acceptors) that hold and safely transport electrons around soil or inside a cell, and deliver them to metabolic reaction sites.

Biochar's high adsorption capacity makes it an ideal delivery system for minerals and their electric charges. Electrons and ions adsorped onto and into biochar are safely, efficiently placed in the root zone, and kept there, ready for ion exchanges with plant roots. Char-adsorped minerals are removed from the soil solution, and thus have minimal mobility to leach and outgas. So, any electrons in char are kept in the root zone, in locations that attract plant roots.

Micronized minerals that are finely powdered are more able to blend into intimate contact with bits of char, and thus deliver electric charges where they are needed. Like micronized char, smaller particles mean greater surface area, and faster, easier digestion by microbes. Stone meal or rock dusts are natural, insoluble forms of minerals that can be mixed with char to charge the soil battery. Synthetic, soluble commercial fertilizers can also be micronized to blend into char to supply electric charge.

Most farm soils have deficits and/or imbalances of major minerals, and thus require amendments. Similarly, char made from biomass grown in mineral-deficient soil will be short of essential elements. Any soil test quickly, cheaply reveals what minerals are needed by soil, and in what amounts. Adding these minerals to soil directly can create losses, and lower effective use of the minerals. But blending these minerals with biochar adds needed nutrients in a high efficiency, targeted delivery system.

Full Spectrum Fertility

Nature's best source for trace elements is sea minerals. For over a billion years, minerals from the land washed into the sea. Every element that dissolves in water is in the sea—including nano- and pico-elements. Sea water is a full spectrum source for every and all elements that are essential for life.

And sea minerals are in ratios that are ideal to sustain cells and organisms. This mix of minerals was blended, sorted, stirred, precipitated, titrated, and energized by geological and biological processes of Earth evolution. For example, early in planetary history, bacteria in the sea ate Iron, and precipitated this magnetic mineral out of solution. Later, cells evolved that fixed Calcium and Phosphorus to create crystal shells to shield their soft bodies. Many biological and geological processes have created the mix of minerals in the sea. Thus, this mix is no accident, but a full menu of all minerals needed by biology in a deliberate, balanced blend, created by intelligent evolution.

Grandfather's Charcoal Garden

submitted by Ken Bourne 10-03-2012

using biochar in my organic nursery over 50 years.

My grandfather was a charcoal burner in Sussex England. He brought home smaller pieces, which he fed to his dogs (and me). He kept his charcoal in a hessian sack next to his compost. One day rain ran off compost to soak the charcoal. Grandfather was so mad he threw the charcoal on his garden, and got the best yields ever. This was his "secret" for years, passed on to my father, then to me.

A few years ago, I learned he wasn't the first to discover charcoal's benefits. Amazonians did a few thousand years ago. He didn't know charcoal is changed to biochar by inoculation with beneficial bacteria and microbes. I realized growing organic with biochar gives better yields and nutrient-rich crops.

Adding inoculated charcoal to poor soil, and using chemical fertilizer has no benefit, as chemicals kill bacteria that extract nutrients from soil. The greatest benefit is adding biochar to soil amended by organic matter with healthy bacteria. Biochar absorbs water, filters run-off, sequesters carbon.

A farmer must see immediate results, and learn why these results duplicate themselves. He must also learn to add rockdust, bonemeal and other organic matter. It's cheaper and better for his crops, family and profits.

Given the weak, depleted, deficit state of most farm soils, I recommend charging biochar with sea minerals as a way to deliver the full spectrum menu of elements needed by biology. Immediately after making char, douse the char with sea minerals dissolved in water. Adding this solution to fresh, hot char accomplishes five tasks in one operation:

1) **Extinguish**: sea mineral solution puts out the charcoal fire by cooling and by steam;
2) **Moisten**: hot char flushed with water generates steam with enough pressure to force itself into char micropores;
3) **Fracture**: steam pressure strong enough cracks open char to expose inner area as external surface, boosting adsorption;
4) **Scour**: alkali ions of sea minerals loosen and remove tar and resin residues from char's micropores;
5) **Mineralize**: sea mineral ions adsorped onto char's electric charge sites load Carbon matrix with a full menu of elements.

Then, when microbes and roots invade char micropores, they find fundamental food all cells require, already in solution, ready to feed them. This elemental feast assures soil a foundation of essential nutrients to support rapid, vigorous, healthy growth.

Biochar's AEC also allows it to adsorp and supply negative ions, mostly nitrates and phosphates. Nitrogen and Phosphorus were #1 and #2 fertilizers in 20th Century farming. Sea minerals don't supply much of either, so N and P must be added in various forms. Biochar is a high efficiency delivery system for anions, with high bioavailability and minimal loss by leaching. In properly prepared biochar, N and P are not only present as nutrients, but also as organic biomolecules of living soil biology. Microbes living in biochar are an ideal medium to retain and recycle these anions.

Microbial Inoculation

Fourth step to prepare biochar for soil is to add life to it. With water, nutrient ions, and vast, empty micropores in the char, microbes move in. We don't eat our houses, and microbes don't eat char. They live in it.

In the paradigm shift from 20th Century chemistry to 21st Century biology, the culture and care of symbiotic organisms is crucial for soil fertility. For endless eons of geological evolution, microbes managed and improved soil to sustain fertility. Creating fertile soil is a fundamental job description for these "no-see-ums" of soil. These least and smallest of all life forms are among the

Earth's most ancient communities. Yet, we ignore what we can't see—microbes—and focus on obvious, visible bulk ingredients—organic matter, compost and mineral fertilizers.

Bacteria are Earth's oldest life forms. While a singe bacteria is simple, as a collective community or culture, they are complex, and more intelligent than plants. One expression of this is that it is primarily bacteria that consume trace elements, and build them into complex biomolecules that perform key, often fundamental, metabolic and regulatory functions.

If minerals are the foundation of biology, microbes are the sill plate—where foundation meets superstructure. Microbes transform minerals into protoplasm in living cells. Bacteria are the primary consumers of mineral nutrients. They also synthesize critical biomolecules that more complex organisms require. For example, all B vitamins are synthesized by microbes, who then supply them to plants and animals.

For example, vitamin B12—so-called "vegetarian vitamin"—is not made by animals, but only by a bacteria. B12's mineral co-factor Cobalt has six valence electrons in outer orbitals, and thus makes six bonds to other atoms. B12 bacteria build a complex structure of Carbon rings to enclose an atom of Cobalt. Unlike Chlorophyll and Heme, whose Carbon rings are in a two-dimensional, flat disk, B12's more complex Carbon rings form a three dimensional structure. Thus Cobalt's magnetic energy is focused and harnessed to perform certain critical, universal energy exchange functions needed for DNA replication, hormone synthesis and red blood cell formation.

Thus, these simplest and least of all life forms digest trace elements to transform them into key biomolecules that are metabolic catalysts and regulators in larger organisms. Similarly, bacteria assemble minerals and biomolecules into primary units of protoplasm, which are fed to cells of larger, more complex life forms, including plants and animals.

Studies show char is an ideal substrate to culture many beneficial microbes. Features that make char ideal for water filtration media also make it optimum habitat for the smallest microbes. Larger particles soak up nutrients and water. With essential nutrients abundant and bioavailable, microbes take up residence inside char. Each bit of biochar becomes a host for colonies of bacteria and fungi, the primary cycle of the soil food web, and their presence anchors the rest of the soil biology. Larger char particles provide enough space for large-scale, fully diversified microbial communities to become established, and nurse the growth of their food-seeking networks.

For example, mycorrhizal fungi take up residence in char, proliferate by abundant sporulation, send whisker-thin hyphae out into soil to search for water and nutrients, and pump them to fungi living in char. Thus, char becomes an active storehouse to stockpile essential nutrients. Fungi interact with other organisms in symbiotic networks to create complex feeding webs. This interactive community helps soil breathe, absorb water, mobilize nutrients, support larger life forms. Together, this living community forms intelligent, adaptable and resilient systems.

Thus, char preparation's final step is inoculation with a wide diversity of microbes to jumpstart their presence and function.

Biodiversity of Digestion

As the emerging 21st Century biology paradigm spreads, it is spawning businesses and services that offer a variety of new inoculants to enliven soils. Many new probiotic products are becoming available on the market.

Most often, simply and easily, char is inoculated by blending it with compost. Properly mixed, in just a few days, char becomes colonized by beneficial microbes. These microbial colonies form a "culture" of interactive organisms that dramatically improve char's value as a soil enhancement. Compost not only provides microbes biochar to inhabit, but also supplies partially digested OM to feed microbes as they get settled into their new homes.

Compost and biochar aren't competitors contesting for available raw materials, but complementary. Wet biomass is best made into compost, while dry biomass is ideal to convert to char. After production, char and compost are perfect partners for soil. Fresh char is lifeless, and needs compost to populate its empty micropores. Char is an ideal media to transfer microbes into new biomass and kickstart compost's digestive processes. Compost benefits from char's super-stable habitat for microbes.

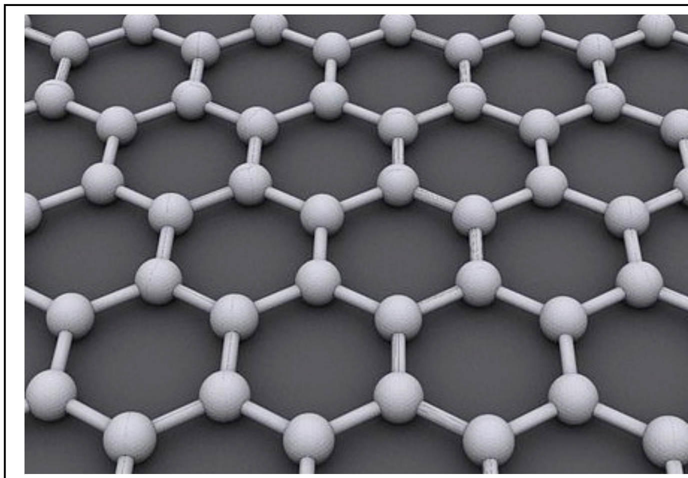
Unfortunately, quality compost teeming with a full diversity of microbes is hard to find. Compost is often treated as inert organic matter, and a way to dispose of "wastes." Much compost is made from high Carbon mono-materials, like wood chips or leaves, and lack fully diverse microbial cultures. Inadequate attention is given to assure strong, diverse, multi-function digestive organisms.

Thus, for biochar inoculation, it's crucial to select compost that delivers a full diversity of microbes. One solution is to use compost made with animal manures, especially from herbivores. Animals with ruminant digestive systems have far more diverse and active microbial cultures. It also helps to include diversity sources of raw biomass that break down into a variety of organic substances. The highest quality composts even include herbs, mineral supplements and even biochar.

In Europe, newly developed EU protocols recommend most biochar is fed to animals. This accomplishes microbial inoculation by passage through animal intestines. Indigestible char moves through an animal gut to be spread with the manure on soil, fully colonized by a full range of digestive organisms.

Currently, several microbial inoculants, inoculation strategies and microbial starter foods are available for purchase:

Rudolf Steiner, in early 20th Century Germany, was among



Carbon Super-battery

In 1962, science discovered "graphene"—pure Carbon atoms in a regular hexagonal pattern as a one-atom thick monolayer sheet. Atoms are densely packed in flat honeycomb lattice, best visualized as atom-scale chicken wire. Graphene is very light; a one-square-meter sheet weighs only 0.77 milligrams.

Research now makes graphene batteries to charge 100 to 1000 times faster, are inexpensive, non-toxic, and surpass current battery technology in efficiency and performance. Graphene nano-technology deposits an atom-thin layer of carbon on an electrode. This super-thin coating quickly adsorps huge numbers of electrons, stores that charge, slowly meters electrons out for use.

An iPhone graphene battery can charge in five seconds. MacBook graphene battery can charge in 30 seconds. Electric cars with a graphene battery can charge as quickly as filling a car with gas. Besides super fast charging, the battery has few negative environmental impacts, and is biodegradable, even compostable.

the first to envision holistic soil microbiology. Steiner taught Biodynamic Agriculture, an advanced farming method that uses eight preparations (BD preps). Some Steiner preparations are microbial cultures and stimulants to inoculate soils with microbes, nurse these cultures into optimum activity. Most relevant to soil microbes is Steiner's cow horn prep.

Dr. Teruo Higa, in 30 years of research in Japan, developed Effective Micro-organisms (EM)—cultures of lactobacillus, photosynthetic bacteria and algae. EM isn't just a product, but a complete technology that includes techniques to incubate and propagate cultures, application methods for many situations and environments, and extensive scientific testing.

Dr. Michael Melendrez, founder of Soil Secrets in New Mexico, first coined the phrase "soil food web" in a 1976 research paper. He developed high quality humus-based inoculants and microbial foods to transform extreme soils of the Southwest. His passion is to create North America's largest collection of oaks, but he first had to transform New Mexico's alkaline, arid soils.

Dr. Elaine Ingham popularized "soil food web", and perfected compost tea as a way to propagate and distribute soil microbes. Compost tea involves adding a little compost, with all its digestive organisms, to a lot of water, plus essential nutrients—minerals, sugar, organic matter. Air bubbled through the water (or whirled in a vortex) for 24 hours adds abundant oxygen to nurse a microbial population explosion. This brewed tea is sprayed on plants, soil and biochar as inoculant. Thus, microbes in a small amount is compost proliferate to cover a large land area or biomass volume.

Dr. Michael Amaranthus at Oregon State University authored over 70 scientific papers on mycorrhizal fungi and their use in soil restoration and maintaining productivity of plants. He created a full array of mycorrhizal inoculants, and had two mycorrhizal genera and many species named in his honor. His company Mycorrhizal Applications produces the world's largest selection of mycorrhizal inoculum used by landscapers, farms, nurseries, soil restoration & erosion control companies, and distributors.

Many new probiotic microbial products are appearing each year. For example, SCD Probiotics. a new company in Kansas City, offers a wide range of microbial cultures packaged for varied applications, including agriculture, livestock, household, compost, and personal health. Their BioAg™ product, with lactic acid bacteria, yeast and phototrophic bacteria, is used as a liquid biochar inoculant by soaking char in a solution for 48 hours.

A special concern is Nitrogen-fixing bacteria, since Nitrogen, the 4th Organic Element of life, is a major growth-limiting nutrient. A National Science Foundation report cataloged over 250 species of Nitrogen-fixing bacteria. Each inhabits its own specialized environment, including strains that live in symbiosis on the roots of specific host plants, such as *Rhizobia* on legumes. Of particular interest for biochar are free-living N-fixing bacteria.

High nitrate levels found in Amazonian *terra preta* suggest that biochar hosts unique strains of free-living, Nitrogen-fixing bacteria. Thus, it seems properly inoculated char can provide additional ways to fix Nitrogen into nitrates. The more the needs and nutrients of these specialized bacteria are readily available, the faster they will proliferate and spread in soil. Biochar plus trace elements can meet these requirements.

So, a key issue is to find these strains of free-living bacteria, and be sure they are inoculated into new biochar.

Carbon-Smart Farming

In 2006, Virginia Tech University began field trials adding biochar to soil growing tomatoes, potatoes and sweet corn. Virginia Tech research demonstrated and highlights that biochar properly prepared by being charged with minerals and inoculated with microbes can achieve remarkable results with very low rates per acre, instead of several tons per acre. These results are immediate, not in the second or third year.

Biochar was supplied by CarbonChar, a new company producing inoculated biochar. Jon Nilsson, an east coast soil scientist and compost expert, guided CarbonChar to create a biochar-based inoculant with beneficial microbes, substrates and microbial food. In initial research with sweet corn, Nilsson found that biochar-based inoculant applied in the planting row at rates as low as 7.5 pounds per acre saw significant increases in yield and mycorrhizal colonization of roots.

When a biochar-based inoculant was used at 2.5 % by volume in a transplant growing mix, it had the following results:

- 30 lb/acre savings in nitrogen for Potatoes (2006)
- 10% increase in Sweet Corn yield (2006-07)
- 22% increase in Tomato yield (2007)
- 51% increase in Tomato yield at first pick (4-year average)
- Tomato yield was 1-2 weeks earlier than untreated plots

Tomato yields were achieved with two cups of char plus inoculant in five gallons of transplant potting mix. In 2010 trials, four cups per five gallons of mix was used, resulting in even higher yields.

Jon Nilsson reports, "Virginia Tech research was replicated results over four years. Trials weren't based on biochar alone, but also included changes in cultural practices:

- soil had decent fertility when we started
- low salt fertilizer used at transplant time (fish emulsion)
- cover crop turned in prior to planting
- low salt fertilizer at low amounts in growing season

"We saw changes in the field through soil penetrometer readings. If my stuff works, who cares what I call it, or what your beliefs are. Bottom line is beneficial microbes are salt intolerant, and much easier to kill than a germinating seed. Farmers using high-salt fertilizers won't benefit from this technology."

Jon Nilsson tells farmers, "Microbes are more efficient than any product you ever bought. They work 24/7, and are lots cheaper than fertilizer. Inoculated products lower costs, yet maintain or increase yield. That's money in a farmer's pocket." Jon is emphatic: "Agriculture will turn on a dime when bio-inoculants show farmers permanent changes to soil fertility and cost reductions. My job is to cut costs and increase yields." (For further information: **Biochar-Based Amendment Enhances Tomato Transplant Growth and Early Fruiting**, Dr. Ronald Morse, Professor Emeritus, Dept. of Horticulture, VA Tech and Jon Nilsson, Soil Scientist, Biochar Applications, Mills River, NC)

This is our 21st Century challenge: to transform farming from antibiotic to probiotic. The future of farming isn't methods that just increase yield, but rather, to create a full menu of soil minerals, regenerate microbes and the entire soil food web, and grow nutrient-dense foods. And the future of humanity hinges on farming that restores Carbon to soil and reduces global warming due to the greenhouse effect.