ECOLOGICAL ECONOMY: INTEGRATING BENEFICIAL FUNGI TO OUR PRODUCTION SYSTEMS

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ECOLOGICAL ECONOMY: INTEGRATING BENEFICIAL

FUNGI TO OUR PRODUCTION SYSTEMS

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For my Grandfather, Capt. USN Vincent Joseph Manara Jr.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The purpose of this thesis is to investigate how much more could be gained per unit of economic and environmental output by utilizing the energy and resources provided by naturally occurring fungi, particularly mycorrhizal types. With the integration of mycological sciences and production technologies would come the opportunity to grow green energy and business, operating under the economic law of marginal growth, but without conflict of finite resources. A bio-restoration research experiment was done to illustrate this by introducing fungi compost to a plot of blue Hopi maize and comparing its yield characteristics to a plot without the additional fungi introduced. The agricultural applications reveal how food and fiber industries could receive comprehensive cost savings by utilizing free energy from fungi. Beyond the economic value of beneficial fungi, the ecological significance is illustrated; with ways dichotomous producers can benefit concurrently from complete mycological systems. The kingdom of Fungi is largely responsible for recycling all types of fabrication, and can be considered the new paradigm for progressive sustainability in business, when recognized for its energetic technology. Without responsible use of earth's complex natural systems, life will likely become finite. The natural system emphasized in this essay is the subterranean network of life known as fungi.

INTRODUCTION

Chapter I is a brief account of mycology, the study of fungi, and is laid out to recount the physiological life cycle of fungi and their interactions in ecological systems. Fungi and other archaic kingdoms mark the beginning layers of our story by performing the vital tasks that allow life to regenerate. The subterranean environmental landscape where numerous species of fungi operate provides the building blocks for the diversified life above ground. Here is also a concise summary of mycorestoration, the use of fungi to restore degraded environments, and explanation of why it should gain the attention of the international food industry and consumers of commercial agricultural goods.

Chapter II introduces the application of mycorrhizal fungi in local and commercial agriculture, and the economic potential in terms of increased productivity that is further ecologically sustainable. A key function of crop productivity that continues to go absent in commercial agriculture is attention to soil health and the cultivation of mycorrhizospheres (fungi that help plant roots thrive) to benefit food and fiber crops. With the integration of beneficial fungi into agricultural production systems, quality and quantity of output will increase, thus optimizing humanities efforts in sustainability while meeting the demands of supply. For economic sustainability to prevail, there needs to be environmental sustainability, requiring boundless biodiversity to ensure resiliency against an array of global instabilities.

A research experiment was done to show quantitative and qualitative results primarily focusing on the effects of plant growth of blue Hopi maize with and without fungi compost application to the soil. Using active compost in outdoor conditions limited the ability to make conclusions due to the variety of uncontrolled factors. To singularly test the affects of mycorrhizae on the crop, one would need sterile greenhouse conditions with filtered air among other controls to limit the complex interactions among a typical agricultural plot. Conclusions estimated economic savings on costs of fertilizer, fuel, water, labor, and increased yield. The test subjects started as 360 blue Hopi maize seeds- 120 grown on a plot with commercial chemical fertilizer, 120 on a plot with Bobcat Blend food waste compost, and 120 on a plot with Kitchen Prides' mushroom compost. The hypothesis was maize grown in mushroom compost would have the greatest yield and would save the greatest amount of energy. Results indicated Bobcat Blend compost provided the most productive maize, with 94 mature ears on harvest date, 60 more than the fungi compost plot, and 74 more than the commercial plot. The economic benefits of the fungi and organic matter compost alike may lead to larger discussion on implementations to the International Food Industry, with maize being a staple food crop across the globe.

Chapter III discusses how much more could be gained per unit of *economic* output by utilizing the energy and resources provided by naturally occurring fungi. Included are possible solutions for more efficient and productive global intensive farming with an analysis of what industrial-scale mycology has the capacity to do, and how this would affect the international food industry. Usually, economic growth is acquired by the depletion of biological growth; economic wealth and biological wealth have always been inversely related, but it does not have to be this way. As mycological science and technology is applied to international food and fiber production, natural resources can be *grown* as fast as they are depleted, benefiting both economic and ecological systems. This allows for sustainable operation under the economic law of marginal growth, without the conflict of finite resources. International application becomes more challenging with so many additional variables to account for, exposing more risk as well as opportunity. There is no one size fits all model, but it is a challenge worth integrating into the market, for nature's systems have considerable free energy to offer. The international economic benefits of incorporating mycological technologies into productive systems can be seen through example, as will be explored in the business plan for *Mycelia Solutions.*

Chapter IV investigates how much more could be saved per unit of *environmental* extraction by utilizing the energy and resources provided by naturally occurring fungi. Here, some other examples of agricultural application are introduced, including myco-gardening, remediation, herbicide, and pesticide. Analyzing fungal colonies up close can determine how and where they can create the greatest impact in procedures beyond the food and fiber field: in urban, industrial, distributional, mechanical, climatic, and aquatic, forestral, nutritional, medical, and chemical systems. An inter-connected perspective from a vast array of multidisciplinary leaders could allow this vision to become compatible with sustaining the international food industry and global market. Optimal sustainability is achieved with maximized biodiversity, meaning the microscopic systems at work in soils and agricultural production systems need to be recognized and accounted for. I have chosen to unveil the kingdom of fungi because it is responsible for recycling planetary organic production, and when recognized in mass would allow more harmonious interaction between the microscopic and macroscopic world. The greatest challenges will be convincing these antithetical systems that they share the same energy.

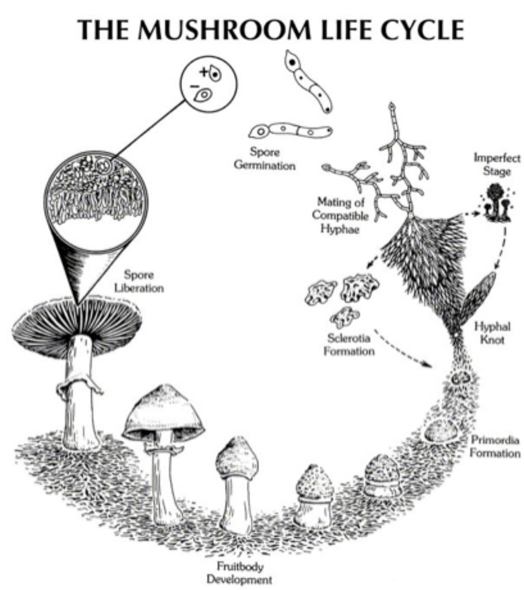
I. The Ecological Role of Fungi

Fungi behave as a planetary recycling agent, responsible for breaking down large dehydrogenated polymers once they have fulfilled their purpose in one biological form, to make them readily available for another. By consuming and decomposing organic matter, fungus creates an environment stocked with resources for the next generation of organisms. Fungi and other equally important microbes and decomposers are responsible for making all terrestrial life's resources available for full cycle use in global systems.

Plants convert photons into carbohydrates to be used for growth, and heterotrophs (organisms that cannot make their own food) such as animals and fungi, consume them. Within the cells of green plants, photons are used for hydrolysis of water, which then allow the free H^+ to recombine with CO_2 to form $C_6H_{12}O_6$, a simple sugar. Those compounds, in partnership with mineral elements from the soil (nitrogen, potassium, phosphorus, iron, and calcium, and more) continue to form more complex molecules of amino acids, proteins, enzymes and nucleic acids, the building blocks of life. But as plants continue to grow and multiply, mineral elements from the soil become trapped in their mass, hindering the availability for new plant growth. As mycologist Dr. George Hudler puts it, spent plant material has to be decomposed one way or another, otherwise we would find ourselves, habitats, and water sources totally overwhelmed by it (Hudler 1998, 4). This is where fungi come in; bacteria, protozoa, and other groups of organisms additionally contribute to the decomposition of complex organic matter. Yet fungal enzymes break down tough cellulose, lignin, and pectin of plant cells, and also have the power to denature toxic petrochemicals back into their harmless, simple molecules, ready for reintroduction to the food chain and ecosystem (Stamets 2005).

An individual fungus starts with a single spore. The spore is the embryonic body of a fungus; it germinates in the presence of enough water to begin to grow into its first structure, a germ tube. With a continued source of nutrients, these tubes will grow into hypha; longer, thicker strands of tubes, which branch and multiply, eventually becoming a colony dense enough to be considered mycelium, the body of a fungus. Mycelium matures as it continues absorbing nutrients from surrounding organic material, and when time, temperature and moisture are adequate, some hyphae will consolidate into even denser masses, collectively forming primordial, baby mushrooms. From here the mushrooms will continue grow, eventually reaching maturity, signaled by the release of microscopic spores, each containing their descendants genetic material. Many types of fungi do not produce mushrooms, but reproduce by asexual means of mycelial spore release. Fungi evolved a way of external digestion that often provides resources for the food source as well. By secreting acids and enzymes such as cutinase and cellulose into their mediums, fungi can absorb what they want and provide a range of benefits including food

Figure 1. Typical mushroom life cycle. Paul Stamets 1995.



and shelter in return. Some fungi partnered with plants, which lacked these digestive properties, thus allowing plants to inhabit land around 400 million years ago, mycologists believe. Millions of years later one evolutionary branch of fungi led to the development of animals, which also heterogeneously accumulate their food sources. Beyond the diverse enzymatic and chemical responses to their surroundings is fungal mycelium's ability to work as a metabolic matrix in response to changes in the environment. Complex challenges and stresses that are inflicted upon ecosystems across the globe require sharp chemical tactics of the vital organisms supporting the members, giving mycelium a monumental responsibility in protecting and providing for some of life's primary materials. The underlying foundation of the food web is mycelium. Mycelium functions like a neurological structure in its environment, encouraging a long-term supply of fuel for itself and ultimately the further reaches of the complex food chain. Leading entrepreneurial mycologist Paul Stamets guides the way through the physiological activity of mycelium; its interweaving chains of cells functioning as a highly interactive web of intelligence, streaming through soil sharing and transferring information and resources (Stamets 2005). These dynamic evolutionary strategies have proven successful, given the age and size of some varieties of fungi (the honey mushroom *Armillaria mellea* is the largest terrestrial organism to date). Mycelia recycle carbon, nitrogen, and other essential elements when breaking down plant and animal debris, which account for the rich organic matter that a healthy soil then reoffers to plants and animals.

Fungus is sometimes considered *The Lost Kingdom*, having more genetic similarity to the animal kingdom than any other. Plants and animals were once separated into kingdoms based on ones ability to make its own food and the other not. Fungi were considered plants for a long time, until it became too unusual to consider something that cannot make its own food among other distinctions, a plant. In 1784, *Fungi* became the third kingdom of living organisms. Some of the unique differences fungi have from other groups of living organisms begin with their composition: a fungus body is comprised of cells with nuclei and walls made of chitin plus other polysaccharides, but rarely cellulose. Compare them to bacteria or archea that have no nucleus, to animals, who have no cell walls, or to plants, whose second major component is cellulose (Hudler 1998). Fungi are heterotrophic, meaning they cannot make their own food like plants do with chlorophyll; instead they absorb nutrients that have already been converted.

Four general categories can identify fruit-producing fungi based on how they acquire energy: saprophytic, parasitic, endophytic, and mycorrhizal. Saprophytic fungi are those responsible for recycling plant bio mass nutrients by manipulating them as they senesce. Their mycelial networks stream around and within the cell walls of plant material as it retires from the landscape, and secrete acids and enzymes that unlock molecular compounds, rebuilding them into available polysaccharides and nutrients, ultimately creating the first line of an available recycled food source. It is at this stage in the cycle of life that essential elements are passed from one generation to another. It is these decomposers that release minerals trapped in plants at the end of their life cycle, back into the soil for the next round of growth. Other organisms that help decompose organic matter are often

Figure 2. Hexagonia hydnoides, a saprophyte in my Texas hill country garden (Lincoff 1991).

unicellular, such as bacteria and protozoa, performing a different degree of decay. In various production fields, saprophytic fungi's enzymatic properties are applied to human recycling needs, a relationship that can continue to be developed to much greater scales. Myco-remediation is the primary process of doing this, using saprophytic fungi's enzymatic properties to eliminate pollutants from soils and the environment. The powerful lignin peroxidases and cellulases that saprophytes release are designed to break down plant fiber, but just so happen to break down and reduce hydrocarbon based pollutants too. Many of the most threatening industrial byproducts are hydrocarbon-based pollutants, including PCB's, PCP, petroleum products, and pesticide/herbicide residues. Saprophytes are ideal candidates for toxic waste cleanup because as they break down these manufactured hydrocarbons, the original harmless compounds are released back into the ecosystem as a readily available food source (Leatham 1992). This removal of pollutants from the air, land, food, water, and habitats with mycelial power is called mycoremediation.

The next groups of fungus are those classified as parasitic. This category appears to be self-explanatory, fungi that take predatory advantage of their host and energy source, being plant or animal, without providing benefits in return. Blight causing fungi are in this category, whether it is a forest or a crop field. For most of time, these predators have been severely misunderstood, and thus feared. Systems in nature always have a reason for such acts such as the parasitic fungal attack of a forests healthiest trees; by selecting the healthiest of the batch, the fungus is protecting the rest of a likely stressed and depleted canopy by quickly recycling those nutrients back into the soil, before all other specimens are too weak to thrive. Paul Stamets declares that a rotting tree in the midst of a canopied forest is, in fact, more supportive of biodiversity than a living tree (Stamets 2005, 21). Blights of the forest or field, yes, but from another perspective, agents for habitat vitality. Unfortunately, numerous fungi digest and devour some of the same plants that humans too have claimed as food. Crops such as maize, grains, corn, potato, and tomato are attacked century again by rusts and smuts that develop new defense mechanisms for the chemicals used to combat them. This cycle is seen by most as a tragedy, but in the long-term scheme, it is a necessary part of nature. After all, the mission of a parasitic mushroom and a saprophytic is one in the same, to recycle habitual energy by creating fertile active soil for new generations of life.

The role of fungi beyond decomposing or manipulating organic matter becomes further complex. Mycorrhizal types carry out the next monumental role of fungi by acting as an interface between plant roots and soil nutrients through mycelial formation. When aquatic plants began to appear on land about 400 million years ago, fungi had already been thriving there for at least 60 million years, occupying resources as crude as bedrock. Seeing the fungus as a potentially helpful assistant in getting acquainted with the new competitive conditions of terrestrial life, plants began to take up partnerships with fungi, providing them with sugars in return for root strength in the soil and protection among the competition (Stamets 2005). Evidence suggests that the two kingdoms evolved with these habits to share what mechanisms they each had for survival in low soil fertility, irregular climates, and against disease and other environmental stresses.

Figure 3. Devonian period landscape (400mya) featuring the fungus Prototaxites. Painted by Geoffrey Kibby, April 2008.

Figure 3 is a painting by Geoffrey Kibby (senior editor of *Field Mycology*, photo featured in April 2008) illustrating a 400 mya Devonian period landscape, featuring the fungus *Prototaxites*, the largest terrestrial organism to have lived by this time. This physical dominance of *Prototaxites* lasted at least 40 million years, about 20 times longer than the genus *Homo* has so far existed on Earth (Moore 2012). Because of the co-evolution of fungi and plants, mycorrhizae are as common on the root systems of trees and most plants in undisturbed soils as chloroplasts are in leaves. Plant roots support many varieties of microorganisms in addition to mycorrhizal fungi. Mycorrhizae (mycos=fungus, rhiza=root) grow on and in the roots of plants in a partnership that provides both the fungus and the plant their food and life source. They do this by attaching mycelial membranes either on or inside plant roots, tapping into sugars and carbohydrates translocated from the plant leaves. These sources provide the mycelium with the fuel to extend the reach and surface area of the roots further, for greater water and nutrient capacity. The mycelial hyphae sent out into the surrounding soil are a fraction of the size of root hairs, allowing the plant access to essential minerals that are tightly compacted into small spaces, that the roots would have otherwise been unlikely to reach (Hudler 1998).

Ectomycorrhizae are those mycelial hyphae that remain around the perimeter of the plants root tissue, feeding it from the outside, while endomycorrhizae actually penetrate the tissue and outer cell walls of the plant root, leaving little or no indication of interaction from external view. According to Leatham, ectomycorrhizae occur on about 10% of the world flora, but endomycorrhizae are much more common, with over 90% of the vascular plant families examined having endomycorrhizal relationships (1992). Mycorrhizal fungi provide the first line of defense against stress in plants that form relationships with them (Fulton 2011). They have extensive multi-branching habits, with hyphae growing considerable distances out into the soil, leaving a much larger and more physiologically active surface area. In return, the fungi gets access to plant-secreted sugars that it further converts into energy (Stamets 2005).

Mycorrhizal fungi are key players in the evolution of rain forests, the most biodiverse places on the planet. When trees are removed from the forest for timber and other production, fragile mycelia, the basis for which such complexity can thrive, are left separated from their food source, exposed to the elements, and unable to defend against direct solar penetration. Yet because mycorrhizae are so ubiquitous across the world, the chance to see how ecosystems would persist without them is rare. Mycelium strengthens all soils it uses as a substrate by creating a web of bondage, building an infrastructure, and protecting soils from erosion. The matrices that mycelia build through soil create a distribution system for water and airflow, bringing the otherwise fluctuating conditions and temperatures to equilibrium with a more hospitable atmosphere (Fulton 2011). In large, mycelia create a terrestrial habitat that can sustainably support optimal organic matter, meaning healthier soil, and thus healthier plants. Mycelia not only supply plants with a greater supply of water and nutrients, but protect the roots from drought, by storage of water in hyphae cells, from disease and pathogens, by enzymatic antibiotic control, and from other biotic and abiotic stresses, by managing them personally (enzymatically). Since mycorrhizal fungi contribute to the chemical composition of the plants that animals eat, they make up a part of the human composition, too. Many mycorrhizal fungi produce delicious fruits with many nutritional and medicinal benefits. Some examples of mycorrhizal mushrooms commonly harvested are the matsutake mushroom, chanterelles, and boletus.

Figure 4. A bountiful hunt for delicious mycorrhizal mushrooms in the San Juan Mountains. Boletus, chanterelles, & puffballs to name a few!

Endophytic fungi are classified by their mutualistic partnerships with other plants, animals and insects. Patterns in nature show that plants and animals have many complex relationships with other organisms in their ecosystems; many insects farm fungi, ants, snails, and termites included (Stamets 2005). And some fungi produce alkaloids that are toxic to humans, other animals, and insects, to protect their plant partner from predation.

Mycorestoration, the use of fungi to restore the weakened immune systems of environments, unveils the microscopic world underneath our feet, and when used in mass would allow society to interact with the macroscopic world more harmoniously. Among mycorestoration practices are mycofiltration and mycoremediation. These technologies are being exposed today as the search for restorative protection and prevention practices begins, though fungi has played a primary role in environmental health for millions of years. Mycorestoration is one of many functions of naturally occurring fungi and has a vital place among the global biosphere, even among the harshest of ecosystems. With mycorestorative practices, the carbon footprint could be reduced and some of the damages likely replaced with economically and environmentally beneficial growth.

Gradually the agricultural revolution led to the cultural reorganization of most of the Earth's surface that was arable or contained some perceived resource. Nearly 10,000 years later a second major technological breakthrough occurred in the form of the industrial revolution, representing the transition from reliance on animate energy, to inanimate energy. A major event in the Industrial Revolution was the refinement of the steam engine, which made it possible to extract the chemically bonded energy stored in wood and coal to do work.

Geographer Brock Brown

Now that inanimate energy has been used to some of its maximum capability, it is time to consider the possibilities for restoring some of the animate origins. Of the 29% of earth's surface covered by landmass, (36% of that is agricultural, 33% forest, 3% urban, and the rest ice, mountain, or desert) a large majority can benefit from (re) introduction of beneficial fungi, especially in the agricultural area, where many fungi have been dismantled due to abused soils (Drummond and Goodwin, 2011).

II. Bio-restoration: Mycorrhizal Mushroom Compost Application to Blue Hopi Maize

In relation to potential mycorrhizal fungi impacts on agriculture, a research experiment was conducted under the supervision of Dr. Ken Mix, Department of Agriculture at Texas State University, with funds from the Texas State University Environmental Service Committee, to explore the agricultural prospects of mushroom compost. By measuring how much of an effect compost application had on crop yield and strength, predictions could be made regarding sustainability endeavors and expansion prospects. With this data came exposure to potential types of energy savings that could be accumulated in regards to microbiological activity. After analyzing the powerful role of mycorrhizal fungi and organic matter recycling in plant productivity, it makes sense that humans would in due course capitalize on this energy efficient process by cultivating staple crops such as maize with their fungi counterparts. Such a method provides possibility for not only economic savings, but environmental, too. This experiment was conducted to compare the difference in crop yield, development, root and soil structure, and water efficiency with and without the addition of fungi compost. Further testing may be done using one specific strain of mycorrhizal fungi to encourage measurable development, implementing soil tests to reinforce the interpretations of nutrient comparisons.

i. Background Info

Maize was the crop of choice for this experiment because of its wide-scale production and intensive farming practices. The heavy dependency humans have on maize is a threat to biodiversity among many other controversial issues. Choosing not to go into too much detail on the fragile circumstance under which food products, consumer goods, and nuclear commodities are being manufactured under the same roof, from the same maize plant material, instead the focus will be proposed solutions for a greener future that will reduce consumerist exigency. Humans have relied on maize as a source of food for over 8,000 years, and the amount of dependence on this crop today as a food fiber and fuel source is immeasurable. Maize provides major direct sources of energy and is in many consumer goods, ranging from toothpaste to ice cream to chips! Research shows that maize can make up to 70% of the carbon in a human body; without it the human population would not be the size it is today (Leathers and Foster 2009). It is is relied on as a third of the world's supply of staple crop material. Because the consequences of overpopulation, chemical toxicity from heavy fertilizers, and nutrient deficient GMO maize are on the rise, mycorrhizal fungi research and solutions are urgent, with emphasis on application to food systems. Mycorrhizal fungi are the natural tool for meeting the increasing economic demand of maize and other staple crops and slowing down their rate of unsustainable cultivation. Mycorrhizal fungi improve soil structure and living quality; ease the flow of plant nutrient uptake and thus yield; and increase water efficiency and drought resistance (Fulton 2011). These fungi also strengthen their partner plants immunity to outside disease and pests, by acting as a shield around the roots. This experiment was performed to see if fungi compost application to soil to strengthen crop root systems is an adequate and cost effective proposal for the improvement for commercial agriculture. In this experiment, the following question was addressed: what differences in maize development and yield will be seen between the plot grown with mushroom compost and the control plot without? An additional plot was added to the experiment that had Bobcat Blend compost applied, to compare the effects of food waste compost on a plot of maize. The aim of this research was to reveal a simply interpreted comparison between the outcome of commercial practices and sustainable compost use. Chemical fertilizers are used commercially to increase yields annually because the laws of economics require marginal growth in sales/yield. Food is a business. But it is well known that chemical fertilizers have depleted soils of minerals and nutrients, and are demonstrably not sustainable. Technological advancements have overshadowed the concealed function of productive soils, ultimately determining the industries unsustainability.

ii. Materials and Methods

The blue Hopi seeds were planted on the Texas State Student Sustainable Farm in San Marcos Texas, and were sown in three plots of local soil for comparable statistics. One of these had Kitchen Prides mushroom compost (referred to as fungi compost) as its addition, one had Bobcat Blend compost added, and the last was the comparative plot, with commercial 13-13-13 chemical fertilizer added, but no compost. The growing conditions were hot and dry, and charted over twenty weeks, comparing the rate of growth, health of the crop, and development of root and soil structure. In addition, the effects of drought conditions were monitored, testing the composts ability to retain more water for longer periods than the plain soil. Hand pollination was done to assure full pollination of the ears since the plots were designed in long rows, limiting their ability to self-pollinate, and final conclusions were made based on the quantity of ears produced by each plot at harvest.

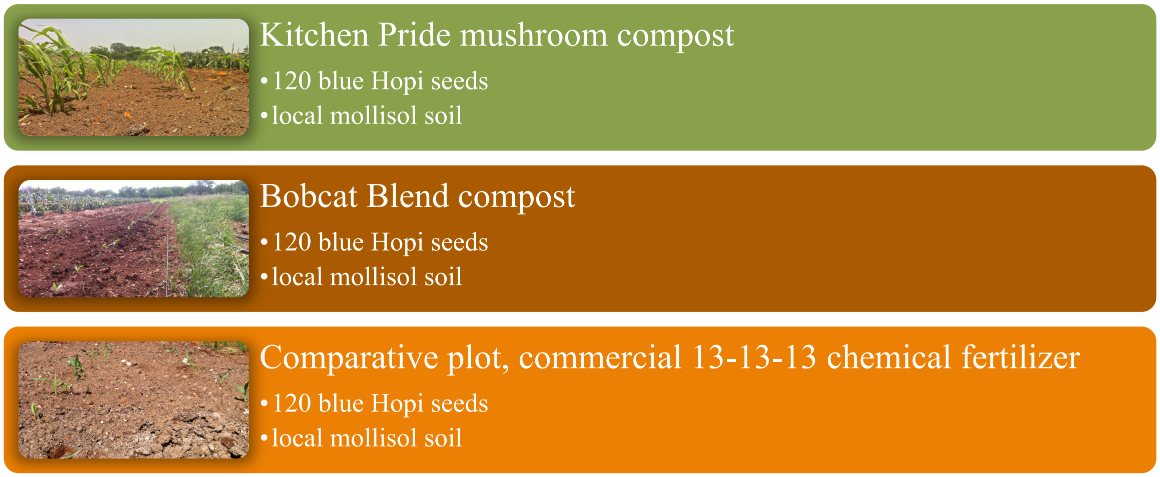


Figure 5. Illustrates the general shape and layout of the three comparative plots.

iii. Results

a. Analysis of data

The blue Hopi seeds were sowed the first week of June, and by the end of the month, healthy consistent growth encompassed both compost plots, but the comparative commercial plot was relatively unproductive, as seen in Figure 6. Ideally the seeds would have been sowed about a month earlier, but a variety of factors pushed the starting date back. Planting this late in the season likely contributed to the stresses that the maize indicated later in the season.

Figure 6. Bobcat Blend plot on the left, showing significant increase in development compared to commercial plot on the right.

By July 5, the stalks of each plot were measured and categorized based on how tall they were relative to the overall average height, as seen in Table 1. With these criteria, the commercial comparative plot had produced 8 tall stalks, 48 average height stalks, and 8 stalks whose growth was stunted, 64 in total. The mushroom compost plot had produced 92 tall stalks of Hopi maize, 14 stalks of average height, and 10 stunted stalks, 116 in total. The Bobcat Blend plot had produced 91 tall stalks, 13 of average height, and 13 stalks that were stunted, 117 overall.

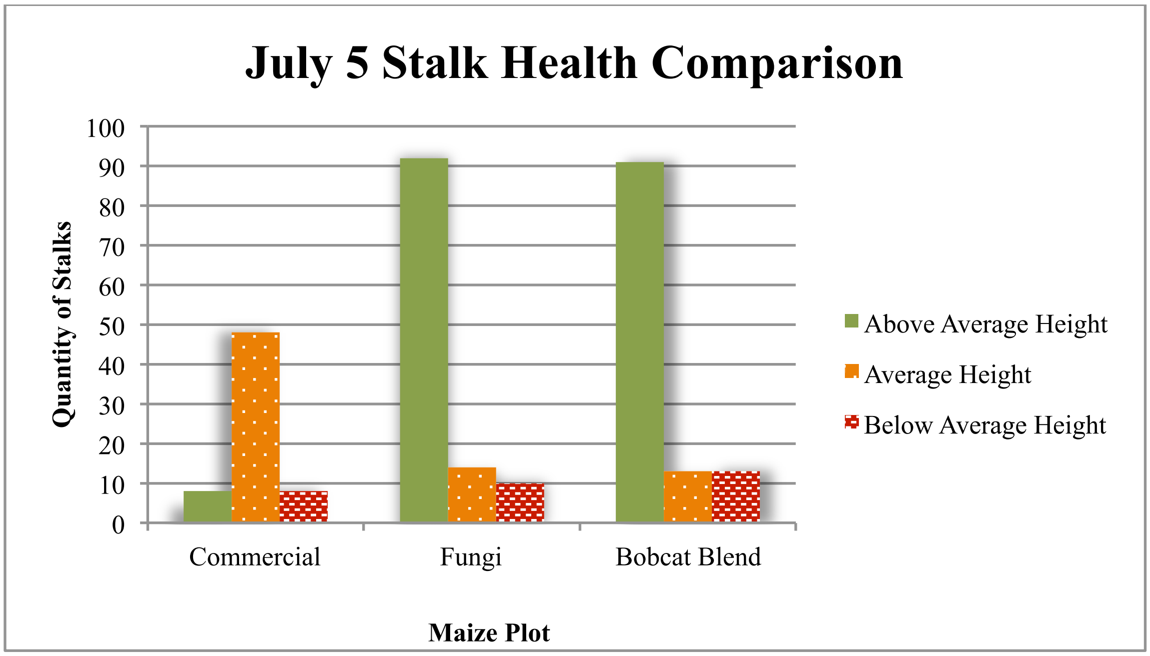


Table 1.

Due to the planting of maize in rows instead of blocks, it was not likely that the stalks would have the capacity to fully pollinate, so hand-pollination began August 4, and continued for about two weeks to attempt complete pollination.

Figure 7. (Left) Tassel, ready to convey pollen to the ear silk (right).

By September 4, the fungi compost plot had 57 ear-developing stalks of Hopi maize, 33 stalks of maize with no ears forming, and 16 small stalks that were stunted but still alive, with 106 stalks in total. The commercial comparative plot had 18 ear-producing stalks, 6 non-producing stalks, and 10 stunted stalks, 34 in total. The Bobcat Blend plot had produced 83 stalks with ears developing, 14 unproductive stalks, and 9 stunted, 106 overall, seen in Table 2.

Table 2.

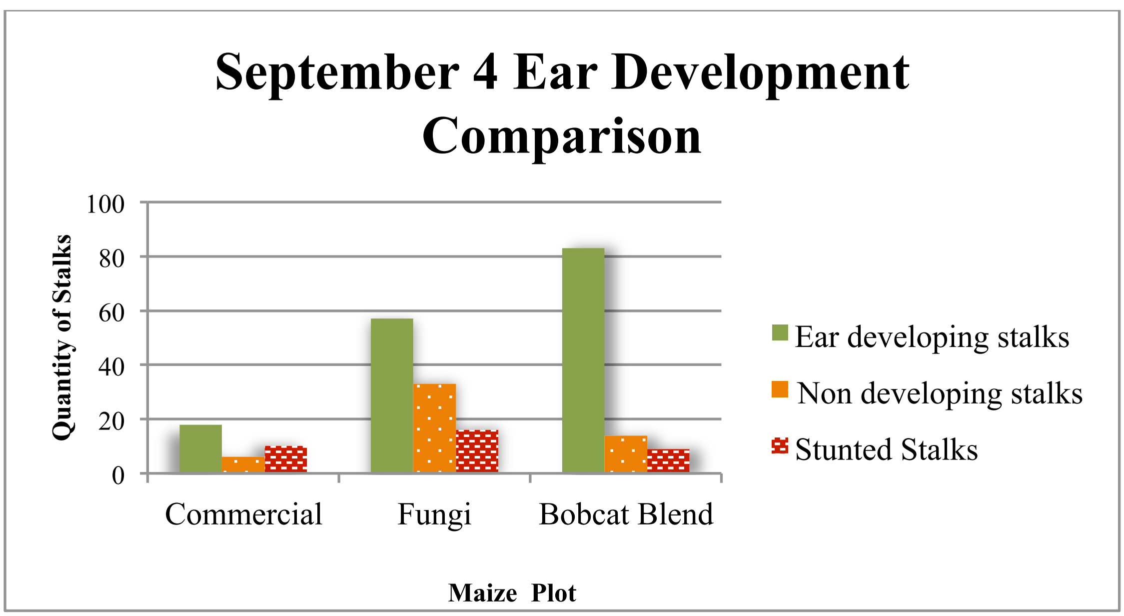
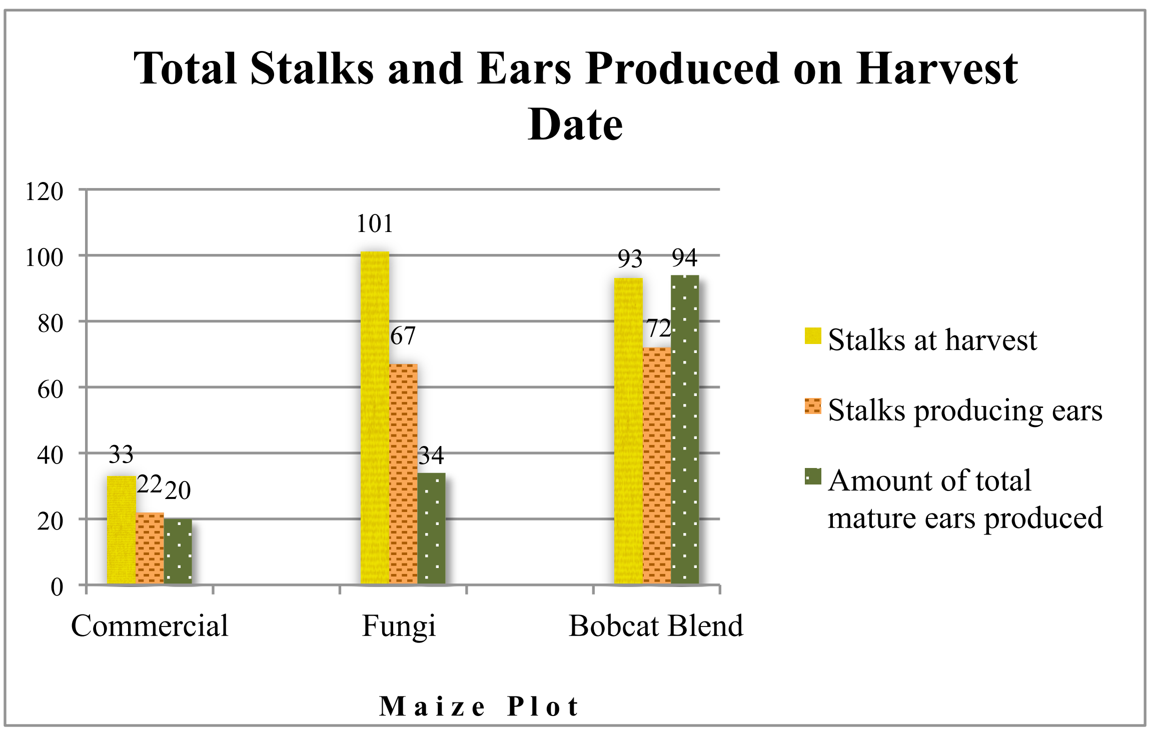


Figure 8. Close up of commercial plot, showing how dry and bare a majority of the plot remained.

On September 22 the mature ears were harvested from all three plots: the Bobcat Blend compost corn produced the highest yield, ending the yield period with 93 live stalks, 72 of which produced ears, with a total of 94 ears. The fungi compost corn produced a total of 101 stalks at the end of the yield period, 67 of which produced ears, but only 34 full-grown ears were produced in total. The commercial group ended the yield period with 33 live stalks, 22 of which produced ears, with a total of 20 full-grown ears.

Table 3. Final Results



When collected for measuring, the average ear of Bobcat Blend maize was 10.6 inches in length with the husk, and 7.5 inches without the husk. The average ear of fungi compost maize was 9.4 inches in length with the husk, and 6.1 inches without the husk. And the average ear of commercial plot maize was 10 inches in length with the husk, and 6.3 inches without the husk, seen in Table 4.

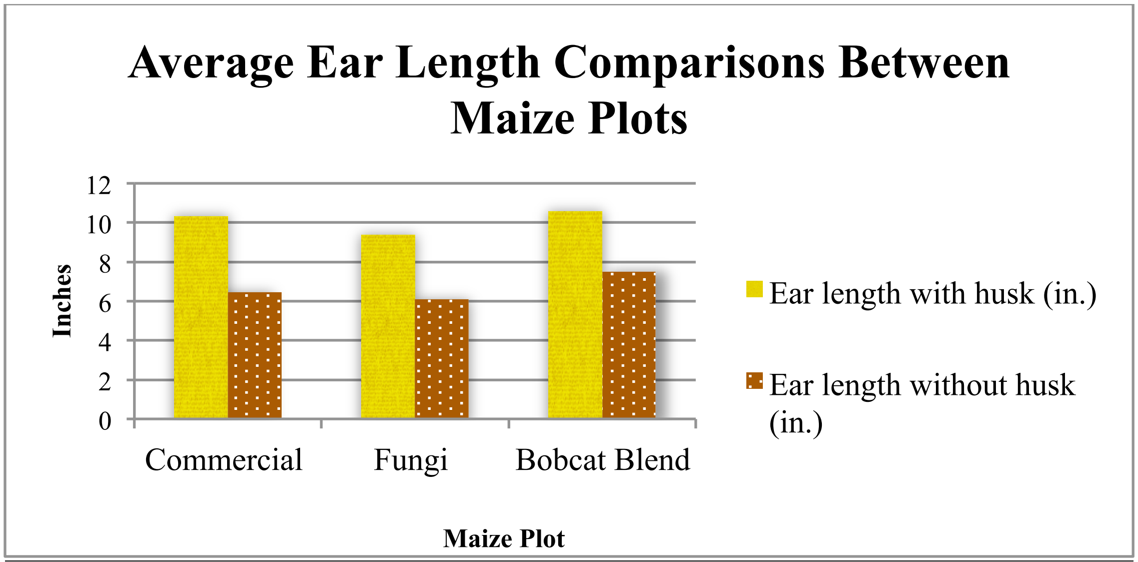


Table 4.

The average ear weight of Bobcat Blend maize was 82.5 grams with the husk, 58.5 grams without the husk, and 28 grams when dried. The average weight of the fungi compost maize ears was 52 grams with husk, 34 grams without the husk, and 15.3 grams when dried. The average ear weight of commercial maize ears was 57 grams with husk, 31 grams without the husk, 10 grams dry weight, seen in Table 5.

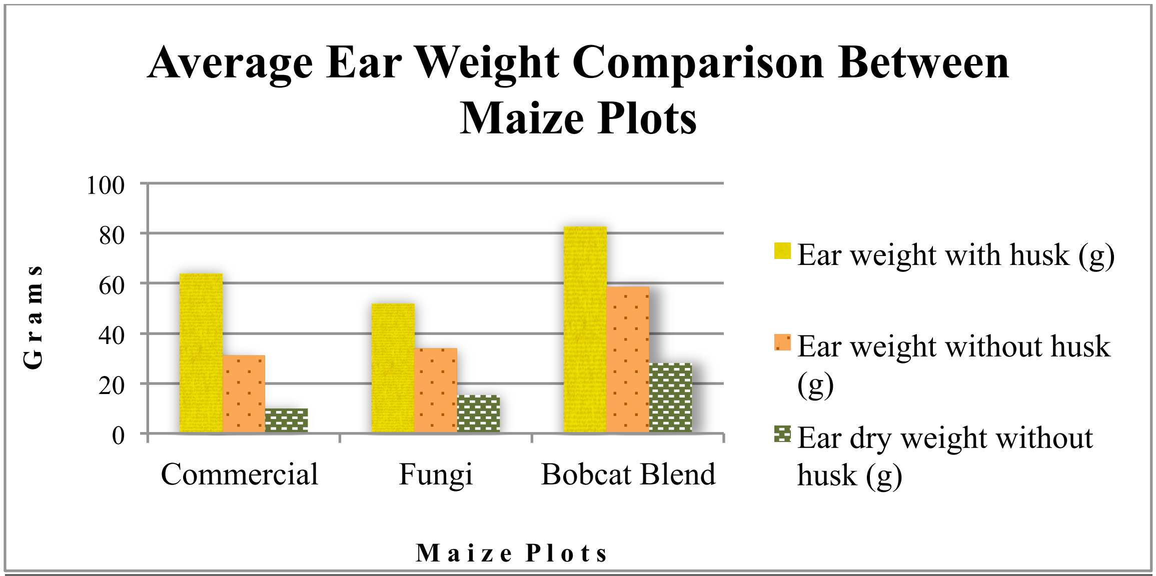


Table 5.

iv. Discussion

a. Interpretation of Results

From the experiment, results showed that Bobcat Blend compost gave the maize an advantage over the mushroom compost and the chemical fertilizer. In Tables 1, 2, and 3, relative trends in the height and quantity of stalks grown on plots with either of the compost types are present. The commercial fertilizer plot produced a fraction of the others, most likely due to scarcity of essential nutrients needed from organic matter that was absent in the soil, as well as stress. What is not known is why out of 101 mature stalks produced by the fungi compost plot, only 34 mature ears were collected in total. One proposition relates this contrast directly to the nutrients involved. The first of three essential nutrients to consider is phosphorous, responsible for encouraging maize to produce ears. In reviewing Table 3, it appears Bobcat Blend compost provided an ideal quantity of phosphorous, since each of its stalks produced one or more mature ears of corn. On the contrary, only about one third of the stalks grown in fungi compost produced ears, reason to believe the fungi compost failed to assist the maize roots in absorbing phosphorous. As young plants, maize roots are more likely to be fully colonized by mycorrhizae if the myco network is already well established in the soil. In this experiment, the fungi compost was spread and only days later were the seeds sown, limiting the time available for an extended mycelial network to commence that could provide access to enough phosphorous (Fulton 2011). In addition, the mycorrhizal species that maize typically prefers were not intentionally present in the mushroom compost, made of spent saprophytic mushrooms and their substrates.

Figure 9 shows an endomycorrhizal fungus (appearing blue) that has effectively colonized roots of maize (From Bittman, S. et al., 2004. Agriculture and Agri-Food Canada). The mycorrhizal hyphae continue extending outside of the root and into the soil, increasing the roots zone of phosphorous absorption as well as other nutrients otherwise remaining immobile in the soil.

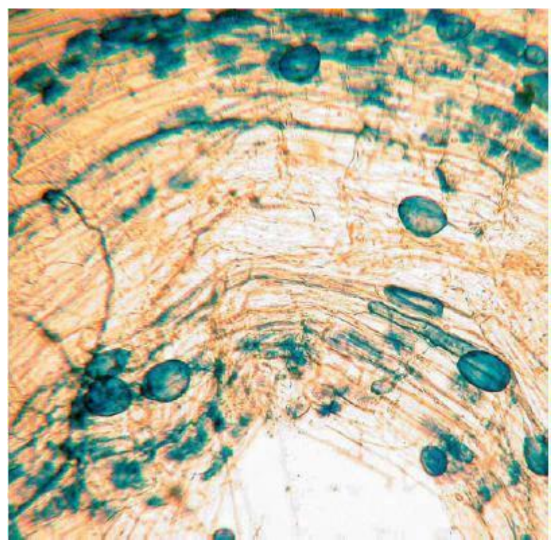


Figure 9. Photomicrograph (60x) of corn roots (tan) colonized by mycorrhizal fungi (stained blue).

The next nutrient involved in this theory is nitrogen, the key element that encourages leafy growth in crops. Maize is known for heavy nitrogen requirements, and in reference to Table 3, the maize of both compost plots seemed to supply sufficient access to it. For the fungi compost it was likely too much (in relation to its supply of phosphorous), causing the maize to become leafy, and appear healthy, but incapable of producing ears. The final nutrient emphasized in this proposition is potassium. This essential nutrient defends the crop from stresses such as harsh climatic conditions. In comparing Tables 1 and 3, the commercial fertilizer plot lost 31 stalks over the course of growth; Bobcat Blend lost 24 stalks, and the fungi compost only 15. If these losses were due to stress, than it can be gathered that the commercial fertilizer plot and Bobcat Blend plot were deficient in potassium, while the fungi compost plot provided a more adequate supply of potassium. This assumption is in accordance with the notion that fungi compost is often recognized for providing plants with relatively large quantities of potassium (Kitchen Pride 2012). Soil tests would be helpful in validating this theory.

The prevalent organic matter on the Bobcat Blend plot is likely responsible for allowing 94 ears to be produced, with many stalks producing more than one ear. The Kitchen Pride mushroom compost was made of nutrient-rich materials, but not of such variety as Bobcat Blends. The main function of mycorrhizal fungi in relations to its partner plant is to translocate nutrients and water to the plant from the soil (Fulton 2011). Since the original soil of these plots was deficient in organic matter and thus nutrients, the fungi compost may have ran out of resources to bring to the maize roots. The substantial quantity of mature stalks (101 total) indicated that the mycelium likely assisted in water retention throughout the dry periods, but the intense direct sunlight on the plot of mushroom compost may have hindered its performance. Fungal mycelium is a very sensitive matrix in the soil, and is especially sensitive to temperature (Fulton 2011).

All three plots produced ears that were around the same length when the husk was still on the ear, as seen in Table 4. But once the husk was removed, the blue Hopi maize cobs produced by the Bobcat Blend plot were almost 2 inches longer on average than the commercial cobs and the fungi compost cobs. Why did the fungi compost plot not produce ears competing in length with those of the Bobcat Blend plot? Length of cobs is directly related to nutrition from soil (Maynard and Hochmuth 2007), so it can be inferred that the fungi compost did not provide as much nutrition to the maize as the Bobcat Blend compost did.

As seen in Table 5, the Bobcat Blend plot produced the heaviest ears of corn, followed by the Fungi plot and lastly the commercial plot, without the husk that is. The commercial plot produced ears that were heavier than the fungi maize plot when weighed with the husk, but the fungi maize ears were actually heavier than the commercial plot ears when the husk was taken off, so it can be assumed that the fungi maize ears were denser inside the husk than were the commercial maize.

b. Results of Hypothesis Testing

In this experiment, the following question was addressed: what differences in maize development and yield will be seen between the plot grown with mushroom compost and the control plot without, in addition to the plot with Bobcat Blend food waste compost? In summary, Results showed that maize development remained steady for both compost plots, but the fungi compost plot eventually slowed the rate of growth and did not reach full maturity likely due to nutrient deficiencies. The 13-13-13 chemical fertilizer plot failed to compete with the composted yields, likely due to nutrient deficiency as well. Maize yield was overall greatest with organic matter compost, and mature ear length and size were additionally affected.

c. Problems Encountered

The greatest issue in this experiment was the amount of uncontrolled variables due to the nature of an agricultural plot with an already established soil system. Nature is

Figure 10. Some of the ears failed to produce kernels entirely.

difficult to manipulate, especially on the first try. Experiments comparing mycorrhizal plants with non-mycorrhizal ones should be done in chambers or greenhouses with filtered air, and test plants should be grown from seed in sterile soil to achieve more controlled results (Bittman et al. 2004). Since the soil used in this experiment was not sterile, rather quite the opposite, the uncontrolled variables included possible competitive and established fungi, as well as other unknown variables. To singularly test the affects of the compost on the crop, one may need sterile conditions among other controls to limit the complex interactions among a typical agricultural plot.

Nonetheless, a mycorrhizosphere developed with the maize roots and contributed to their water retention throughout the season. The mushroom compost likely suffered from an over-abundance of solar energy that damaged its developing matrix throughout the soil, suffocating the metabolic pathways between the mycelium and the maize roots, ultimately preventing most of the stalks from reaching full maturity with production of ears (Stamets 2000). Mycelium of any kind is vigorous when conditions are adequate, but fragile when exposed to intense heat among other stresses (Fulton 2011). The last notable issue in this experiment was caused by the shape of the plots being long and narrow, as opposed to a square, increasing probability of self-pollination. If the silks do not individually catch pollen from the tassel overhead, then kernels do not develop, as seen in Figure 10.

d. Solutions to Problems

If repeating this experiment in an indoor setting, entirely sterile methods with filtered air would have been used, concluding with soil testing that verified comparative qualities in mycorrhizal development. Trying the experiment with a specific isolated strain of mycorrhizae, such as *Stropharia rugoso annulata* (commonly used on cornfields in Eastern Europe), would contribute to accuracy in comparisons of yield and crop development based strictly on the myco-relationship (Bittman et al. 2004). Needless to say, the chosen strain would need to be tested to be certain it could adapt to the physical, chemical and biological conditions of the soil and site.

If repeating this experiment in outdoor conditions, it would have been procedure to undergo ecological adaptation procedures for the mycorrhizal fungi to truly be tested, without hindering competing soil microbes and fungi. Mycorrhizal fungi's ability to have successful relations with crops depends on the environmental variation it is equipped to contend with. These systems are complex in nature and introducing non-native fungi to a field has many implications but can also offer a vast range of benefits for the crop and soil (Bittman et al. 2004). This method may be preferred in favor of long-term field production, considering maize and other field crop candidates are always going to be grown outdoors. Unfortunately today, mycorrhizae performance is still underappreciated, limiting the technologies available for commercial management.

Mycorrhizal fungi have many ecological and physiological differences and preferences, so understanding the local conditions before application is key to long-term sustainability and optimal production. If utilizing mycorrhizae for crop benefit, the fungal network should be allowed time to develop a matrix throughout the soil, before the crops are introduced. More fieldwork needs to be developed in selecting, propagating, manipulating, and managing a few of the more desirable fungal species to expand the relationship between mycelium and global agriculture. In addition to improvements on the field, relations with forest and varied sustainable ecosystem initiatives need to be expanded and recognized. These fungal adaptations are the requisite to survival against threatening conditions.

In addition, further testing should be done to compare nutrient content in the soil/compost mix of each plot, and to test the proposition of phosphorous, nitrogen, and potassium availability. This also would have been beneficial to analyze, due to concern of current nutrient deficiencies in more common varieties of intensively grown maize, and maize grown without additional mycorrhizal influence. Water efficiency should also be more carefully compared and analyzed between the two plots, to measure the potential savings on a mass scale.

v. Conclusion

From these data, it can be presumed that the greatest yield of blue Hopi maize could be seen from a plot that combined organic matter compost with fungi compost to utilize the advantages of both. The most direct illustration of the importance of organic matter in crop development was the numeric difference in maize yield, with and without compost. Organic matter proved to provide better soil conditions with increased porosity, water retention, and nutrient availability to the maize (Kabira et al. 1998). The mollisol soil of all three plots had some to offer, but Bobcat Blend compost showed a sharp increase in crop growth rate and yield. Using active compost in outdoor agricultural conditions limited the strict analysis of biological effects due to uncontrolled factors, such as other soil organic matter, competing fungi and bacteria, climatic conditions, and pests. Through this experiment it was discovered that mycelium indeed provides solutions to agriculturally related crop stresses, but should be introduced in a series of ecological adaptation to fulfill long-term production expectations. The intense direct sunlight on the plot of mushroom compost hindered its ability to flourish and prove optimal nutrient availability to the maize (Bittman et al. 2004), thus future field application should consider mediated temperature and sunlight.

vi. Future Development

The total estimated cost of this project was $1,106, but the actual total cost was around $700, mostly due to transportation of hauling compost. This research may continue and finish out the budget with further lab tests needed for soil nutrient analysis. Based on the results of this experiment, if a combination of Kitchen Pride mushroom compost and Bobcat Blend compost were applied to a 333-acre average sized field of corn instead of traditional chemical fertilizer, 506,393.1 more ears would have been harvested. In addition to the yield surplus, 20% of costs on traditional fertilizer would have been saved using compost instead. With close analysis, it is evident that even more money, resources and energy would be saved using the compost, including reduced irrigation usage, fertilizer application rates and maintenance, and a reduced need for pesticide. Beneficiaries beyond the agricultural field could include a variety of suburban landscapes, golf courses, forests, rehabilitation projects, and any green space. Developing stronger relations between farmers looking for sustainable solutions, and mycorrhizal fungi product providers is essential. The biggest challenge of this development is overcoming economic and political incentives that prevent industrial scale farmers of maize and other staple crops from seeking more sustainable methods of production. The right way usually is not the easiest, but as sustainable solutions become increasingly sought after and even mandated, this model will likely become more commonly demonstrated, and the market for myco solutions will be soon to follow.

vii. Summary

Mycorrhizal fungi utilization may appear to be a small niche in the realm of sustainable agriculture, but with the intended application of this organism could come a green web of biological reactions among earths terrestrial energy system, restoring the ongoing depletion of fungi where humans have failed to notice or account for its influence. For the soil, benefits of mycorrhizal fungi come from the biological infrastructure it creates, reversing erosion and organic matter depletion. This infrastructure also provides porosity and protection against flooding and runoffs, encouraging water transportation to living plants and organic matter in the soil. For the crop, a more sturdy soil composition means a more stable supply of essential elements, reducing fertilizer inputs, and more efficient energy expenditure with reduced stress. Extended root surface area with a mycorrhizosphere allows for amenable water absorption and retention, reducing irrigation inputs (Hudler 1998). More efficient growth of biomass crops like corn can mean more productive bio fuels and fibers. With more sustainable soils and crops, economic and environmental benefits increase overall. Just as depleted woody habitats are being reforested, soils and woods should be inoculated with eco-adapted beneficial fungi. Attention to the biological producers of soil is one part of the global food solution, but there is no single silver bullet. Producers who responsibly perform sustainable procedures and management must be willing to continuously adapt their practices.

Figure 11. From left to right: Bobcat Blend root soil structure, mycorrhizal fungi root soil structure, and commercial fertilizer root & soil structure. Notice the advancement in the fungi compost-soil-root matrix.

One of the benefits this research hopes to conclude with is the opportunity for a long lasting impact; especially on the primary life underground, determining our food security and environmental stability. If continued progress is shown in soil health and thus environmental quality, this model and method hopes to be transferred into a food production stream on viable farms, where the model can be modified per agri-system. Fungi occupy most soils and most established plants have mycorrhizal relations plus other populations of root microbes already, so introducing new varieties of fungi may take time to incorporate into long established soil systems (Stamets 2000). The short and long term benefits of growing maize in soil containing varieties of compost will hopefully lead to greater quantities and expanses of compost application, providing a longer, healthier lifespan for soils and thus plants, animals, and whole ecosystems. What other types of energy could be saved with this microbiological cultivation and further myco-technologies?

Mycorrhizal Fungi as Sustainable Fertilizer

Integrating beneficial fungi into production systems could start the chain reaction of sustainability in the economy, by reducing the insecurities currently present from fluctuating resource availability. To a mycologist, concerns lie in the conditions of the current arable soil, most of which is severely depleted of nutrients from chemically altered fertilizer that is added to imitate the elements that should have already been present. These chemicals instead suffocate the organismal nutrient recycling systems that have been in place (Bharucha 2013). Living soil biodiversity is what should be preserved; not GMO seed for an expanding population, but quality of soils to sustain enough biodiversity to maintain healthy competition in plants that will provide long-living, dynamic, arable fields. No-till farming is one of the first steps in preparing a field for beneficial fungi treatment, instead of fertilizer. To a farmer who has been tilling and applying fertilizer for decades, this sounds risky. On a no-till plot, native fungi reduce erosion by slowing water and nutrient runoff by absorbing soil moisture, creating a sponge like infrastructure. Tilling breaks apart a soils structure into finer fragments, demolishing living microbial habitats by compacting it, thus reducing porosity and aeration and encouraging anaerobic organismal growth, at the loss of oxygen-starved mycelium (Fulton 2011). From there, the carbon cycle is stalled, and nutrients fail to be absorbed, making importation of fertilizers inevitable, to resume profitable farming (Stamets 2005, 61). The characteristics of fungi in soil have already been demonstrated, but have not been utilized in the mainstream production of healthy soils. Mycelium strengthens all soils it uses as a substrate by creating a web of strength and bonding, providing the soil dweller or farmer many advantages, most primarily, a sustainable resource with reduced threat of salinization, mineral and nutrient depletion, and so forth. A variety of mycorrhizal fungi products are available for purchase by growers today, mostly from small businesses here in the US and in Europe.

Mycofiltration

After experiencing the role of mycorrhizal fungi in soils and habitats, it was discovered that mycelial matrixes regulate water flow, mitigate erosion by strengthening soil structures and breaching the flow of particulates, and provide framework for biodiverse soil biota. This intelligent infrastructure has even further biological purpose called mycofiltration, the filtering of microorganisms, pathogenic bacteria, pollutants, and silt, with mycelium as the filtration membrane (Stamets 2005). Mycelium thrives on a variety of nutrients, some of which come from microbes and bacteria that are toxic to plants and animals, including us. The mycelial net digests these pathogens and inhibits their flow beyond the matrix, leaving a liquid free of contaminated debris.

The most urgent need for mycofiltration techniques lies on, under and around CAFO's (concentrated animal feeding operations) and other agricultural factories and farms where point-source production of animal products is leaking unsustainable amounts of fecal-rich waste, sludge, and bacteria-ridden effluents into the ground, water, and beyond the site. A resilient environment that is full of filtrating fungi flora and fauna meets this outflow of waste; but unfortunately nature's defense mechanisms can no longer hold up against such a massive amount of debris. The filth has long exceeded amounts that most habitats can absorb, leaving streams of manure and fecal coliforms, laden with Pfiesteria, Listeria, Streptococcus, Escherichia coli, amoebic parasites, and viruses, all posing human health risks (Stamets 2005, 59). Mycofiltration can be introduced to agricultural runoff effluents polluted with these microbes, and implemented in a layout that encourages the effluents to be directed through the mycelial filter, breaking down toxic bacterial colonies and leaving a less polluted liquid. Another example of an agriculturally ignited threat is the deleterious role of nitrogen contamination from agricultural fields using isolated chemical nitrogen as fertilizer. Excess synthetic nitrogen products in the ground and water have become a huge threat to global food security. The excess nitrogen stifles fungal growth, and if too much occurs and fungi are further inhibited, as will be their mycorrhizal partners, most trees and plants across the planet. The ecosystem is one massive interconnected stream of life, and often the fine details are overlooked, in denial and distraction with how the surface appears to be. There may be a fungal specimen that can condense the excess nitrogen fertilizer from cornfields and farms before in runs off into streams and rivers, which could be trained in the form of a mycofiltration system. Mycofiltration units can be installed around farms, factories, zoos, hospitals, stressed or depleted habitats, landfills, or anywhere with foul liquid runoff likely contaminated with undesirable microbes (Stamets 2005). The filtration system can be designed and adapted to suit the location with a selected mushroom species that will target the observed contaminants. Beyond the biological contaminants are the petrochemical and industrial, also toxic to us. Suburban areas, roads, and any overused systems, most all sites of industrial development, can be a potential site for mycofiltration.

To combat this predicament a long journey has begun in creating a resource for mycofiltration products and designs, custom to most urban and rural plots. The objective of my business plan, *Mycelia Solutions,* is to utilize the environmental benefits of mycofiltration by introducing myco-units to the perimeters of urban and rural sites looking to reduce their runoff contamination. Given how many mycelial species known with antibacterial properties, the dynamic adaptability in customization per plot is promising.

Mycoremediation

Mycofiltration has shown to be a promising system that can be adapted to a wide range of watersheds in rural or urban settings. In addition to accumulating organic debris, many mycelial bodies can target inorganic pollutants. Microbial treatment of hazardous wastes has generally been credited to bacteria, but mycelial enzymes have begun to show dramatic degradation capabilities that are unmatchable by any other bio or synthetic technologies. Mycelial enzymes are naturally suited for decomposing durable petrochemical byproducts that are held together by resilient bonds similar to those in plant material (Stamets 2005). The removal of pollutants from the air, land, food, water, and primarily soil habitats, with mycelium is called mycoremediation. The protocol introduces white or brown rot fungal mycelium to the contaminated soil or landscape, allowing the enzymatic break down of the toxic substrate to take place. Lignin-degrading white rot fungi are the most common candidates for mycoremediation; the powerful lignin peroxidases and cellulases that these decomposers release are designed to break down plant fiber, but just so happen to break down and reduce hydrocarbon based pollutants too (Leatham 1992). Many industrial and agricultural byproducts are hydrocarbon-based pollutants, including PCB's (polychlorinated biphenyls), PCP (pentachlorophenol), petroleum products, and agricultural residues. Aromatic chlorinated compounds like the infamous PCB's, are highly toxic and difficult for microbes in the environment to degrade, but certain lignin-degrading fungi are proving their ability to attack these complex aromatic compounds. Some varieties of white rot fungi have proven powerful capabilities of degrading one of these harmful compounds, the wood preservative PCP (Leatham 1992). The White rot fungus *Phanerochaete chrysosporium* has been used to treat effluents from the kraft-pulp bleaching process, containing chlorinated, heavily oxidized fragments of lignin. Other chemicals dismantled by white rot fungi include the insecticide DDT, chlorinated biphenyls and harmful dioxins. White rot fungi are a wood decaying fungi; one of the main decomposers of photosynthetically fixed carbon and highly lignified tissue (Leatham 1992), and continues to demonstrate the capability of degrading a wide range of hazardous organic compounds. Commercial agriculture produces food and fiber crops at the cost of the environment, with many negative side effects, including residuals from herbicides and pesticides, and depleted soils. White-rot (and some brown-rot) fungi are suitable for application to soil contaminated with these residual organic compounds, and for degraded soils as an organic matter supplier and stimulator. Petrochemical oil pollution is also paramount among this topic, as oil spills and aquifer contamination threatens food and water security constantly (Strobel 2008). Mycelia can be selected and directed to break down these organic (and manufactured) hydrocarbons. As they disband the hydrogen-carbon bonds, they release originally harmless metabolites back into the ecosystem, primarily in the form of water and carbon dioxide (Stamets 2005).

Another function of mycoremediation is the minimization of heavy metal contamination, by introducing a heavy metal-accumulating mycelium to a contaminated site, to allow the mycelial body to selectively retain the metals into a hyperaccumulated mass, in the form of a fruiting body. Metal contaminants in soil undergo complex reactions with not only inorganic components, but organic ones too. The organic matter in soils is the living component but also the decay or metabolic products of the living. Fungal interactions with metals is not entirely understood, but it is clear that these useful types of fungi selectively pull metals including cadmium, mercury, arsenic, lead, and even radioactive cesium, out of the soil or substrate, pushing them along through their mycelial matrix, and finally into fruiting bodies that can then be removed from the site and disposed of properly with other toxic waste (Stamets 2000). Research has shown a variety of methods of doing this, with results concentrating anywhere from 1-10,000% of the heavy metals into the fruiting mushrooms (Stamets 2005). This bioremediation process is not a widely used and uniform method, but offers solutions for dynamic disciplines, especially to industrialized wastelands and developing areas, threatening the environment of inhabitants close to them.

The international food industry is riddled with expanding problems leading to environmental degradation and large-scale waste. Most industries involved in manufacturing, agricultural processing, and chemical productions have contributed to the widespread release of hazardous toxins into the environment. Combatively, remediatory strains of mycelium each have their own particular variety of enzymes capable of metabolizing nutrients from toxic byproducts of man-made industrial materials. This capability makes fungus the industrialized world’s natural detoxifying agent; the species just need to be isolated and inoculated into contaminated sites for their unmatchable remediation abilities to be initiated. This fleet has already been in the works for decades, but there needs to be an upgrade and integration into other industries, commercial agriculture in particular. Technologies can be adapted to apply and maintain fungal remediation treatments to lead to a well-known and understood process that will change the fate of growing wastelands. As humans capitalize on mycelium's digestive power by directing it to decompose toxic wastes and pollutants, organic compounds will again be available to the ecosystem. The environmental landscape of which vast arrays of fungi thrive and communicate is to thank for the colorful and complex lives lived above ground.

III: The Economic Role of Fungi

Usually, economic growth is acquired by the depletion of biological growth. Economic wealth and biological wealth have always been inversely related, but it does not necessarily have to be this way. As mycological science is applied to production systems and sales grow, the outcome will be growth of the natural resource itself, rather than just the depletion of it. 'Growing' market products allows for operation under economic law of marginal growth, but without collision with finite resources. Related corporations should be encouraged to adopt myco-technologies as a means of becoming sustainable and energy efficient. Providing green business in this way can truly influence both contrary parties beneficially, though political and structural editing largely inhibits the public interpretation and depth of understanding of these circumstances. After analyzing the agricultural implications of fungi, some other methods to consider in relations to industrial, mechanical, and pharmaceutical industries, and in what ways beneficial fungi would have an impact should be considered. It is evident that fungi play a foundational role in the global ecosystem and in the microscopic roots of the food chain and life cycle. The global economy impacts our day-to-day lives in an interconnected web of unavoidable dependence.

We are inseparably tied to the rest of the world in this era of globalization for many of our goods and services, for much of our labor, and for many of our markets. The old idea of 'us and them' just doesn't work anymore, there is only one "us" and it is comprised of the entire global community. We share one global environment from which we extract our resources and we share a global economic system that determines who will get what on this planet.

Brock Brown

This fertile productive world depends on the extraction of natural resources to support the human population. Those resources are complex living systems whose composition is usually 'rooted' underground. The micro producers that make up soils are responsible for our complex experience above ground. According to mycologist Paul Stamets, there are more species of fungi, bacteria, and protozoa in a single scoop of soil than there are plants and vertebrate animals in all of North America (Stamets 2000, 2). Industrial mycology and biotechnology is already used in a variety of production settings, but these scientific breakthroughs have yet to be introduced to a commercially available market that recognizes the value. Innovative solutions for the negative side effects of over consumption are on the rise, as every resource is beginning to be considered finite.

Mycelia Mycofiltration Solutions

In the previous chapter, it became clear that mycelium plays a dominant role in filtering waterways in most environments. The process of mycofiltration, the use of mycelium as a biologically active filter against microbial contaminants, can be manipulated into rural and urban settings where current filtration methods are unsustainable or nonexistent. To address this potential, a business plan is being developed for a solution that will provide myco-technological alternatives to many conventional systems utilized every day. The long-term goal is to see this science applied to a dynamic spread of activities across current world order and collaborative economies.

Mycelia Solutions is an idea for an establishment designed to initiate a new way of thinking about human quality of life by means of mycorestoration. Mycology, the study of mushrooms and fungus, has a forthcoming application called mycorestoration, which utilizes mycelium (the fungal body from which a mushroom originates) to restore habitats and production systems to a more natural or sustainable state of being. Our objective is to utilize the environmental benefits of mycofiltration by introducing myco-units to developing or inefficient urban areas to filter out toxic pollutants and bacterium from the runoff water and effluents. This plan combines filtration and remediation techniques by using the fungal strains often guided for remediation, but applying them in the hydro-active setting with filtration. Current models developing under Mycelia are mycofiltration units designed for installation on and under street drains in dense urban areas to sieve water flow as it percolates thru the filter inoculated with a variety of saprophytic and endophytic fungi, netting immense proportions of chemical and bacterial toxins before they continue flowing thru the city and into the primary intolerant waterway. This first series of units are designed with durable stainless steel screen filters that get installed directly underneath street drainage gates, and are pre-inoculated with *Pleurotus ostreatus* (Oyster mushroom) spawn and a variety of other fungal strains that capture and devour synthetic hydrocarbons and heavy metals before they can reach sensitive bodies

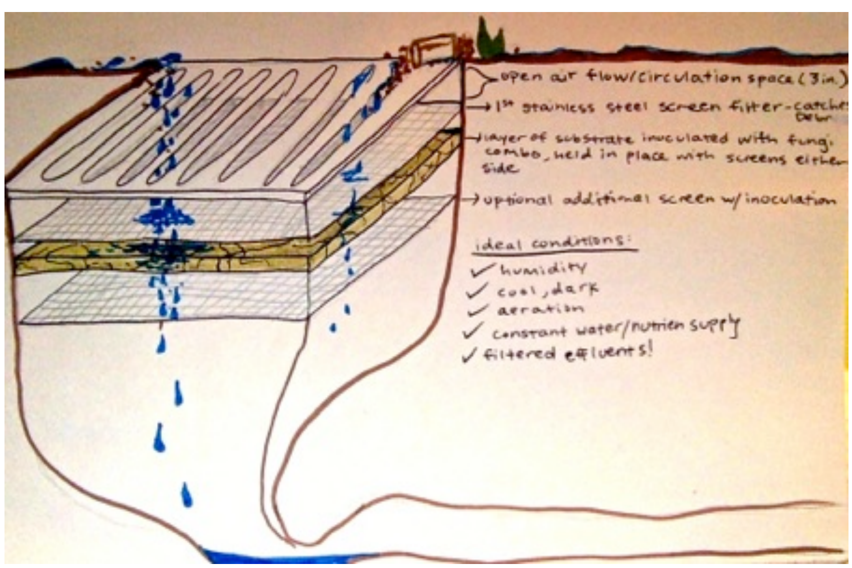


Figure 12. Rough sketch of design for Unit 1.

of water downstream. Another function of these myco-filters can eventually be to replace current filtration systems that are not cost or resource efficient. The next series of mycofiltration units will be designed to fit runoff chambers and pipelines transporting this wastewater from expanding industrial ventures leaving behind the scraps of development. Plans for the future involve expansion beyond the urban habitat to engage in suburban environments, followed by rural ones.

While studying abroad in Chengdu, China, one rather negative daily experience that stood out above most was the smell of rotting human manure mixed with chemical effluents on the street. Walking past exposed street drainage every dozen meters or so, a whiff of this would turn any mood sour and be hard to bear. This routine sparked the idea of urban mycofiltration and its potential to rid the streets of toxic fumes and scents, and decontaminate the liquids below them. It was not long before introducing the idea of mycofiltration to some Chinese professors in Chengdu, who were enthusiastically supportive of the idea, but unfamiliar with the science. Mycelia Solutions has not chosen to do business in China to gain from the large economic opportunities, but rather to service terrestrial Asian habitats that are suffering as a result.

Figure 13. The Funan River bisects Chengdu, transporting the burden of supporting 14 million residents on to many cities and ecosystems downriver

Industry and Consumer Analysis

The market for Mycelia S. is of great potential, primarily being urban developers, and eventually large agricultural corporations and plantations, all that are under pressure to clean up their waste and residues threatening the surrounding habitats. Vertical integration in industry and agriculture is making it hard to personify those responsible for these pollution issues, but on the upside it makes for a shorter list of subjects to approach with mycorestorative technologies, as they become a desired alternative. Mycology analyzes a natural process that is happening across the entire expanse of land on this planet, and without it life would not exist. With the power of mycelium, negative byproducts of general human activity can be harnessed and reverted to fresh organic material. The ability to readily incorporate industrial and municipal byproducts into a natural rehabilitation system goes beyond pure competition in the industry; it recycles and regrows the industry all together. The target audience of Mycelia Solutions is first and foremost consumers and producers who have an interest in making the world a more sustainable place. Hopefully this perspective becomes a reality with myco-influence, and the audience will grow to encompass all citizens in urban and rural areas that have been introduced to myco-innovation. As of now, the world of mycology dominates life existing among the earth's soils, but has little audience on the macroscopic scale. With extended myco-education, populations could easily pick up interest in a natural system that is so essential to our daily life. With the existing mycofiltration unit design, target audiences are city councils, planners and representatives in and around pilot cities that would be involved in approving the installation of the units underneath street drainage gates. Beyond this audience are private entities partially responsible for the pollutants;

then would come personal and customized units for household and apartment application, to replace or enhance current filtration models for sinks and sewers. The next phase of design will appeal to farmers and ranchers with similar problems, leaning more toward biological microbial threats than industrial.

Competitive Analysis

Mycorestoration is a tool that has the potential to clean the planet of poisonous elements that have appeared as byproducts of industrialization over the past few centuries. The key strength Mycelia Solutions intends to offer is limitless customization to a variety of environmental problems. With extended experimentation and research, the tasks this plan is capable of achieving are ones that have not been challenged by other corporations or fields out there. For mycorestoration initiatives to become worldly productive, many parties would need to accumulate and spread insight on this renewable resource. Once this is achieved, the products can further develop into convenient units that are easily installed inside and outside homes, workplaces and environments. The only competition now and in the future is our own will as consumers, to do the right thing and take responsibility for our demands, by engaging in more sustainable systems.

Marketing and Financial Plan

How will this product be sold? Once designs are fully tested and patented, steps will be taken to market the idea and design to the potential consumers mentioned above. Starting at the municipal level and replicating the same patterns designed by the mycelium itself, the units can then be customized for a variety of sites with ranging pollutants, extending Mycelia Solutions to future installments in densely populated and suburban areas alike. Mycelia S. strives to promote sustainable living and development, using real life examples to embrace the shared services of the community. To excel in the market as a product supplier, Mycelia S. will generate revenue from sales of filtration units. As these designs evolve, more revenue can be drawn in from larger installments in dense cityscapes suffering from heavy metal and chemical pollution. Other environmentally conscious joint ventures will hopefully express interest in Mycelia S., which would open new avenues for expanding mycorestoration opportunities. Unlike most proprietary filtration systems, Mycelia Solutions does not require large capital investments or have significant additional maintenance costs, which would be unsuitable for developing urban areas. As the units gain attention and revenue, the benefits will far outweigh the minor expenses of installation and design. Further mycological biotechnology needs to be developed to bring the filtration units to the next level of specificity and purification. Custom designs will require profiling the site, followed by tests determining what combination of fungal species would provide the best defense, based on the contaminates present. Factors affecting general efficiency include site temperature and humidity, the substrate used on the inoculated filters, the optimal collection of fungal specimens, and the flow rate and consistency of the infected liquids being filtered. Given how many hundreds of mushroom species known with antibacterial properties, the variety in custom designs suitable for dynamic plots is promising.

Mycoremediation Application

With the introduction to mycoremediation, it was discovered that certain saprophytic fungi could break down manufactured hydrocarbons, a huge opportunity for new technologies to manipulate this remediation process for large-scale treatment of toxic habitats. A recent experiment done by Michelle Legaspi and Kaury Kucera at Yale

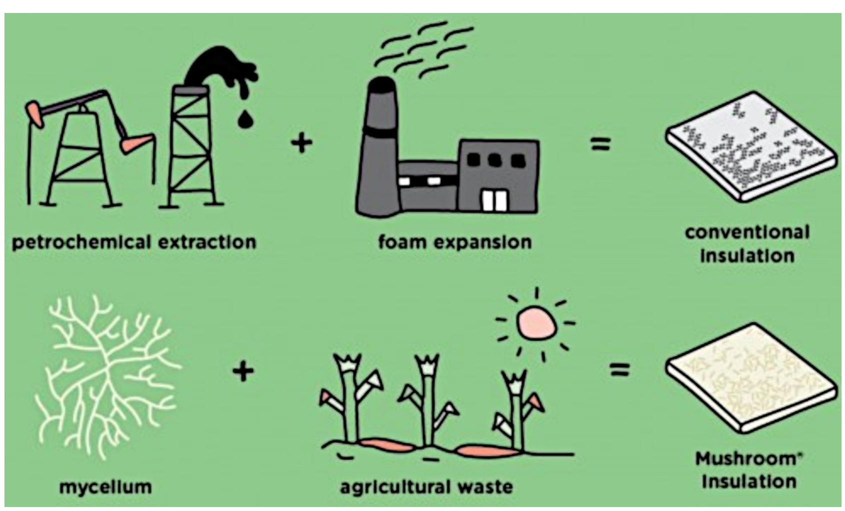
University has shown success in using endophytic fungi to biodegrade plastic and rubber waste. They trained the fungus to biodegrade polyester polyurethane plastic, a synthetic polymer of which over 250 million tons is produced each year, according to their studies. These young scientists report that current disposal methods are insufficient, considering these materials are manufactured cheaply for single or short-term use, and though recycling helps reduce the amount of synthetic waste accumulation, only about 15% of plastic is successfully recycled globally. Other common methods like incineration cause chains of issues threatening the environment. The teams goal is to provide an alternative (or complementary) method of dealing with plastic and rubber waste, that would otherwise pollute for hundreds of years, since the materials are manufactured to be highly resilient. The endophytic fungus that they identified as a potential large-scale degrader of plastics and other synthetic materials was *Pestalotiopsis microspore.* (Legaspi and Kucera, 2014).

Technologies like this will ultimately become necessary for incorporation into foundational recycling systems like waste management. Some mycoremediation products are commercially available, but there is a gap between the scientific designs and the product marketing. The revolutionary use of white rot fungi to degrade pentachlorophenol and other chlorinated aromatic contaminant offers extraordinary possibilities for land recovery, but current limitations from undeveloped patents have slowed the availability of this technology down (Leatham 1992).

Product and Plastic Replacement

Beyond the breakdown of these harmful products is the technology designed to replace them. Companies and organizations are emerging that produce mycelial products to replace consumer goods that negatively impact the environment. Ecovative LLC for example, engineers' products made of mycelium and agricultural waste, as replacements for Styrofoam, plastic, and other materials used to make daily household consumer goods. "Mycelium is natural, self-assembling glue, digesting crop waste to produce cost-competitive and environmentally responsible materials that perform" (Ecovative 2014). By training mycelium to digest the substrate they provide it with, usually a combination of husks, hulls, and other common excess crop material, they fill a mold of the given product they are 'growing' instead of manufacturing. Ecocradle® Packaging is a material offered by Ecovative that competes with traditional Styrofoam packaging, and Greensulate® is an alternative to traditional insulation for housing. The final product produced by Greensulate is not only cost competitive with conventional insulation, but surpasses it in many product tests, including fire and water retardation. The bulking agents used, a combination of rice husks, buckwheat hulls, and cottonseed hulls, have a naturally high silica content that prevents the product from burning readily (Ecovative 2014).

Figure 14. Ecovative's illustration of their insulation products.



Consumer goods make up 70-80% of the economy in the United States (Drummond and Goodwin 2011). It is no wonder there is little awareness of the need for conservative use of disposable materials. More sustainable recyclable products are of serious need in this country, considering up to 99% of these consumer goods end up being "thrown away (in landfills) within 6 months of their original purchase! (Leathers and Foster 2009) An environmental model like Ecovative's truly eliminates the zero sum game by discontinuing use of harmful and finite inputs, and replacing inefficient output with a product that is immediately recyclable, without any extra costs. Biodegradable products offer a dynamic list of benefits compared to conventional manufactured textiles, including an effort at 'closing' the system.

Myco-fuel

The Law of Conservation of Energy states that energy cannot be created or destroyed; it can only be redistributed or changed from one form to another. That desired form of energy might as well be acquired with minimal resources expended, wasting the least amount of inputs possible. If biofuels are really something on the market for global cultivation as an alternative to fossil fuels, then the production of which should far exceed the other in sustainability. Sustainably meaning specifically a *long term* cost-benefit, not just short term. Are new fuels paying off? Hardly in the short term, and long term use will certainly deplete soils supporting these crops to a finite degree (Leathers and Foster 2009). Yet scientists and economists have quite a different answer to the same question. The current paradigm is not following this underlying premise of sustainability, but could begin to reach closer to this goal with pursuits of myco-technology in application to cultivating biofuels, and as the fuel itself. Application agriculturally and mycorrhizally, so that intensively grown mono crops could come steps closer to functioning as a closed system, by reintroducing the nutrients they use back into the cycle.

Matter can change form and location within the Earth's system, but it does not leave the Earth's system! When wood is burned the wood appears to vanish. Indeed, the wood is gone, but all the matter that made it up is still in the Earths matter system. Some has been converted to ash. Other elements of wood, such as carbon, have been converted to gas, entered the atmosphere, and are ready to be used again by plants. Matter is never lost, just changed!

Brock Brown

Take Ethanol for example; made from corn, this biofuel is not sustainable or renewable. The main issue with "renewable biofuels" is they are not renewable; intensively growing a crop to strip it from the ground to burn it as fuel and repeat, means the nutrients from the soil needed to support future yields are removed, and not replaced. And as that energy is used in the form of fuel, it is ejected back into the environment as greenhouse gas (Leathers and Foster 2009). Growing a food crop and turning into fuel before feeding it to the hungry is also an extremely controversial question at hand. Biotechnologies are making fuel 'cheaper', but at the cost of fresh water and arable land, and the expenditure of even more energy and labor and numerous other agricultural resources. Other biofuels are showing signs of something closer to sustainable measures with much less damage, such as pond-grown algae, some that even utilizes invasive species as the resource to convert.

New research has shown potential for another notable role carried out by fungal decomposers, in making myco-diesel, by training fungi to rapidly decompose plant material, and then converting the byproduct into a liquid fuel. Biologist Gary Strobel has been working this idea with endophytic fungi as the fuel producer, and variety of plant waste material in a lab setting as the imitated forest setting, where endophytic fungi likely played a large role in breaking down organic matter millions of years ago, just as they do now. He has shown that this process can be sped up by laboratory manipulation, and is preferred over other biofuels, because unlike other methods that use refined sugar, starch, and corn to grow the fuel, the fungi requires nothing more than oxygen, water, and a common variety of spent plant material. The endopaths break down the plant material into hydrocarbons (like the ones seen in oil), that are then trapped in a layer of shale, to be drained, dried, and heated, releasing the fuel as a gas, then to be cooled with liquid nitrogen. He comments that in this laboratory process, some of the ingredients of crude oil can be produced by these fungi in a matter of days or weeks (Strobel, 2014).

Food and Fiber made by Fungi

Globalization and immigration of ethnic groups and importation of their long used fermented foods has changed the way the western world eats, offering a new arena of selection, products developed from organismal fermentation. Soy sauce for example, fermented by Aspergillus fungi and other yeasts, is now a common western household product. *A. flavus* is purposefully cultivated on soybean extracts to make soy sauce and other kinds of soy food and drink. Fermentations like this can improve palatability, increase digestibility, expand nutrient content, eliminate the need for synthetic processing, and increase shelf life (Leatham 1992).

Pharmaceutical vs. Medicinal

Western beneficiaries are fortunate to have access to such a dense medical and pharmaceutical presence, but what conventional pharmaceutical treatment omits is the severe importance of physical and self promoted healing. There may be an exceptional doctor here and there that encourages engagement in the all-inclusive process of healing and strengthening the body, but the general trend is that medicine is a paycheck, and treatment is a facade. Like all other production systems in the US, health and medicine are a business, an industry that exists for profit. The current pharmaceutical supply of antibiotic drugs is designed to directly terminate the symptoms expressed, meanwhile suppressing a plethora of other cellular functions, with a long list of side affects in return, that get resolved with an additional handful of manufactured compounds. Antibiotic-producing mushrooms may provide a better alternative to this threatening Pharma-cycle. Mushrooms share deeper evolutionary history with animals than producers and consumers take into account. Thus humans and mushrooms share risks of infection from many of the same microbes and bacterium, and both human and mushroom have immune systems and defense mechanisms to cope with these competitors (Stamets 2005). Fortunately, these medicinal mushrooms can easily be consumed for their powerful antibiotic-secreting abilities, active against bacteria, viruses and other infectious agents causing disease in humans. A few examples of these isolated antibiotics and their fungal producer include:

- Penicillin from the fungi *Penicillium*
- Calvacin from giant puffball mushrooms (*Calvatia gigantea*)
- Armillaric acid from the honey mushroom (*Armillaria mellea*)
- Coprinol from inky caps (*Coprinus species*)
- Corolin from the turkey tail mushroom (*Trametes veriscolor*)
- Agaricin from agarikon (*Fomitopsis officinalis*)
- Sparassol from cauliflower mushrooms (*Sparassis crispa*)

(Stamets 2005, 40)

Dozens more provide antibodies that have been consumed by man for thousands of years, only a mere relationship considering the estimated 150,000 species of fungi each with latent capabilities that await medicinal discovery. In addition to antibodies, mushrooms often contain medical compounds such as triterpenoids, glycoproteins, and enzymes that invigorate health. Keep in mind just how influential these mushrooms must be on their natural environments, subduing bacteria and viruses from destroying their hosts en mass and stabilizing entire ecosystems. Endophytic types of fungi mostly produce these antibiotics as an effort to gain a competitive advantage over other microbes and competitors in their environment; most often in soils with diverse microbial populations (Stamets 2005).

Now that the medicinal community widely recognizes the health-stimulating properties of mushrooms, a combined market for gourmet and medicinal mushroom products is rapidly emerging (Stamets 2000). Our eastern counterparts engage in healthy habits and lifestyles that cultivate energy, such as qi gong (qi= energy, gong= cultivate) as a prevention method against bad health, rather than the current paradigm of a temporary, costly, supplemental, "solutions" with pharmaceuticals. A changing political climate and improved communication with East Asian cultures has allowed the western world to see opportunity in medical treatments that have been practiced for hundreds and thousands of years. Many eastern cultures continue to consume fleshy mushrooms as protection from a mass variety of ills and to cure them of others (Leatham 1992). Where traditional mushroom medicine is practiced, western vascular ills and caners- the primary causes of death in the US, are hardly even present. The average mushroom consumption in Japan is said to be about 3 ounces per person per day. At a per capita consumption of mushrooms in the United States of 4 pounds per year, that is what the average Japanese person consumes in just three weeks (Lincoff 2010, 7).


Figure 15. Ganoderma variety and other medicinal mushrooms at a Sichuan market

The monumental powers of *Ganoderma lucidium* (Reishi), the most infamous medicinal woody mushroom, provide defense mechanisms against many cancers, coronary heart disease, hypertension, bronchitis, hepatitis, arthritis, myasthenia gravis, and muscular dystrophy. The chemicals absorbed from this medicine improve blood circulation and thus the hearts functioning, improve digestion, and boost the immune system, releasing antitumor agents (Lincoff 2010). And surely the shitake mushroom, *lenitula edodes*, sounds familiar, but probably not for its powerful antitumor and antiviral activity. Medicinal and culinary mushrooms do not stimulate the immune system, but modulate it, initiating apoptosis of negatively infected cells (Stamets 2005). Mushrooms contain medicinally beneficial polysaccharides that provide framework for cholesterol reducing drugs. And remember those fungi that release antibodies against the same bacteria and threats that humans fight? Penicillin is a prime example of a pharmaceutical whose derivative is one of these beneficial fungi, and is only one of many varieties that display antibiotic characteristics, providing cures for an impressive range of bacterial infections (Leatham 1992). People have utilized many of which since the sixteenth century BCE according to records, and likely long before that. No better way to celebrate this unification then to move attention away from the flaws in the affluent health care system towards focus on preventive measures like consuming more nutrient rich plant and fungi provisions.

Nutritious Mushrooms vs. Junk Food

As if mushrooms didn't already have enough astounding characteristics to take advantage of, there is a grand finale they have to offer: delicious and nutritious edibility. The chemical makeup of many already used culinary mushrooms has the genetic capability of making humans stronger and healthier, by strengthening the immune system and detoxifying impurities from the body's circulatory systems and organs. Culinary mushrooms are already a multi-million dollar industry, but in the US, only a handful of the countries thousands of native edible mushrooms are actually on the market (the white button agaricus mushroom, the crimini's, and the portabellas most commonly). On the contrary, some markets in Italy will offer up to 200 varieties of fresh picked mushrooms (Lincoff 2010). As professional consumers, westerners treat food and nutrition as expendable activities that have no limits boundaries or budgets. Americans eat as entertainment, a sport, a lifestyle, and a hobby! Emphasizing the cheap greasy sugar ridden addictive nature of processed foods, with little regard for where they originated. Processed food simply adds nutrient deficient ingredients to products, lowering the cost and quality. Americans spend an average of 7.5% of their income on food, whereas Europeans spend around 35%, 50% in most parts of Asia, and in developing countries, more than 75% (Leathers and Foster 2009). In most countries beyond the US, food is not wasted and thrown around irresponsibly like any other consumer good, but is derived from a sacred and respected source, that is often taken into conscious consideration. As many countries develop closer ties to the consumer way, the quality and traditions of food are threatened, but nonetheless remain a principle founding in cultures.

The mushrooms produced by many strains of fungi contain some of the most densely concentrated micro and macro essential nutrients and vitamins man or animal can find, in addition to highly beneficial anti-inflammatory, antioxidant, and anticancer compounds. But possibly most impressive are their immune modulating compounds; Dr. Arthur Haines presents them as a special group of carbohydrates, complex polysaccharides called glucans, which are known to activate the immune system. Glucans stimulate the growth of natural killer cells that destroy invasive malignant cells, prompt maturation of T-Cells that heighten cellular immunity, stimulate B-Cells to produce antibodies to tumor antigens, and up-regulate production of Interferon alpha from white blood cells to improve viral resistance in the body (Haines 2013), among many other functions. Edible mushrooms are additionally rich in protein, very low in simple carbohydrates, rich in high molecular weight complex carbohydrates (polysaccharides), high in antioxidants, and very low in fat. They lack cholesterol entirely, and are a good source of B vitamins- riboflavin (B2) niacin (B3) and B5, and D2. High in dietary fiber and essential minerals like selenium, copper, and potassium (all of which are important for reducing free radicals) mushrooms offer a wholesome package of vitality (Haines 2013). Edible mushrooms are a great substitute for meat. In the US, only 3% of the maize grown is for human consumption, the rest is to feed livestock that will turn into animal products, or for ethanol biofuel (Drummond and Goodwin 2011). It takes on average 6 lbs. of grain feed to yield one lb. of meat. Intensive meat production is simply unsustainable, and luckily there are extremely cost effective alternatives to this dilemma. Culinary mushrooms provide an excellent course of iron, vitamins and protein, all the things that animal meat contains and the only things that justify consuming it.

Figure 16. A delicious chicken mushroom spotted in my neighbors yard on the base of an oak tree.

With more whole complexes and natural foods, people may become less prone to vascular ills and obesity due to a decrease in cravings for sugary foods. Most processed food products supplied at the local grocer lack an intact whole plant (or fungi) complex, making ones body ask for more of whatever nutrients the main food intake is lacking. In response, that hunger for nutrients is likely attempted to be fulfilled with the same deficient food groups that created the feeling to begin with. Another perk of edible mushrooms is their key complex called lysine, an essential amino acid that is notably absent in American food staples (Stamets 2005). Americans spend $42 billion+ a year trying to lose weight, when an estimated $24 billion per year is needed to eliminate world hunger (Leathers and Foster 2009). With the cultivation of culinary mushrooms, weight loss could be achieved with the replacement of junk foods with nutritious mushrooms, and populations could be fed in adequate regions where edible mushrooms can be cultivated. These fruits enable the provision of a wholesome trustworthy food source and can help combat global vitamin, protein, and mineral deficiencies (Gianotti et al.).

A study was done by researchers at Aloha Medicinals in Carson City Nevada to determine ways that mushroom cultivation could be accessible for traditional farmers in disadvantaged communities and small villages like those of West Africa, by using local resources and minimal technology to provide a crop that has full cycle benefits, at a low cost. In *Diversified Agriculture Part 1: Simplified and Lower Cost Methods for*

Mushroom Cultivation in Africa, the fungi of choice was an oyster mushroom complex (*Pleurotus ostreatus* and other *Pleurotus and Hypsizygus* species), which can grow on many plant material substrates, including banana waste, coffee residue, sugar cane bagasse, paper or cardboard waste, river grass, and sawdust (Gianotti, et al.). This cultivation process would allow secondary crops to be produced from primary agricultural by-products with vey little training, capital, and infrastructure requirements. Incorporating isolated farm communities into the cash economy as sellers and buyers of food crops is a novel effort in today's common nutrient deficient supply of foods.

Mushrooms are becoming an exciting cash crop to produce and consume, and producing beneficial crops like this is a great way to restore pieces of the carbon footprint. The agricultural waste from growing mushrooms is extremely fertile soil that can be reused as compost indefinitely. Incorporating myco-nutrition into global markets will require adaptation to population's perceptions of nutrition and fungi and can then dynamically provide access to products or natural sources available. Nevertheless, it is marketing that will determine the ability for super foods like mushrooms and green plants to reach people and show the full cycle benefits of a more wholesome responsible choice.

International Application: An Innate Dichotomy

China's environment has issues incomparable to those in the US, yet they are caused by massive American demand that is outsourced to China. All of the single-use goods wasted each day are produced in harsh settings in China, and other countries lacking land and environment protection. In 2005, China used 26% of the world's crude steel and 47% of the cement (Flavin and Gardner 2006, 5). If the air is so bad that it is not only visible, but so opaque one must protect the body's airways from breathing it directly with a mask or filtration system, imagine how bad the rest of the conditions are. The food, water, and soil? Again, what makes industrial China's conditions so harsh are the byproducts from such intensive manufacturing, to keep up with high consumerist demand. The 1.3 billion-person population is given little alternative when it comes to providing for this endless demand. As the Chinese environment suffers, workers only gain a fraction of the benefit of comparative advantage of trading goods and labor with the US. As relations between the US and China become ever so tightly woven, their fabric of cultural codes is losing recognition, as society disregards where the fruitful fibers were once planted. Materialism has rerouted the tasks of producers, and blinded consumers from grasping the complexity of today's international agricultural economy. There are many issues and complications with the Sino-US agricultural relationship, in short being economic trade relations, communication between markets and distribution of agricultural goods, rural development, and food security (Flavin and Gardner 2006).

First of the major agricultural problems and issues that affect the development of relations between the US and China is the commercial trade imbalance. The unequal exchange becomes more complex as both countries expand their economies with differing long-term aspirations. Each has a very different work ethic and industrial structure, so it is hard to measure and predict what 'trade balance' should and would look like. Over the past decade, the annual U.S. trade balance with China has gone from a small surplus to a deficit of over $57 billion, directly due to China's high trade barriers in agricultural goods (Carter and Li 1999). Each country had specific preferences on how and what should be traded in the agricultural sector. Many western societies have the privilege of holding high expectations of food quality (or as far as they know and taste),

ure 17. Culinary and medicinal
ıshrooms at a market in Chengdu.

and have grown more precautious of what is and is not healthy to consume. It is no secret that food quality related scandals continue to appear all across Chinese territory, leading to global consumer outcry. The melamine-tainted dog food scare and the carcinogenic-tainted seafood import restriction are both incidents that lead to measures such as the "China-free" label (Flavin and Gardner 2006). Analyst Michael Bristow reports on China's relatively low sanitary standards (SPS) for its agricultural goods. Corruption in the government, such as the bribery of former head of State Food and Drug Administration, Zheng Xiaoyu, has also complicated China's regulation difficulties (Bristow 2007). Trade restrictions with developed nations such as Japan, the United States, and the European Union exist because of food security issues, such including excessive pesticide residues, low food hygiene, unsafe additives, contamination with heavy metals, and misuse of veterinary drugs (Dong and Jensen 2007). Even the Ministry of Environmental Protection of the People's Republic of China is not afraid to admit that about one tenth of China's farmland is contaminated with heavy metals (Wang and Evans 2011). These food quality issues are derived from even deeper rooted environmental problems, mistreatment, and over-farming of land. The Sino-US trade relationship will only become steady and sustainable when both countries come to terms with what is best for both when outputting labor and goods. Food fiber and water make up the agricultural sector of global economics, resources are far too significant to toss back and forth. If trading such massive quantities of these goods is so necessary, then finding sustainable avenues that suit both parties is imperative.

Most farm communities in China are disconnected to direct relations with international and even domestic markets for their products because they do not have the technological resources or political assurance making it possible to grasp an understanding of their role in the market (Bristow 2007). Lacking this information means inability to expand or update production or business. Farmers either remain familiar with poverty, or turn in their land to the monopolies and move to the city. In the US, farmers are prosperous, business-oriented, and usually very connected to the domestic or global market. Chinese agriculture exceeds American in terms of methodology and experience, but lacks the modern distribution system allowing for efficient communication and exchange. Chinese farmers often have no way of measuring the demand for their crops, so in hopes to maximize their profits they opt to produce those that created the highest regional revenues in the previous year, if that information is even available (Inside China 2012). Even more insecure is the physical distribution of goods; according to figures from the Commerce Department, up to 25% of fruits and vegetables rot before being sold (compared to around 5% in a typical developed country). As intermediaries cannot sell the rotten produce, they reduce the farmers' pay, though the problem is caused by post-production inefficiencies (Inside China 2012). Finance News also reported that the small profit available for farmers could not grow without rural development involving inputs such as large-scale machinery and fertilizer (2006). When resources are available, opportunities arise for farmers to profitably compete in the agricultural market and take advantage of a rising economy, as those in urban Chinese industries benefit.

Chinese agriculture predates American agriculture by about 9,600 years. There is much to be said for the traditional farming methods and systems that are still successfully in place today. But modern development has taken on a Dual Structure (Urban and Rural) in China as it did in the US a few decades ago. This has now influenced migrations of farmers to major cities, in turn forming the growing Redundant Rural Labor Force. The US handled its own similar experience by creating a mechanical agriculture industry, which quickly began replacing farmers with large-scale equipment. As the urban centers grow exponentially in China, rural enterprises move in a reverse direction (Flavin and Gardner 2006). Mechanized agriculture has yet to establish its place in China, primarily because of minimal expanses of arable land. Attention is shifting to these issues considering rural development is inevitable if the world's populations are to remain active consumers. Small countryside farms will continue to be forced to merge with so much of the population migrating to urban areas. This agricultural upgrade will probably begin to look a lot like Americas rural development over the past century, but whether or not this shift will be sustainable is another story.

Now that agricultural trade between China and the US and farming issues in China have been analyzed, it is possible to assess some solutions and future predictions. As for the general trade imbalance between China and the US, China's increasing domestic demand means that imports are expected to increase. As the agricultural relationship improves, these negotiations will be adjusted alongside the market. An increase in technologically influenced farming techniques in China will likely guide the international relationship to a more sustainable future. Past history of international and domestic trade patterns can help direct maximum efficiency for both (and other) parties in the future. The same issues are always dominant, and putting monetary values on intangible goods will always be a difficult circumstance to negotiate. In this case those goods are natural agricultural resources that are heavily depended on. In order to achieve market progress in China, better bilateral communication, internationally and domestically between farmers and agricultural markets will be foremost. Second to communication is the need for improved distribution systems across China, making the transportation process from farm to table more sustainable and efficient. The Chinese agricultural sector still faces many challenges, despite rapid growth in output. Provinces such as Shandong, Zhejiang, Anhui, Liaoning, and Xinjiang lack a strong tie to modern markets (Carter and Li 1999). With more efficient transportation systems and communication with markets, Chinese farmers could sustain their plantations and invest in the agricultural inputs needed to sustainably raise productivity.

Twenty years ago, most of China's population was still in the countryside. Now, booming urban development grows exponentially with minimal regard to rural security. To keep rural development from lagging behind and to balance out the population shift from farm to city in China, an increase in imported farming technology and machinery is vital (Paul 2007). Obama's reindustrialization strategy involves export of specialized machinery such as Caterpillar construction equipment to China, rather than large quantities of less applicable resources. It does seem that rural development in China is inevitable, if the economy puts energy in stabilization. Because the current Urban vs. Rural trend in China is following a pattern the US displayed half a century ago, it is important to recognize the vulnerable, fragile environment, and take careful precaution to ensure a sustainable agricultural future. Because there is less arable land available for large-scale mechanized farms, it will also be important to keep some small-scale labor-intensive sectors alive. These areas should perhaps focus on high value export products, such as fruits, nuts, or vegetables, while the larger expanses of land should focus on higher yield production of mass crops like rice, wheat and other grains (Dong and Jensen 2007). According to scholar Xiuzhi Wang, these efforts to adjust agricultural production patterns for greater comparative advantage despite resource constraints has already shown an increase in production efficiencies.

Figure 18. Sunshine Organic Bio-farm in Sichuan, with mushrooms tied closely to crop production.

The sparse green agricultural trends spreading across the US could trigger change in traditional agriculture in China. It is possible that without enforced food security policy by Chinese government, American consumers will eventually lose confidence in agricultural products, leading to a failure in the stability of agricultural trade. As early as the 1980s, steps towards organics were being developed by the governmental sector of Chinese Ecological Agriculture (CEA). Initially, the main goal was to limit the input of harmful chemicals into additives and fertilizers, but there was very limited success in persuading farmers to adopt CEA guidelines (Paul 2007). Scholar John Paul states that success eventually grew out of this effort, and by 1990 there were an established 1,200 pilot ecological agriculture villages or, eco-villages producing organic crops (2007). Additionally during this year, the Ministry of Agriculture created the *Green Food*

Program, which has been a remarkably successful Chinese innovation in quality food production, subsequently paving the way for China's Organic Revolution (Paul 2007). Continued efforts to terminate food scandals and ensure food security will further allow the international market to prosper. China and the US cannot live without each other, so compromise is important to seek food security for a sustainable relationship. In Chinas case, the norm was sustainable for centuries until the market economy opened up and consumerist demand spread like a virus. The rate of growth is unsustainable, technologies are irresponsibly replacing natural methods that have been in place for centuries and dangerous consequences are rattling the globe. If China can begin to emphasize the importance of some of the more sustainable and natural methods that were previously in place for millennia, there is hope for systems that can reconnect the consumers with their natural resources. Some environmental protection in China would be a start.

Protection and security in China can begin with capital investment in green growth of biomass, bioremediation to combat contaminated soils, and in a variety of opportunities available with beneficial fungi that are already traditionally used in the country. Medicinal and culinary mushrooms have been consumed in China for millennia, and the modern culture continues to value them highly as a cash crop and as a primary figure in the cycle of life an in productive ecosystems. If the US consumer market incorporated medicinal and culinary mushrooms into the demand, this cash crop could change the face of agriculture and exceed both American and Chinese expectations and standards. Chinese mushroom farmers would see improvements in their economic and environmental situation if demands were created for their traditional crop. The US already imports mushroom products from China annually, but these are a small fraction compared to processed foods. Current levels of soil contamination are a reason to be skeptical of edible mushroom quality and of other crops alike, but with mycoremediation activities, two opportunities can be taken concurrently. The Chinese already have a deeply archaic symbiotic relationship with fungi that is visible all the way to the dinner table. Traditional Chinese dependence on fungi for holistic medical healing by most of the population can still be found widely today.

Figure 19. An extensive dried local mushroom selection in Chengdu.

In summary, some of the ways fungi could potentially make the economy and the environment more sustainable and efficient per unit of energy: more productive agriculture with mycorrhizal application, edible resource for plant and animal nutrition, reforestation efforts, oil and toxic pollutant cleanup, biofuel alternatives, landfill reduction, flood control, and even medicinal breakthroughs. Understanding fungal colonies up close will determine how and where they will create the greatest impact in urban, industrial, rural, chemical, and microbiological systems. Planetary powers are trimming the global biosphere, and the dichotomy of rapidly expanding economies and the function of primordial fungi is fragile but interdependent nonetheless. The collaborative suggestions offered thus far hardly skim the surface of what the possibilities would fare. The products and technologies that were discussed in this chapter are game-changers, but require a conscious effort in the short term to be celebrated in the long term.

Intangible values are often financially equated, translating environmental costs into monetary ones. There is much to be explored in the resources already available, and they are indeed finite unless acknowledged as part of the human life cycle.

Figure 20. Organic oyster mushroom production outside Chengdu. This facility recycles all of the soil and substrate as compost.

Over time, humans increasingly developed the technological ability to alter the flow of energy and matter through natural/physical systems and, therefore, alter the nature of the Earth's environment itself. As affluence increases people consume more, which requires more resource extraction. High levels of technology on the part of affluent people make it possible for a relatively small group of people to drastically alter the existing flow of energy and matter through the Earth system and culturally modify the environment in a short period of time

Brock Brown

Most places across the globe sustain an interdependent community where resources are shared and used moderately; the US spends and wastes so irresponsibly that the entire globe has to pay.

IV: Integral Ecology

Benefit for the Macro-Micro Community

The greatest challenges will be discussing antithetical systems in the same context, with proof that they can often both benefit without ones sacrifice of the other. Finally, the interconnectedness between the two worlds of human benefit and AO (All Others: plants, animals, microbes, landforms, farms, systems, anything of value lacking a human body as a vehicle) will be solidified. . The laws of thermodynamics state that energy cannot be created or destroyed, only transformed. With this in mind, economic producers could manifest a symbiotic relationship with naturally occurring energy producers such as beneficial fungi. Both parties are responsible for determining balance in biological populations. From mycological patterns, the most successful biological models can be traced as environments adapt or collapse due to natural shifts and to human influence. The mycelia cycle transforms barren landscapes into diverse habitats by attracting life in all shapes and sizes thru a series of food chains. Being one of the first candidates in the microscopic food chain gives fungi the allegiance of establishing a line of predators and partners soon to follow, expanding well into the macroscopic world. The energy that flows in and out of each of every individual daily is never separated from a singular lineage that is shared throughout earth's space and for distances beyond. All systems are undeniably interconnected, especially those among microscopic Biospheres providing infrastructure for higher forms of life. The impact humans have on the physical world is far below what the eye can see; it is deep within the nuclei of cells covering unaltered expanses of the planet.

Ethnomycological Ancestors

So if fungi have so much to offer humans, why aren't the benefits already recognized? This complex question cannot be answered without looking at ethno-mycology, ways people have used fungi throughout history and across cultures. The fear developed from judgment by occasional misuse of poisonous plants and fungi has robbed many of their experience with favorable resources right in their own yard. For most of recorded human history, fungi were characterized by the mysterious mushrooms that some produced; springing up out of nowhere, they were viewed by many as the probable work of evil spirits (Hudler 1998, 5). Many people today view fungi as the opposing team to pro-bacteria, pharmaceutical saviors, and chemical solutions to agricultural and related issues. For decades the great minds of science have been bottlenecked into monopolies of big Pharma and industrial medicine, or for few, put on the sidelines in environmental protectionist nets. Fear of fungi and mushrooms sometimes reaches phobic extremes; Paul Stamets defines it as *mycophobia*, the case for those individuals and cultures that look upon fungi with fear and loathing: "true to their beguiling nature, fungi have always elicited deep emotional responses: from adulation by those who understand them to outright fear by those who do not" (Stamets 2000, 1). There are few things that strike such fear in the average American as the mere mention of wild mushrooms; like snakes or worms, they are regarded as unorthodox and creepy, the vermin of the vegetable world, as John Kitsteiner of Temperate Climate Permaculture puts it (2013). Classical English writers usually refer to mushrooms or 'toadstools' with disdain and disgust, which can simply be conceived as fear, from the mycologists' perspective (Haines 2013). This literature is partly responsible for why the average American today chooses to leave any mushrooms they come across unacknowledged.

First and foremost, the largest contributor to American mycophobia is the unexpected site of a mushroom. Mushrooms are considered to be symbols of death decay and rot (rightfully so), though many people do not realize the miraculous enzymatic duties they fulfill when disassembling organic matter. Without fulfilling the role they (and a variety of other organisms) do, endless piles of dead organismal bodies would cover the earth, and life would seize to exist without access to all of that trapped energy. Condemning fungi as grotesque poisonous rot is the equivalent to calling living, respiratory soil, dirt. After all, the edible varieties improve human immune systems in a style that relieves from bacteria, viruses, and cancer. But if you have lived with unquestioned caution, it would not be easy to assume that the nearest wild mushrooms are conceivably more nutritious and superior to anything in the pantry.

The higher a societies standards of living, the less likely they are going to indulge in natures complementary gifts, such as delicious gourmet mushrooms. Since the industrial revolution, the ego of the American individual has insisted on confrontation with nature, as if it is something to overcome and conquer (Gray 2014). The wealth of this nation provides the convenient chance to opt out on the consumption of wild or locally grown mushrooms and plants; in Americans choose the easy way out, especially when it comes to nutrition. Learning about nutritious mushrooms in America is as uncommon as learning about any other advantageous edible plant or organism. Most people only consume the goods on the shelves of their closest cheapest grocer, without consideration of what is beyond that market or what whole foods and plants the products were derived from. In the US, over 300,000 people are hospitalized each year eating *safe food* (Haines 2013). Compare this to Europe, where people are more likely to put in easily acquired effort in learning about an ingredient for consumption, likely because they have energy to spare, given the naturally immune-enhancing characteristics of their wholesome diet. Americans are very out of tune with the true plants that compose refined and processed foods and fibers. Fungus contributes to the growth of many crops and is responsible for the production of everything from alcohol to corn syrup. The consumeristic attitude of everything *now*, for the smallest price imaginable, initiates carelessness in what the ingredients are or what the process requires to make it. Westerners are simply unfamiliar with plants (or organisms like fungi) in their natural raw context. English cultures make up a majority of mycophobic populations; in contrast, mycophilic (mushroom loving) societies can presumably be found in mass throughout Asia and Eastern Europe (Kitsteiner 2013). Take the market of truffles for example, a pungent mushroom that just so happens to hold the most expensive 'food' title in the world! They are a hearty underground mushroom that accumulates a generous amount of flavor and essential nutrients, and because of their rare appearance above ground, one fresh pound costs as much as $3,500 (Lincoff 2010)

Many varieties of mushrooms will give off odors at times of sporulation to attract pollinators that will unintentionally spread their genes. Such odors are also designed to repel predators such as birds, deer and other foragers (Haines 2013). These odors frighten most people that cannot imagine mushrooms having such a capability. It is rare to be told that of the thousands of species wild mushrooms to be found in North America, only a fraction are poisonous, and a handful lethal. Once you know what to look for, it is about as difficult to tell a deadly *Amanita* from a savory chanterelle, as it is a lima bean from an artichoke, Kitsteiner says (2013). As a vegetarian, I was once ridiculed for ordering a portabella mushroom dish at a restaurant, by a claim that "mushrooms are evil- for why would God put something on this Earth that would be poisonous to humans?" This critic fails to recognize a parallel similarity such as the act of harvesting and consuming wild plants without first consulting a field guide or expert. Dozens of local trees flowers and shrubs have toxic even fatal chemical properties if consumed by humans. So sure, there are a few types that have the power to knock you off your feet if consumed in a large enough quantity, but just as it is not recommended to go out and eat the first red berries found in the forest, nor is it rational to mushroom hunt without any field guide or instruction. Wild mushrooms should never be harvested without first consulting an experienced forager or with sure positivity that they are a preferred species. On the contrary, many cultures of third world countries have slim pickings when consuming wild mushrooms and plants for a caloric source of energy; there is not the rational option of avoiding or simply mowing ever these resources. Mycophobia is not directly correlated to every individual in wealthy America, and mycophiles are not only those of third world societies, but there is certainly a notable correlation. The less choice one has, the more likely they will indulge in the wild edible foods available. Avoiding mushrooms due to hearsay means you are merely missing out on a rewarding feature of wild nutrition. *Don't fear the wild; embrace it* (Haines 2013).

igure 21. An exciting flush of
small puffball mushrooms
Calvatia) can be tasty if
readed and fried.

While most of the future with fungus appears to be bright, there is an ongoing battle with pathogenic fungi in humans. Progress has been made in treating many other diseases by using drugs that depress the immune system, and it is in this context where a normally benign fungus becomes pathogenic (Hudler 1998); an embarrassingly high quantity of anti-biotic medications are ingested, so much so that there is often no biotic guard left to protect the bodily systems. Mycoses, the general term for a human fungal infection, should not be reason to disregard the entire kingdom. Similar to bacteria, fungi take the brute of the varieties that are undesirable. An example for bacteria's case, 10 times as many bacterial cells live on and in our bodies, as *human* cells (Stamets 2005).

Even more unfortunate is residuum of the 'War on Drugs' campaign that revisits the nation, misinforming teens and adults alike of the dangers of nature-derived drugs- those occurring essentially among ecosystems across the planet. No type of plant or organism exists without a purpose. Whether or not that purpose is for human advantage is a different question; yet all existing to date have evolved and adapted to today's risky standards. It is every individual's responsibility to familiarize with his or her biotic surroundings to a degree cogent enough to make appropriate decisions about what to call food or flint. After all, Stamets assures that mushrooms evolved into their basic forms long before even the most distant mammal ancestors of humans (2005).

With all historical validation, psilocybin-containing mushrooms have long been a part of humankind's cultural and social development (Hodge 2010). For over 2,000 years, a secret ceremony persisted taking place in Eleusis, at an unusual sacred temple, where sacred mushrooms were the reason for gathering, and were used as a tool for heightening mortal purpose (Hodge 2010). Founders of Western philosophy including Aristotle, Plato, Homer, and Sophocles all partook in this ceremony, whose activities had to remain the utmost secret from outsiders. The ceremonies continued until repression in the early centuries of the Christian era (Stamets 2000). These pursuits alone elucidate the profound impact that fungal predecessors have had on the progress of the modern Western archetype. These particular fungal tools are an undeniable source of credibility for some of the world's greatest thinkers, yet American enforcement does not want society to ponder alternative lifestyles or nonconformist possibilities. The flimsy D.A.R.E. programs in primary school are the epitome of the American custom- that which threatens the status quo will be put in the category of dangerous, threatening, poisonous and even deadly (Gray 2014). As Terrence McKenna once reported the message of entheogenic plants, "culture can be re-engineered as a set of emotional and spiritual values rather than products. This is terrifying news" (1991), and may be reason why psychotropic plants and fungi are classified

Figure 22: The infamous Amanita muscaria, recognized for its mysterious characteristics.

as Schedule I drugs. Humans continue to fear what is not known, and in most cases punish those who attempt to seek it out. The standard, "if we can't patent it, lets prohibit it" must go.

So what now? To generally revert these issues, the attitude of American coteries would have to be revised, transforming political, religious, and economic irregularity, into confident efforts of sustainability and harmony. Much is to be learnt about our fungal allies, but will continued to be hindered if so many deem them all to be poisonous, dangerous, distasteful, or even evil. Surely some people will grow out of exploiting them recreationally so they are not perceived as a threat, but rather a sacred tool for reflecting on the foundational ideas of our forefathers. At that rate, perhaps much of societies greed, depression, and suffering could be eliminated. A far-reaching proposition imagines the combined capabilities of all mushrooms as a whole as the single solution for all social issues. If mycophobia could be combated, how would the world be a different place? All phobias are typically treated with the same medicine: education. Once a person starts to understand and comprehend all the aspects of the subject they fear, the fear starts to diminish (Kitsteiner 2013).

Science, as opposed to religious dogma, is not about certainties; it is changing all the time. But, as in any other field of human endeavor, the status quo tends to hang on for far too long, on account of vested interests in huge profits, top jobs, big research grants, and personal prestige and reputation. It is incredibly hard for new findings and new ideas to get a hearing in the scientific community, or for old, discredited theories like Neo-Darwinism and reductionist biology to die. And all the more so when big corporations that have taken over every sector of society back the old guard including our most sacred and revered academic institutions.

Mae Wan Ho

For the matter in question to be straightened out, it needs to be addressed as an all-inclusive whole, with correspondence from determining political leaders, choosing to note every factor without avoiding the features most difficult to manipulate or contend with. The greatest designs possible are those that perpetuate personal engagement, making individuals themselves more resourceful. When using what is in ones local resource pool, stress is taken away from depleted domains and income is redistributed to those at loss under irresponsible operations. Biological wealth and economic wealth can grow on the same plane if fungi is utilized and understood by more public consumers. More open minds in this wealthy country will increase the scope of informational sharing that could perpetuate a more sustainable future and a cleaner production environment. If the interconnectedness between human and AO benefit is determined, the rewards will surely be prolific.

As it has been examined, the types of fungi largely talked about are limited to those poisoning animals and crops, but what remains unnoticed is the magnitude of fungal bodies providing infrastructure to habitats and ecosystems, making them adequate for bio-diverse sustainability. Humans live communally with fungi and would not be here without this kingdom of life. The current paradigm of global food and fiber productivity is dangerously misguided. Current analysis of bio-economic correlations and patterns do not typically account for planetary metabolic-latitudinal relations. The Latitudinal Diversity Gradient (LDG) shows that biological wealth increases where economical wealth decreases and vice versa. For example, poorer people live in tropic regions straddling the equator, where there are abundant natural resources, which outsiders from polar hemispheres have excavated for centuries. Neurologically diseased patients increase toward the poles, but diversity and quantity of disease, virus, and bacteria decrease. Further from the equator, plant and animal (particularly mammal) heights tend to increase, due to less organismal diversity and resource competition, whereas the equatorial tropics experience slow growth from such vast diversity and resource sharing. Most notably in these regions is the immense variety in small competitors; the warm, wet environment has provided the opportunity for biodiversity to coexist for billions of years, which is in part why these regions should not be passively treated equivocally to farther reaches of the hemispheres. The slow growth of plants animals and microorganisms in these tropics makes the situation even more critical. The latest edition of the *Living Planet Report* determined that global population sizes of vertebrate species have halved over the last 4 decades. The Living Planet Index (LPI) measures over 10,000 populations of mammals, birds, reptiles, amphibians and fish, and totals have declined 52 percent since the year 1970. Biodiversity is declining in both temperate and tropical regions, but the decline is greater in the tropics, with Latin America showing the most dramatic decrease, of 83 percent (WWF International 2014). These ecosystems delegate the survival of all life on earth, considering life is one interconnected vessel, dependent on the transfer and sharing of energy.

These examples highlight some of the reasons the planets tropic regions should be protected from deforestation, mining, unsustainable farming, and other resource manipulation that continues to threaten a biotic future with elimination of biodiversity. Developmental, industrial, and agricultural trend setters should take the LDG into consideration. With this understanding, technologies can be designed and agricultural measures taken that adapt and integrate, instead of monopolize and conform.

Ecological research usually cannot be narrowed into a controlled experiment, so conclusions are often measured with percent difference in variability. The ecological footprint analysis for example, designed by Mathis Wackernagel, measures what an economy needs from nature: inputs that fuel it and wastes that emerge from it. It uses a single metric number of global hectares of land and water to compare ecological burdens created by various activities (Flavin and Gardner 2006, 6). Since food is a business, and the increasing demand from populations is in permanent growth, science & development, research & technology, are responsible for creating ways to meet this economic equilibrium. Traditional economic methods of production are outdated and cannot achieve productive tasks sustainably according to todays demand (Kabira et al. 1998). Environmental economics take a step closer to the goal by considering the complex network as whole, with all participants dependent on these shared natural resources. But increasing food production calls for either *extensification,* converting forests, grasslands and other natural ecosystems into cropland, or *intensification,* increasing the quantity produced per hectare of existing cropland. The latter is generally preferred; hence the modern obsession with GMO's and related technologies. Intensive agriculture will thus be responsible for closing yield gaps (differences between current yields and those obtainable under optimal management), to meet food demands (Bharucha 2013).

Intensification has serious ecological consequences too, some of which have already been discussed. A growing science and practice is that of Agroecology, which manages agricultural ecosystems as a whole, while continuing to monitor their individual factors like plants and soil. New methods are showing ways to meet the requirements of intensification in a sustainable manner, the first being conservation agriculture (CA). CA consists of three interlinked principles: minimal soil tilling, maintaining permanent organic soil cover, and cultivating diverse crop species (Bharucha 2013). Tied to these methods is Permaculture, originally 'Permanent Agriculture', coined by Bill Mollison in 1978.

Permaculture is a philosophy of working with, rather than against nature; of protracted and thoughtful observation rather than protracted and thoughtless labor; and of looking at plants and animals in all their functions, rather than treating any area as a single product system.

Bill Mollison

This philosophy has developed into a way of life for many, and encompasses everything from growing food to building communities, all with as little environmental alteration as possible. Permaculture aims to encourage people to think like producers rather than consumers- that are capable of full cycle sustainable living when using the patterns in nature. It also encompasses ecological design, construction, architecture, engineering, and other human development, while adapting to cultural and regional differences.

International agribusiness is culturally influenced, so looking to ethnomycology for behavioral patterns that influence consumer choices can help create an avenue for potential beneficiaries to start gaining access to a map of the microscopic biosphere. International producers can be offered this idea, starting with Mycelia Solutions and other fungal enterprise products that have already proven cost and resource effective. Leading technologies have the capability to equate where production is most inefficient, and with this data, the four corners of social responsibility, production efficiency, economic viability, and environmental compatibility, can be adjusted accordingly. Social and environmental issues all come down to a finite supply of natural resources. Measuring the economic value of nature with an appropriate equation, comparing resources utilized vs. sustainable production, can escort the direction of future technologies and efforts. One of the largest threats to all of our foundational systems is the excessive overconsumption of consumer goods (Leathers and Foster 2009). It is all about supply and demand, and if consumers continue to demand purposeless market products, the resource cycle will become more consequential. Reducing excessive consumption in this country could create the largest social opportunity in history. With savings from less wasteful spending, more inputs could be redirected to green sustainability. True sustainability means scaling down the degree to which goods are wasted, especially materials in agricultural, industrial, distributional, and mechanical systems (Kabira 1998).

Myco-cropping and recycling

Enhanced productivity with myco technologies is an exciting journey that many agriculturalists have started on. Operations as entertaining as myco-tourism are taking hold of this optimistic market, offering tours of privately run fungi farms and labs, be it for culinary, medicinal, remediational, or agricultural fungi products. To feed and clothe the world, an agriculturalist must consider the roots of where the business begins- at the beginning of the food-resource-energy chain. Humans access the elements essential for life through the soil web. After reviewing some of the intellect mycelium carries, it should seem apparent that there are many other applications in agriculture, providing promising alternatives to conventional practice. The environmental benefits from sustainable agriculture by means of mushroom composting and myco-cropping for example, are tied to all other assets in environmental stability. The earth recycles its resources naturally, until humans extract or manipulate them (Brown 2006). Composting provides the ability to contribute to natures recycling process for human good as well as the environments. Increasing individual amount of direct participation with this system by reusing organic materials and recycling nonorganic ones can eliminate the need for synthesized fertilizers that cause the system to lose sustainability to begin with. Replenishing soils will provide a lasting infrastructure for organic matter to be fully transferred from one season's crop to the next. "When the natural benefits of fungi have been repressed, the perceived need for artificial fertilizers increases, creating a cycle of chemical dependence, ultimately eroding sustainability" (Stamets 2005, 9).

All living things have grown from the planetary recycling system of essential elements, and the more humans contribute to efficient recycling, the better the quality of life will be for all plants animals and people around us. Compost reduces wasted energy and resources by utilizing leftover food as fertilizer instead of transporting it to landfill. It also reduces the chemical pollution in the soil, air, and water, created by commercial fertilizers currently used on a dangerously wide scale.

"Today, society demands efficient use of natural materials, so recycling of wastes into agriculture is viewed as important. Many municipalities are producing solid waste materials that can be used on the farm as soil amendments and sources of nutrients for plants. The technology of compost production and utilization is still developing. One challenge for the grower is to locate compost sources that yield consistent chemical and physical qualities"

Maynard and Hochmuth 2007

Soil is the skin of the earth- permeable and aerobic, providing complex chemical reactions that sustain terrestrial life. Using chemical fertilizer on soil is the equivalent of using antibiotics on our immune systems- it kills microflora and microfauna like antibiotics kill undesirable microbes as well as those that protect, too.

Myco-pesticides

Pesticides, invented to protect food and fiber crops, have turned on us, directly threatening lives by accumulating in our bloodstreams, fatty tissues, drinking water, and environments- polluting non-targeted organisms. Although many original chemical pesticides have been banned due to their potent hazardous toxins, still remaining are their residues and those of current chemicals that continue to demolish the biosphere. Biopesticides are of growing interest, due to their sound means of controlling insect and pest populations among crops. They lack the long-term consequences and damage that conventional methods create. Mycopesticides are those that manipulate fungi (mostly endophytic) to attack insects threatening a commercial crop. Almost all insects interact with fungi- mutualistically, symbiotically, or parasitically, trading positions as predator and prey per species and genus. Some mycorrhizal fungi secrete chemicals that are lethal antibiotics to the insects and bacteria that infect crops. Neotyphodium for example, is an endophytic fungus that produces insect-deterring alkaloids, and is used commercially as an inoculum for seed in the turf grass industry. These fungi can also be used to help protect intensively farmed crops against insect attack from pests like nematodes and worms, and are of high interest to the agricultural pest control industry. The soil organisms that cause major crop loss are only given the chance to do so because of monocropping. Monoculture crops (only one species intensively grown in an area) can only exist with the heavy assistance of antibiotic chemicals to kill off all other life competing with its resources. As this agricultural method eliminates all of the crops competitors, often more than one of the thousands of organismal varieties of fungi, bacteria, aphid and nematodes advance past the applications of chemical antibiotics, with adaptive mechanisms, thus multiplying and causing mass blight, without any predators to stop it. Integrated Pest Management (IPM) is gaining speed to update the way these issues are approached; IPM combines targeted use of agrochemicals, cultivation methods, and biological techniques to control pests. IPM assessments have shown varieties of ways to improve crop yields, while reducing overall pesticide use (Bharucha 2013).

Myco-fungicides

Parasitic fungi cause plants and crops to rot, and can be very costly agricultural nuisances. Traditional fungicides combat this parasitic prey with chemical fungicide that harms other soil biota too. Certain filamentous fungi characteristically attack other fungi in nature, suggesting fungal-based fungicides could be effective when adapted accordingly. Trichoderma species for example, are not plant pathogenic, and are highly competitive against other fungi, thus have been developed and patented for use against parasitic fungi that target market crops (Leatham 1992).

Myco-herbicides

Myco-herbicide technology is very complex and just as skeptical as other methods of plant competition control. Some specific examples show the astounding ability of fungal herbicides to inhibit the growth of some particularly troublesome weeds, inadvertently introduced to the Hawaiian Islands (Leatham 1992, xiv). Introducing beneficial fungi to agricultural plots can develop into a remarkable tool with many green benefits for the ecosystem and economy, but the complex systems in nature must not be underestimated. When any given characteristic is manipulated, nature has a defense mechanism on hand, usually becoming a consequence. The vast majority of plants in *natural* environments thrive in cohesion with mycorrhizae and other fungi, reason to believe this biotic matrix is better suited for agricultural needs than what is synthetically modified.

Figure 24. A happy cluster of Lepiota's in the Houston suburbs.

Mycoforestry

Agroforestry is a sustainable farming method that incorporates trees or shrubs into cropping systems. This operation offers replenished soil fertility and strengthened plot characteristics, as well as an additional crop at harvest, for food fodder and timber (Bharucha 2013). Mycoforestry is the use of beneficial fungi to nourish forests and sustain their biosphere. Fungi play a foundational role in all forest ecosystems, as a primary decomposer of woody debris to resupply the living matter with nutrients, among other benefits. Technology for improving the maintenance of and significantly expanding forest timber stands has already been in place, but is constantly updated and adapted to ever-depleted areas. This depletion is directly caused by endless growing demand for wood and fiber products. The funds supporting successful re-forestation programs are highly dependent on the survival and vigor of the young fragile trees planted. Dramatic increases in survival and productivity can result from the inoculation of trees with beneficial ectomycorrhizal fungi (Leatham 1992). Afforestation efforts have supplied several commercial formulations for fungi application to roots of new transplants and established trees, leaving many feats to explore in potential varieties to incorporate in the planting process.

Although all systems are interconnected, there is never one universal method of usage that meets ever systems optimal productive needs. Instead of passively watching monotonous production and blanket application of intensive mechanisms, consumers should seek out decentralized, locally designed food and energy security programs that value the unbreakable relationship of terrestrial plants and animals. Market-oriented agriculture determines economic stability, but must find a balance with cohesion of the fragile terrestrial biosphere. The challenge for agriculture is three-fold: increase agricultural production (especially nutrient-rich foods), do so in ways that reduce inequality, and reverse and prevent resource degradation (Bharucha 2013). Emphasis on multi-speciation has proven net primary productivity, on the field and in the forest. Not only have fungi proved their reliance as a potential economic stabilizer, they have displayed environmental sustainability too, playing the role as one of earth natural immune systems.

The following list summarizes the benefits from integrating fungi into our account:

- Closes a full cycle food and resource supply
- Sustainability that saves time money and resources
- Protection of current fragile and valuable ecosystems
- Security of biodiversity in ecosystems and agriculture
- Overall plant and animal health and nutrition
- Soil health increased maintained and protected
- Cost comparative supply of agricultural products and plastic alternatives
- Safer alternative to synthesized pharmaceutical chemicals
- Help relieve human hunger and nutrient/mineral/vitamin/protein deficiencies
- Environmentally beneficial cash crop potential
- Fungi cash crop production in isolated farm communities would reduce agribusiness

inequality, improve distribution systems and social infrastructure
- Healthier food = healthier field & factory = healthier domain = happier organisms
- Relieved stress on producers and consumers who've both become more resourceful
- Unmodified biotechnology that supplies unmatchable green energy
- More efficient growth of biomass crops = safer biofuels
- Potentially more sustainable herbicide, insecticide, fungicide, and fertilizer alternative
- Polymer product decomposition & replacement
- Maintain terrestrial resource extraction (mycoforestry)
- Minimize habitat & ecosystem stress
- Facilitates greater variety in biosphere, thus future terrestrial resources
- Urban waste minimization and more efficient means of recycling

The goal of sustainability in agriculture is to minimize inputs and maximize eco-systematic contribution. Ag sustainability will always rely on the environment, which will always rely on biodiversity to be able to thrive.

Figure 25. Enjoying a side of Enoki Mushrooms in Beijing.

Human Wellness

The fungus is among us, providing a natural alternative to prevent, preserve, and heal bodily weaknesses from patterns of daily-misguided consumption and all of its polluted side effects. Because Americans continue to try and conquer nature the way remunerative endeavors demand, the freedom and free fruits of the natural world are almost impossible to obtain. In fact, many species of fungi are losing the ability to adapt as quickly as the environments' changes are requiring them to, disappearing before opportunities are taken to discover them. On medical terms, specific fungal species have the power to repair and strengthen humans against microbiotic and micro-synthetic threats. This is a dangerous proposal to the first-class technology of the United States Pharmaceutical Industry, implemented to serve and cure exceptional diseases. Where western medicine progresses in mechanical yield, natural and supernatural connections become increasingly dissociated, hindering substantial attempts in humankind's relation to natural health and medicine. Where the formula becomes entirely calculable, solutions provide an aura of connectedness beyond the terrestrial space and into the cosmos, where the physical ego is lost and consciousness is not only endless but also irrelevant. Holistic wellness still elucidates eastern medicine, where mushrooms with medicinal properties are prescribed by commercial doctors as cures, for a variety of ailments, in any of the bodies given circulatory systems.

Fungi have the potential to connect humans to nature by guiding us outside our narrowly calculated hypotheses to yield new ideas and designs of progress. This is counter-intuitive to the exceptional individual in America; after all, the most dangerous thing that can be done as an American, is *not* consume (Gray 2014). Fungi break down the ego's yearning to be the exceptional American and make way for interconnectedness between mind body soul spirit and the natural world. As philosopher and ethnobotanist Terrence McKenna puts it: "Ego is a structure that is erected by a neurotic individual who is a member of a neurotic culture against the facts of the matter. And culture, which we put on like an overcoat, is the collectivized consensus about what sort of neurotic behaviors are acceptable" (1991). The fear that pervades Americans and other societies alike is based on deviation from the norm, and according to the culture industries' protocol, that could mean undesired consequences. Psilocybin containing mushrooms are not illegal because the DEA is concerned for your safety and does not want you becoming “addicted”, but rather because psilocybin has been shown to promote neural networks and activity between brain regions that otherwise remain disconnected with sensory blocking of catalogues of possibility: meaning cultural expectations become temporarily disbanded, debunking the insecure models of behavior and questionable prototypes of society, allowing the consumer to recognize a more primitive yet vastly complex bio-psychological blueprint (Hodge 2010). Unfortunately, the typical American experience distributes disconnect between the individual and the communal aspects of society, spotlighting the grand illusion of *freedom*. Americans are obsessed with individuality, at the same time, idolizing equality; it is okay to be proud of yourself when everyone has the same opportunity (Gray 2014). The independent worker is still the dominant notion in America; work hard for yourself- gain your own riches. Fungi are above this notion of *the individual*, and the constraints of such conformity. Conformity is simply a tool of the culture industry in America, and under foot, in the world of microbes and mycelia, there is no conformity, only full cycle birth growth duplication death and decay.

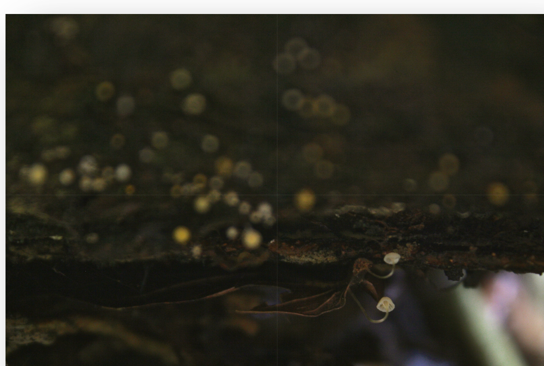
Conclusion

I envision a world where people interact with the microscopic biosphere daily as they do with the macroscopic biosphere. If this relationship is engaged, many fruitful surprises await. Engaging in the microscopic world could present the opportunity for more efficient organismal producers and consumers that could in turn achieve a greater purpose. Meanwhile the carbon footprint would be filled in with complex bio systems facilitating a renewal in suffering biota. Engagement in microscopic arenas would likely lead societies to feelings of desire for personal resourcefulness by interacting with their environment as a pioneer of previously overlooked opportunity. Fundamental processes need to be ubiquitously understood; passive progress in development and related technology must be interrupted with participatory models. The goal of this thesis was to touch the surface of diverse examples showing how much more humanity could gain per unit of energy if utilizing the fungal kingdom for its vast natural application.

Beneficial fungi and myco-technology have so much to offer- why isn't significantly more effort made to utilize this? Besides mycophobia, the fungi kingdom is an organismal dictator on this planet that humans are just beginning to recognize as a serious shareholder. Mycology does not often leave the food science laboratories or the forestry institutes, but needs to be exposed in all other fields applicable to the global biosphere, such as sustainable business solutions, green technologies, healthier foods and holistic medicines. Initiation will require a designated segment of human intention on marketing the ideas provided by the researchers and scientists of these fields, so the ethno-ecologic relationship can continue to grow and advance alongside us. The solutions lie in the microbiotic ecosystems that make up soil that generates plants that feed animals and families. The importance of incorporating all vital aspects of human and environment fragility is paramount to our comfort as an interconnected system.

Life takes place in a non-linear system, and the causes and reactions of producing and consuming the environment must be taken into consideration. Consumer values will have to veer away from material goods towards the wholesome resources from which those goods came from. More cooperation and alliance between scientific and economic communities will proliferate the likeness of this journey. Corporations should be encouraged to adopt myco-technological functions as a means of becoming sustainable and energy efficient. There is a balance between economic and grass roots growth when harmonized in a model that grows the products in partnership with flora and fauna, in comparison to manufacturing them. Applying Dr. Brock Brown's perspective of geography on the current state of the world can help expose how natural methods like mycorestoration could be applied as considerably effective energy savers. All parties should be attentive to the role of microorganisms for this breakthrough in consideration could potentially make all resource systems more efficient.

Again, there are many terrestrial catastrophes fungi are responsible for, causing plants trees and food crops to suffer, yet there are incomparably more essential roles they play that have dictated our chemical complexity for millions of years. The beneficial and profitable characteristics need to be identified and shared. The occasional pathogenic fungi should serve as a reminder of how vulnerable life is on this planet and how large of an influence the kingdom of fungi plays alongside us. The impermanence of a mushroom forces us to credit the non-linear behavior of nature, and to embrace the patterns for what they are, without manipulating them into categorized matrices of isolation.



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APPENDIX B

Some Useful Web Sites

Ecovative. http://www.ecovativedesign.com.

Fantastic Fungi. http://fantasticfungi.com/for-the-scientist/.

Fungi for the People. http://fungiforthepeople.org/mushroom-info/myco-remediation/

International Commission of Food Mycology. http://www.foodmycology.org

Mushroom Mountain. http://mushroommountain.com/bioremediation/index.asp

Mycokey Information Site. http://www.mycokey.com

Myconet Journal. http://www.fieldmuseum.org/myconet

North American Mycological Association. www.namyco.org.

The Cornell Mushroom Blog. http://blog.mycology.cornell.edu.

The Fifth Kingdom. http://www.mycolog.com/fifthtoc.html.

The International Society for Ecological Economics. http://www.isecoeco.org.

The Mycological Society of America. http://msafungi.org.

The National Sustainable Agriculture Information Service. https://attra.ncat.org

The Permaculture Research Institute. http://permaculturenews.org

Science & Development. http://www.scidev.net/global/

World Wildlife Fund. http://wwf.panda.org.

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