Agricultural Efficiency and the End of the Oil Age: Building a Future of Longevity

Keith McHugh

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Readers: Richard Hazlett, Jennifer Perry

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Introduction

"The care of the earth is our most ancient, most worthy and, after all, our most pleasing responsibility. To cherish what remains of it and to foster its renewal is our only legitimate hope."
-Wendell Berry[1]

I tend to look at my feet as I walk. I think this is a practice I learned from growing up hiking in the mountains of New England. The trails of the White Mountains are treacherous; the trees have not given up their places on the path and remind hikers of this constantly with stubbed toes and skinned hands. Although when traversing the walkways that link the classrooms, dining halls, and dormitories that currently support me there is no need to watch for tree roots, I still am careful to see where my feet land and notice the countless ways our species has modified and built upon landscapes.

The food we eat is our direct connection to the land. While there exist many belief systems that may value other aspects of the resources we use, consuming the Earth's energy is fundamental to life. By eating biomass we take advantage of green plants' ability to capture sunlight to support our bodily functions. Other animals join us in collecting food to eat, but none have been able to do it as effectively as humans. In 2011, humans have appropriated about half of the world's plant population's

[1](Berry, 14)

photosynthetic capabilities due to the reorganization of natural processes, what we call agriculture (Vitousek, 368).

Agriculture is arguably the invention that most separates us from other species. Other animals collect food to eat at the moment and some, like hibernating mammals, even store it for later use. About 10,000 years ago our species diverged from this paradigm when we made the leap from hunter-gatherer tribes to agricultural societies. By manipulating the world's natural processes we were able to ensure that there would be enough food to feed our communities throughout the year. To farm the land is to reorganize how its organic material extracts nutrients from the ground and energy from the sun. Agriculture has allowed us to accumulate extra energy on a seasonal schedule.

This acquired food security provided excess energy that communities used to develop infrastructure and increase their populations (Eating Fossil Fuels, 7). Today, many communities are characterized by the foods that are most prevalent in their locale. Ethnic diets are by nature distinct for a location, and nomadic peoples or no communities at all characterize places with too little food to eat. In this way cultures are linked to the land. However, what is often overlooked is the unique techniques of food production behind these special meals.

A large variety of farming methods have developed, but they mostly fall into three categories based on the scale and purpose of the farm. The largest category is comprised of industrialized monoculture farms whose purpose is to produce massive quantities of food, usually grain, to be shipped throughout the world. Extensive fertilizer and pesticide programs characterize these farms, as they are required to

achieve the high yields that are consistently desired each year. Community based farms can also be large, but their purpose narrows to providing for only the surrounding population. Since the life of the community is a product of the farm's output, the fertility of the soil is valued and therefore generally healthy, negating the need for chemical fertilizers and pesticides. The smallest scale of farm[2] is the family subsistence farm on which the fertility of the earth is often celebrated as a spiritual gift.

Each of these scales is an example of how the values of the people in charge of the farm are translated into their use of the land. For example, large corporations control industrial farms. They value maximizing their profits and so grow a monoculture of select "cash crops" by utilizing large amounts of petroleum based fertilizer, waging chemical warfare with local insect populations, and mechanizing their farmers with large tractors. On the other hand, community and family farmers value longevity. These farmers choose to grow a variety of crops, despite specialization in a few products being the more profitable choice, because their community needs a wide selection of foods and, by rotating crops, they promote soil health.

Since the end of World War II, industrial farming has supplied material for the majority of the world's meals. At a glance these farms provide much higher yields per acre than smaller plots. However, analysis of the system beginning in the 1970s, has pointed out that it is a flawed and wasteful system. The so-called Green Revolution has been a dramatic failure, although perhaps in our country it is not as obvious. A common critique of this system is that it is inefficient because the

[2]Here I make the arbitrary distinction of *farm* as a plot of land used to supply all food for a group of people, which is apart from a *garden*, which only provides additional food.

chemicals it puts into the land degrade the soil and create pesticide resistance so each season more application is necessary. While this criticism is accurate, it does not reveal the underlying issue that caused chemicals to be used in the first place. Industrial agriculture attempts to take advantage of economies of scale and feed the world with a few super-farms. This solution shows a fundamental misunderstanding of why people suffer from hunger.

What the world needs is not an increased food supply; there is considerable excess of foodstuffs produced each year in the United States. What the starving people around the world need is increased access to food (World Hunger Education Service, 2011). The Green Revolution actually made meals in some areas less available. Because production became so effective in the United States, agricultural corporations were able to sell food to African villagers for cheaper than it was for local farmers to produce it. At face value this may seem valuable, perhaps farmers were now able to generate more capital doing other activities. However, industrial food prices are dependent on oil and diesel costs and so as fossil fuels inevitably become more expensive, this food will no longer be affordable to these villages. Furthermore, since little agriculture has been practiced in the last sixty years due to extensive aid programs like PL-480, there will be no food available for these people (Vandermeer, 264).

Even the United States and Canada, the leading exporters of staple grains, could suffer from increases in food costs. If we assume the US population will maintain a constant growth rate of 1.1 percent a year, the current population will double by 2050. Pimentel and Giampietro estimate that this increase in population will

result in a loss of an acre of land per additional person (Pimentel and Giampietro, 1994). The minimum amount of land required for growing food for one person is 1.2 acres (Pfeiffer, 40). By 2050, the current 1.8 acres available per capita will reduce to 0.6 acres (Pimentel and Giampietro, 1994). The economic consequences are just as staggering; by 2025 it is estimated that the United States will cease to export its foodstuff due to internal demand. If this were to happen, millions of people, including Americans, would no longer have a food supply unless they were to find another trade partner or grow their own food (Pfeiffer, 40).

If tomorrow there were no fuel and all the trucks and freighter ships failed to carry their shipments, what would you eat? How long would the food in your cabinet last? Food security must be recognized as an issue of national security. Analysis of our current food production system is required to answer the question of how to provide an adequate diet for a world population estimated to be more than 11 billion by 2055 (Pimentel and Pimentel, 359). In this thesis I argue that the answer is to bring people into more direct contact with their food systems with a switch to smaller, more efficient farms that rely less on fossil fuel and are connected with the communities they supply for. This conclusion is found by evaluating the efficiency of how resources are used to produce food. I also derive the important corollary that the survivors of great population decreases that will occur as high-yield energy becomes less available will be the ones close to their food sources. The efficiency analysis of industrial agriculture provides the insight on how to move forward.

This thesis explores the needs and possibilities for agricultural change at a general level. Chapter 1 presents a historical summary of human food production to

provide a background for how modern food issues have arisen. Chapter 2 discusses resource efficiency and analyzes the techniques of industrial agriculture. Chapter 3 introduces a unique understanding of sustainability and analyzes how some non-industrial farmers use ecological and community based philosophies to step away from systems of exploitation and profit maximization.

Chapter 1

Origins of Modern Food Systems

Early Food Production

Not much is known about the actual events that caused the beginning of agriculture, but we can make educated guesses about what probably happened. Nomadic hunter-gatherer societies would have slowly transitioned into planting their own crops to harvest. While bringing fruits, vegetables, grains, and seeds back to a campsite some seeds were dropped and inevitably plants would have sprouted. Returning to this campsite, perceptive individuals might have noticed that the plants they foraged for were now growing where they had eaten them or, more likely, where they went to the bathroom. Others might begin to associate seeds with plants and begin to cultivate crops by putting the seeds in the ground. What we do know about early agriculture is that it was difficult work with small returns including poor nutrition (Pimentel and Pimentel, 51). However, as the populations grew, their mobility decreased and secure food sources that were tied to specific locations became necessary. It should also be noted that perhaps population growth corresponded

with the beginnings of agriculture, for the relative ease of harvesting crops that have known locations and seasons decreases the energy that the society needs to spend on producing food (Pimentel and Pimentel, 51).

Continuing population increases meant that settlements became more permanent and planned farms emerged. The beginnings of deliberate removal of other species so as to farm more land mark a critical event in the expansion of agriculture. Expanding villages were forced to plant on more land in order to increase yields, thus starting a need for human expansion that would become global. In the name of claiming land, humans have plowed fields, leveled forests, displaced hunter-gathers, waged wars and eliminated other species populations until the planet's arable land had been claimed; by 1990, our species had appropriated about 40% of the planet's photosynthetic activity (Vitousek, 1986). This quest for land can perhaps better be categorized as a society's wish to increase its energy stores. Thus agricultural history can be seen as the chronicle of humans using energy to shape their environment to benefit society.

Energy Transitions

From the beginning, agricultural food production and energy have been intrinsically linked; arranging the planet's resources to benefit us requires an input of energy. In fact, as a general rule the more we want to change a landscape, the more energy is required as an input. Thus, stages of agricultural advancement can

be characterized by their energy inputs. For thousands of years we input human and livestock labor to arrange, nurture, and harvest crops for consumption and now the energy that grows our food mostly comes from the complex hydrocarbons we call fossil fuels. These ideas are akin to those of the cultural ecologist Leslie White. White argued that cultural advances correlate with a society's ability to harness or to more efficiently use energy (White, 1949, Part 3). As we will see, the history of agriculture supports this theory of energy transformation, however, modern farming techniques provide an exception because while they have captured more energy, their use is causing drastic changes in the world's climate.

Returning to the hunter-gatherer societies, we look at the energy they consumed to travel on foot to collect food and bring it back to their camp. One example is the !Kung of northern Botswana. For !Kung Bushmen Mongongo Nut gatherers, these activities are estimated to have cost 2680 kilocalories (kcal, called calories on food packaging) with an output of 10,500 kcal for nuts that were 4.8km from their camp. These numbers boil down to a 3.9:1 labor energy to food energy ratio. If instead the distance traveled is doubled to 9.6km, an extra 532 kcal is needed, lowering the ratio to 3.3:1(Derived from Lee, 39-60).

Harvesting crops dramatically increased the available energy for some of its early adopters. For example, in primitive New Guinea, using swidden agriculture (slash and burn), villages were able to generate more than 11 million kcal per hectare. Livestock labor also importantly allowed farmers to increase their production through tilling and making it possible to transport their goods more easily. These increases in energy meant that the village sometimes produced more energy than it needed

and so they began to feed livestock the extra food. During years of surplus, instead of creating waste, New Guinea farmers fed extra food to pigs. The direct benefit of this for their society was that it acted as a buffer for years with poor harvests; the villagers could eat the pigs that had stored the energy from previous seasons (Pimentel and Pimentel, 54).

When discussing food production, it is common to define advances in agriculture as the accumulation of excess energy. However, I feel this is often too abstract of an analysis. The energy' in question is food, and we all can understand that why societies have strived to create an abundance of food is because without it there is chaos; for instance, in the contemporary world, not being able to feed oneself is an order of magnitude more dire than not being able to turn on a light bulb.

Even a little extra food allowed for great achievements because with it, some of the population could exert themselves in doing activities that did not produce food. For example, in the time of Ancient Egypt (about 2780 - 1625 BCE), an abundance in their staple calories of bread and beer allowed 5% of their population's energy to support Pharaoh leadership and the construction of the Pyramids. The other 95% of the energy they produced was used in agriculture (Pimentel and Pimentel, 4).

Contemporary energy use is astronomically greater than that of Egypt. We see evidence of this all time as we watch complex structures be constructed in a matter of months. The rhetoric used to describe energy today necessarily differentiates between human energy from metabolizing food calories and energy creation outside of the body. Endosomatic food energy created the pyramids, harvested lands, explored the Americas, and powers sports players. Exosomatic energy is generated outside

of the human body, such as burning gasoline in a truck or using coal to create electricity, but also solar energy falls under this category. Exosomatic energy now prevails over endosomatic in a 90:1 ratio in the United States. The trends of society no longer call for human labor to directly power economic processes. Instead, small amounts of labor are allocated to send information directing how to use exosomatic structures (Pfeiffer, 20). The reason is that high-yield energy sources called fossil fuels are capable of creating large amounts of energy quickly and therefore they now dominate our energy infrastructure. For example, the 38,000 kcal in a single gallon of gasoline equates to about 3 weeks of human labor (Pfeiffer, 21).

Fossil Energy

These fuels originate in the time of the dinosaurs, millions of years ago, when gigantic plumes of algae existed in the ocean. These single-celled organisms would die and fall to the bottom of the ocean. Eventually the Earth's make up changed and the dead algae were covered in inorganic matter and over millions of years the energy in these cells was compressed into the hydrocarbons that we now call fossil fuels. Depending on the heat it was exposed to and its purity, the compressed algae either became crude oil, natural gas, or coal (Pfeiffer, 3).

For almost all of humanity's existence, fossil fuel has not been used. Until recent times, energy for heating homes came from firewood and animal and human labor were the driving forces behind construction and agriculture. It was not until

the 16th Century when England and France were running out of firewood due to increasing populations that coal was first considered being used. Purification and harvesting techniques for coal were primitive and so the fumes from burning it were noxious. Thus wood was the preferred fuel. It would be absurd to support the current energy desires of the United States on energy derived from wood. When European settlers first came to this part of the continent, they were able to support themselves on wood. However, they only used about 5% of the total energy that we do, and the American forests were flourishing due to relatively little harvest activity (Pimentel and Pimentel, 14). Nowadays our country has an insatiable appetite for energy, which is mostly due to the abundance of it created by burning fossil fuels. The society in New Guinea described above mostly used their energy to produce food, which is thought to have taken about 750,000 kcal to do per hectare. The United States has an area of 916,192,300 hectares and uses about 26 x 1015 kcal in fossil fuel, which yields a ratio of 112,421,810 kcal per hectare. Of course, the majority of the land in the United States is not directly used by our society so this ratio would increase if these lands were not counted. Just as additional energy from agriculture allowed societies to expand and build infrastructure, so did the adoption of using fossil fuels. It is around this time, during the rise of fossil fuel, that we see Americans move from rural towns into modern cities.

Origins of a Modern Food Dilemma

In the 19th century, as modern cities became more populated, food could no longer be produced locally for everyone. Due to a high population density and the increased usage of land for buildings, agriculture was often impossible within cities so food came from the farmlands outside city limits. This demand for food to be transported into the city meant that farmers who before grew subsistence food for themselves and their neighbors were now growing cash crops and supplying for thousands of mouths (Vileisis, 6). However, preservation techniques were still not strongly developed in the beginning of this migration so oftentimes city food was unacceptable by consumers who demanded high quality food like they had experienced while living in the country; they wanted fresh produce in similar states to how it used to come out of their gardens. The answer to this was that food production companies, which were also founded to answer city peoples' food needs, began to search for new methods of preserving food and it was not long before chemicals were used to make their products last longer. This unnatural processing however was met with an outcry against these companies. People did not want corporations to meddle with their food (Vileisis, 118). To counter these protests, agencies began a nature-focused advertising campaign, which would allow for a radical transformation of food production in the United States.

Originally the goal of placing natural settings on seemingly less natural products, such as margarine or preserved produce, was to gain the public's trust. One advertising guru of the time commented that "ads worked best by making products seem familiar" so many campaigns "called upon nature and used its allure to offer

harried housewives the perfect antidote for urban malaise" towards processed foods (Vileisis, 118). Examples of this strategy are still seen today; manufactured foods' containers often depict cows in open grass fields, mountains and waterfalls, natural grains, or other picturesque outdoor settings. Overtime this campaign succeeded in convincing the public to trust the validity of the scientific food being pushed upon them and "went on to shield an increasingly industrial style of food production from public scrutiny" (Vileisis, 8).

No longer did consumers buy food based on its location or the methods that produced it, they trusted branded corporations to bring them quality products. Thus began the modern food dilemma: the vast majority of consumers are separated from their food supply; they have no knowledge of how it is produced, prepared or distributed.

Chapter 2

Industrial Agriculture

"If I had a little miniature factory farm up [on stage] here
people would call the cops, people would walk out, people would start crying,
get upset, would never come back [here]."
-Jonathan Safran Foer[1]

On his book tour for the recently released *Eating Animals*, writer Jonathan Safran Foer challenged each audience to present to him with a valid argument for why factory farming should continue to be practiced. Many of his arguments for why these processes should be shut down are moral, and discuss the inhumane ways in which the animals whose flesh and milk we consume are treated. With facts such as 80% of antibiotics produced in the United States are fed to animals to keep them healthy (Foer, 140), to discussions of how the cages and pens these animals live in are only barely larger than their body sizes and they will never see sunlight (Foer, 60), he opens the eyes of a reader not yet informed of these atrocities.

I decided to mostly omit livestock production from this paper. Unlike in historical agriculture, in modern industrial systems livestock and produce are no longer parts of the same operation. Therefore, due to the intrinsic inefficiency of

[1](Safran Foer, 2009a)

large-scale animal production for food, I chose to focus on the nontrivial analysis of produce growing. Briefly on animals, to produce meat, milk, or eggs, soil nutrients that could feed humans must be fed to animals, which then use most of that energy in daily processes; the resulting food will only have a small fraction of the energy that was originally coming from the ground. Foer also points out that animal production is the cause of 37% of anthropogenic methane as well as 65% of anthropogenic nitrous oxide, making it easily the largest contributor of Greenhouse Gases and therefore Global Warming (Foer, 58). Yet these facts are strangely absent from most global warming conversations. Foer summarizes the effects of livestock on the environment: "Most simply put, someone who regularly eats factory-farmed animal products cannot call [themselves] an environmentalist without divorcing that word from its meaning" (Foer, 59). This is the end of this paper's discussion of the issue of animal production, but more information may be found in the Campbell, Foer, Patel, and Pimentel and Pimentel citations and by viewing the short film The Meatrix (meatrix.org).

Unfortunately, many of the techniques that are used to harvest animal proteins correlate to similar ones used in produce production. As mentioned earlier, chemical inputs and monoculture characterize these facilities. The goals of this chapter are first, to explain how industrial agriculture came into being, and second, to put on display the devastating results that these processes have on the biotic communities within and surrounding industrial farms, the workers that apply the chemicals, and the consumers of these products.

A Green Revolution

The movement that industrial agriculture built itself out of had the intentions of abolishing world hunger and creating food security equitably for all. In fact, its goal was peace. The technologies that enabled this dramatic increase in food production came out of the scientific push during World War II. The chaotic post-war world brought forward thinkers like Norman Borlaug who preached under the mantra from John Boyle Orr, "You can't build peace on empty stomachs," that in order to bring peace to the world, hunger must be the first issue addressed. He declared in his 1971 Nobel Peace Prize address, "With science we must not only increase our food supplies, but also insure them against biological and physical catastrophes by international efforts to provide international granaries of reserve food for use in case of need. And these food reserves must be made available to all who need them – and before famine strikes, not afterwards" (Borlaug, 1971, 1). Borlaug succinctly summarizes the goals of the imminent agricultural revolution: develop scientific methods to increase yields, construct secure food stores to aid when relief is needed, and distribute this food to all of the world's population. William Gaud dubbed this great humanitarian effort the Green Revolution in March of 1968. Gaud, then USAID administrator, in celebrating the diffusion of new wheat technologies spreading across Asia exclaimed that "[the new wheat varieties] and other developments in the field of agriculture contain the makings of a new revolution. It is not a violent Red Revolution like that of the Soviets, nor is it a White Revolution like that of the Shah of Iran. I call it the Green Revolution" (Borlaug, 2002, 3).

And a revolution it has been. Global grain yields increased by 250% between

1950 and 1984 (Pfeiffer, 7). The Green Revolution did not grow more food by capturing more sunlight, nor was the extra yield due to expansion. In this period, agriculture became more productive because it began to borrow energy from fossil fuels in the form of chemical pesticides and fertilizers. With the industrialization of agriculture came also the conglomeration of smaller farms into larger ones to take advantage of economies of scale and the increased harvesting speeds that the new machinery allowed to maximize food yields like never before.

A main argument for industrial farming is that by consolidating food production to fewer, but more productive farms, it saves land, like rainforests, that would otherwise be razed to allow for more low-yield agriculture to take place. Alex Avery, one of the most outspoken contemporary Green Revolutionists, argues that "through pesticide use, fertilizers, confinement of meat production and modern food processing, modern high-yield farming has already saved millions of square miles of wildlife habitat" (Avery, 2000).

However, the advances made in agriculture have failed to bring food to those who need it. The Green Revolution has caused a 17% increase of food calories per person even with a 70% increase in population in the past thirty years. Yet, there are about 925 million people who are identified as hungry. Out of 7 billion people, this means that 13.2% of the world has deficient access to food (World Hunger Education Service, 2011). Even in the United States, a main exporter of grain, from 1999 to 2002 the number of hungry people increased by 3.9 million and around 1 million of those were children (Pfeiffer, 10). Borlaug's final goal, to make food "available to all who need [it]" has not been realized, despite his noble ambitions, due to a

misunderstanding of the systems he works with (Borlaug, 1971, 1).

The Green Revolution succeeded only in supplying scientific advancements that allow for the exploitation of natural processes. In Borlaug's laboratory, he began a breeding program that yielded new, highly productive varieties of wheat that could only grow in environments saturated with chemical fertilizers, pesticides, and steady water sources (Vandermeer, 264). In order for these varieties to be planted worldwide this heroic science must be transported with it. There are many socioeconomic reasons for the failure of the Green Revolution, but the focus of this paper is resource use efficiency. Therefore my analysis of food production concentrates on understanding the wasteful techniques of industrial agriculture to develop more efficient methods for the future.

Uninformed Economics

There are many food production firms in the United States, all competing with each other and maximizing profits. Of course companies take risks with activities that they lose money on, but generally a profit-maximizing organism will purge itself of the extraneous and use its resources as efficiently as possible. For the sake of an illustration, let us say that we own an apple orchard and are selling our fruit. For simplicity, we assume that the only input that goes into having apples is having the trees; therefore, we disregard picking the apples here. If every apple that is grown is sold, then let us pat ourselves on the back, all of our inputs translate to outputs! Unfortunately it is likely that the market will not buy all of the apples; some of

our inputs now only bring us costs and not revenue. At this point there are two options: we stop accumulating the extra inputs, or we somehow make those apples more desirable and they get sold. As we will see, the solution of maximizing inputs is the driving issue of agricultural efficiency in the United States. The reason that many farms are able to wastefully use egregious amounts of fertilizer and pesticide on their plants is that there is no recognition of the environmental costs of this practice; they simply do not realize the inefficiency and the long-term consequences of these actions. To these firms, maximizing production, and therefore profit, is the ultimate goal. However, many other goals such as sustaining environmental services like soil fertility and food security are equally as important. To understand why agribusiness is misguided, this notion of what I call uniformed economics, the apple orchard is again a helpful example.

In the example above we considered no inputs besides the apple trees, but now we broaden our scope and also examine the soil that supports our apple orchard. Again we find ourselves in the celebratory situation in which the market wants as many of our apples as we can possibly produce. To make more money we could grow more apples and plant trees on the land on the outskirts of the orchard, which is the habitat of a native species. This animal's life cycle is distinct from that of our orchard and so we bear no costs from its disappearance, but the planet does; the ecosystem is taking on our expense. We could also increase our yields by applying petroleum-based pesticides to quell invading insect populations or buy trucks to bring our apples to places where they do not grow. Again, we would not notice, except in news stories about scientists far away that claim the planet is heating up, that

the fuels used to do these activities are harming the planet. We do not notice these effects because they are not a part of the system that informs us of how much an action costs; the monetary prices we pay do not factor in environmental costs.

In his book *The Value of Nothing*, Raj Patel discusses how prices, the costs that consumers pay, of products no longer correlate with actual costs of supplying that product. One enlightening example he uses is a McDonald's Big Mac hamburger. The five dollars that they charge accurately reflect the economic costs that McDonald's bears, but do not come close to stating the price that will be paid on an individual, community, and planet level. The most egregious of these is the climate change that carbon dioxide emissions cause. The annual production of Big Macs has a carbon footprint equivalent to 2.66 billion pounds of CO_2 a year, which is more than 55 countries do (Patel, 44). Adding in the other social costs of health care bills to be paid later in life for diabetes or heart treatment or the environmental damage to the soil that grows the corn on which the cows are fed places the actual cost of a Big Mac closer to $200 (Patel, 46). Modern economics names these costs that are not calculated into a transaction, 'externalities'. These extra costs are the brunt of uninformed economics. If we are to create efficient systems, all costs must be managed, especially the ones which effect the health of the planet.

The current pricing mechanism is therefore backwards; it represents no consequence of the externalities of soil degradation due to chemical use and other exploitive methods, climate alteration from fossil fuel use, or health risk due to the chemicals prevalent in food with diminishing nutritive returns. We are effectively taking a loan from the Earth by using its nonrenewable fossil fuels to exploit ecosystems; we

are not yet absorbing the costs of our actions (Patel, 49). Buying the produce or animal products that come out of industrial systems contributes to the façade that agriculture goals can be independent from natural limits.

Energy Use

In Chapter 1, I discussed how increases in energy availability have great consequences for societies. The Green Revolution has been extraordinarily successful at producing food energy due to its ability to harness energy-dense fossil fuels (Pfeiffer, 10). It is characteristic of discussions of agricultural energy efficiency to boil down numbers to ratios of kilocalories of inputs to kilocalories of outputs. When only the energy of labor and food is analyzed, like Chapter 1's discussion of energy, this notion makes sense; we can easily relate to the concept of eating calories and expending them in labor.

However, this notion of energy becomes too abstract and unhelpful when fossil fuel energy is examined. For example, consider corn production in Mexico using only human power. Farmers here are able to harvest about 6,901,200 kcal per hectare per year with an input of about 642,000 kcal per hectare per year (Pimentel and Pimentel, 100). The input/output ratio here is 1:11. The situation of corn production in the United States is on a different order of magnitude; American farmers produce 31,158,000 kcal per hectare per year with inputs of 8,115,000 kcal per hectare per year, yielding the input/output ratio of 1:3.84 (Pimentel and Pimentel, 105).

Despite industrial production creating five times more yield than when only

human labor is used, these ratios still show that farming done only by human labor is more productive than the industrial analogue. In this chapter we will see that it is the case that industrial agriculture is less efficient than other forms of agriculture, but it is naïve to think these ratios are able to justify this. There are fundamental differences between the calories that we consume and the ones that are released by decomposing the complex hydrocarbons of oil and natural gas. As opposed to human or livestock labor energy, fossil fuel is not supported by farm production; gasoline powered farm machinery, petroleum-based pesticides, and synthetic fertilizers do not eat crops like humans and livestock do. Fossil energy is an external source whose use, in terms of production, is only beneficial. Removing this energy from the ratio increases its input/output ratio to about 1:160, which more accurately reflects the great increases in yield that the Green Revolution is characterized by.

A discussion of energy cannot be complete without acknowledging the external costs of its use. Fossil fuel burning has been a major contributor to the accumulation of Greenhouse Gases in the atmosphere, causing the drastic effects of changing the planet's climate (Corti, 800). This is not the only externality of fossil fuel use in agriculture. The rest of this chapter describes how synthetic fertilizers, whose production requires fossil energy, and petroleum-based pesticides affect farming systems and their surrounding environments. These extra costs, in addition to those of global warming, make using fossil fuels in agriculture an inexcusable decision.

There Is No Way To Increase Rainfall - Realizing Biophysical Limits

The most obvious example of living by uninformed economics is one that drives the world's food supply: the belief that we can continually alter agricultural ecosystems in beneficial ways for the long term by adding chemical fertilizers and pest control. One cannot efficiently use resources if one does not understand all limitations of its resources, as is the case here. By using chemical fertilizers and machine ultra-tillers, industrial farmers are destroying their soil even though they are convinced that they are breathing life into it. What they fail to realize is that soil is not a commodity like a bag of fertilizer, it is a living thing; it is a vast network of microbial communities that are able to break down organic and inorganic matter into nutrients that are then transferred to the plants living among them. If nurtured properly, these communities can yield amazing crops for us to eat, but when we poison their inhabitants and destroy their cities, we lose this powerful support structure. While the technology can temporarily sustain crop yields despite the soil being ravaged, this process will begin to fail as fertile topsoil is eroded and the fossil fuels that create these chemicals become more expensive. We begin with an analysis of fertilizer.

Fertilizer

The idea of adding mineral ions to soil to increase crop yields came in the middle of the 19th century when Justus von Liebig, a German chemist, postulated the

Law of the Minimum. He noted that plants require a specific proportion of required nutrients in order to mature. Therefore, growth was dependent on the limiting nutrient, the mineral that plants needed in greater quantities to grow more (Vandermeer, 118). Liebig pointed out that capitalism's will to incessantly increase production rates would inevitably cause there always to be a limiting resource; there is never enough of all factors to increase production indefinitely (Vandermeer, 148). Thus an industry was formed around producing mixes of the most important mineral ions: nitrogen, phosphorus, and potassium, abbreviated NPK on most fertilizer products.

The history of nitrogen production aptly enlightens the connections between chemicals and agriculture. Originally, nitrogen was extracted from guano, which is bird dung that has accumulated on tropical islands. However, the chemical industry soon developed techniques to synthesize ammonia directly through the Haber-Bosch process. L.F. Haber, the son of the chemist, has commented that, "[Haber-Bosch] cemented the relationship between chemicals and agriculture" (Vandermeer, 151).

Unlike phosphorus and potassium, nitrogen does not naturally occur in mineral form and it cannot be mined. Instead, nitrogen is farmed from the air, where it is the most prevalent gas. To do this is energy intensive; fixing nitrogen to hydrogen to produce ammonia is only possible at high temperatures and pressures. The Haber-Bosch process heats up the apparatus to about 600 degrees Fahrenheit and exerts about 300 atmospheres of pressure on it (Fisher and Fisher, 2001). With the help of an obscure metal catalyst called uranium and the engineer Bosch, Haber was able to scale his production systems to become commercially lucrative. It is still used today.

There are many issues with inputting fertilizer into agricultural systems. For one, the notion of a farm being an ecosystem is lost if natural cycles are not respected. Liebig was wary of the system that his *Law* may form (Vandermeer, 120). By providing the minerals necessary for growth artificially, there is less need to return to the land the waste products of eating the biomass; instead of adding nutrients to the ground by completing the cycle, humans have grown fond of polluting waterways with their excrement (Pfeiffer, 69). Cyclical processes are intrinsically efficient because they promote a return of reusable material. However, perceptions of sanitation and corporative systems have created a linear system for farmed nutrients, which begins with fertilizers and ends with polluting the oceans.

Water pollution is a major issue with fertilizer use. During the awakening of environmental awareness in the 1960s, fertilizer industries began to be scrutinized because of their use of toxic ions. One study found that 73% of drinking wells in the United States contained nitrate at levels above the safe level. Unfortunately, due to the nature of nitrates, this figure will only get worse. This compound slowly seeps through the soil, so even if fertilizer use were to end now, nitrate would continue to contaminate deeper aquifers (Vandermeer 151).

In regards to efficiency, it is important to understand the systems that fertilizer hopes to enhance. Soil-mineral cycles are complicated, involving complex interactions between biological and chemical factors. There is still a lot to know about how these processes work. To grow to maturity, plants need all three of the limiting resources that Liebig discussed, nitrogen, phosphorous, and potassium, and so if one mineral is missing, fertilizer can help replenish that stock. When Liebig announced

his findings, knowledge of nutrient cycles was limited. Pictured in Figure 1 is the basic understanding that drove the inception of fertilizer use in agriculture. Under this model it makes sense to add these macronutrients directly to the soil because the obvious result is more food to harvest. However, by examining the natural

Figure 1: A simple model of soil nutrient cycles (Vandermeer, 150).

cycles of these nutrients in the soil under the best models we have today, it becomes evident that adding extra amounts of them can have undesirable consequences. These nutrients may help the plants grow in the short term, but the land is not ready to accept such high concentrations of these key elements in its natural cycles. In order to increase soil fertility, we must also be proficient in soil management. Figure 2 shows some of the many possible paths that these nutrients could take. Natural processes strive for a balance in order to promote their own longevity. Although nutrient cycles are not completely understood, the scientific consensus is that the brute force approach of adding inorganic mineral ions disrupts desired equilibria, necessitating the application of increasingly more fertilizer as soil systems become dependent upon them (Vandermeer, 150). Evidence of this is found in nutrient run-off and erosion; a horrific case being the Dust Bowl of the 1930s in the American Midwest (Vandermeer, 319).

Figure 2: A more accurate model of soil nutrient cycles (Vandermeer, 150).

Pesticides

In agriculture, pests are the unwanted. The definition of a weed depends not on species names, but location. For example, in many areas, especially agricultural plots, grasses are considered annoying; they suck nutrients and water from the soil that would otherwise be used by crops more desired by the plot's human caretakers, but yet they are featured in the vast majority of lawns across the country. Gardeners and farmers of the world are the labelers of pests, but they are also the ones whose cultivation of the land is desirable to these insects and plants; they follow the fertile land and the fruits it bears. Recently, pest control strategies have become primarily chemical-based; pesticides are sprayed on fields each harvesting season to protect the crops. Some, like Borlaug and the agricorporation Monsanto, argue that these chemicals are necessary to achieve the great yields that our world depends on. During the scrutiny of DDT, a now banned pesticide in the United States, caused by public reaction to the work of Rachel Carson and other biologists on its effects on animal and human populations, Borlaug warned against the claims of environmentalists. He claimed that harvests would be greatly diminished without pesticides and that this wave of activism could cause other chemical bans on agricultural products, "even fertilizer" (*Nature*, 1971).

Pesticides are used globally in agriculture despite their environmental and social costs. Here it is sufficient to show the inefficiency of using pesticides in regards to agricultural profits, but if the social costs of health care and contaminated water were factored in, the solution would be even clearer. For more information on the social costs of petroleum-based pesticides, Carson (1962) and Pimentel and Pimentel

(2011) are great scientific sources, but briefly take note that the average American has at least 13 types of pesticides in their body, and these are usually at levels way above what has been designated as a safe amount (Pfeiffer, 23). Also, pesticides that are banned in the United States are used in countries that ship food to us, such as some tomatoes grown in Mexico.

Pesticides are widely used in the United States each planting season. About 1.2 billion pounds of more than 600 different types are applied annually at a cost of $10 billion (Pfeiffer, 22). That is about 17% of world consumption and 25% of world cost. When the recommended dosages are applied, these costs correlate to an annual loss of 37% of potential crops due to pests in the United States (Pimentel and Pimentel, 161). Again, inputting chemical substitutes for natural processes is unwise. Chemical pest control products are effective at killing insects, fungus, and weeds (Vandermeer, 222). However, their use is fundamentally naive to the natural forces at play. In the absence of pesticides, agriculture was productive for thousands of years without remarkable damage from pests. The pests' natural predators, not humans wielding chemicals, were the regulators. When pesticides are sprayed, they destroy insect, fungus, and plant without discrimination of pest or predator. And so the predators are wiped out, allowing for the more populous prey to thrive.

There have been major pest breakouts since the 1950s, like the cotton bull worm, cotton aphid, and cotton loopers, and the apple eating European red mite, oyster shell scale, rosy apple aphid, and two-spotted spider mite. As mentioned, similar results have occurred in regards to fungus that would normally keep arthropod pests at bay (Pimentel and Pimentel, 166). In addition, secondary pest populations

that are usually out-competed by primary pests are given a chance to infiltrate the field, necessitating farmers to add even more pesticides and sometimes more expensive varieties to ensure the demanded harvest (Vandermeer, 224). The additional crop loss and extra application of chemicals is estimated to cost American farmers another 500 million dollars (Pimentel and Pimentel, 167).

An enlightening case study is that of Indonesia in the 1980s. In the first half of the decade, Indonesia dramatically increased its uses of pesticides. The belief that pesticides "were a mighty weapon [able] to guard and protect the rice plants from any and all pests" led the government to subsidize their costs by 80% of the retail value (Soejitno, 14). The increased use of pesticides due to this program destroyed populations of the natural enemies of the brown plant hopper. Of course, hopper populations also declined, but as is usual in nature, prey outnumbered predator and due to a beneficial quick life cycle, the pest population exploded and destroyed 185,000 acres of rice crop (Soejitno, 12). Rice yields decreased so significantly that Indonesia was forced to import its grain and estimated a loss of $1.5 billion in rice yields within a 2-year period. Fortunately for Indonesia, Dr. I.N. Oka, a resident agricultural researcher, had previously developed a successful low-insecticide rice program specifically designed for Indonesia. He advised President Suharto to return to a treat-when-necessary' program and emphasized the importance of the natural predators of pests. In 1991, Suharto banned 57 of the 64 pesticides used in his country and reduced all pesticide subsidies to zero (Pimentel and Pimentel, 167). The outcomes of this action are that in the ten years following, pesticide use has decreased about 56% while still returning a 10% increase in rice yields (Resosudarmo,

1).

Studying Indonesia confirms that industrial agriculture misunderstands the ecosystems involved in a farm, but this case study also shows that it is possible to move past the chemical paradigm. It is not the farm's fault that pests have invaded and are feasting on our crop of apples and we should not punish them by drenching them with pesticides. Instead, we must change our cultural understanding of agriculture and begin to practice other pest controls and crop strengthening practices like crop rotations, soil and water management, fertilizer management, planting schedules that follow biorhythmic cycles, crop-plant density analysis, poly-culture and many more, which, if used could reduce US pesticide use by 50%, without any reduction in crop yields or cosmetic standards (Pimentel and Pimentel, 168).

Currently, pesticides are profitable for farmers; each dollar of application tends to return $4 in protected crops. Short-term evidence of the benefits of pesticides is easily found, for at the beginning of its application it is able to effectively wipe out a pest infestation. However, when the system of applying pesticides to increase crop yields is analyzed over time, it is seen to be losing its effect. An experiment in the 1960s created a comparison between chemical-free fields and fields on which insecticide was used. At first the insect populations on the treated plots were about half of the other plots. However, after a week, the treated plots were not only infested, but had four times the pests as the insecticide-free plots. As subsequent treatments continued, the gap decreased, but did not disappear, seemingly negating the effects of the application of the chemicals (Vandermeer, 223). Since 1945, pesticide application has increased more than 10-fold, and yet losses from insect damage have still doubled

from 7% to 13% of potential total crop (Pimentel and Pimentel, 161). The failure to hold back insect populations mostly comes from pesticide resistance.

The extensive use of pesticides and herbicides has resulted in the evolution of resistant strains of insects, plant pathogens, and weeds. Resistance to a chemical originates in the survivors of its application. It is unlikely that a pesticide designed to remove pests but not harm crops would be able to kill all insects in the target area. Inevitably some will be protected from physical cover of plants or soil and survive, but even more problematic is that some pests will have developed a mutation that happens to make them unsusceptible to the poison. The latter category of survivors will reproduce and soon repopulate the field with insects that are no longer harmed by the chemical. The natural response for a farmer therefore is to switch pesticides; the mechanism of the next chemical may provide better results. However, the process of resistance will always continue to diminish the returns of pesticide application as each subsequent chemical will promote a new immunity in pest populations (Pimentel and Pimentel, 168). Figure 3 shows the evolution of pesticide use in the past 70 years and how it has correlated with increased resistance in the pests that were supposed to be removed.

Figure 3: Graph of pesticide applications since 1940 and the total number of pesticide-resistant insects. The dates in each box are when resistance was first documented and the line shows the growth of resistance over time (Wilshire, 52).

In monocultures, plots that focus on growing only one crop, the results are even worse. A monoculture may allow for a high yield of one crop, but it also

leaves space between crop rows. This empty space is inviting to weeds that are attracted to the land's fertilizer. Since weeds are being brought forth, the farmer must invest their labor or capital in either weeding or buying herbicide (Rossett, 5). The characteristics of monoculture also attract insects. For example since switching from crop rotations, corn monoculture losses have increased from about 3.5% to about 12% despite an increase of insecticide use by more than 1000 times its original amount (Pimentel and Pimentel, 161).

Other farming communities do not recognize insect populations as pests and certainly do not wage chemical warfare on them. In the 1990s Helda Morales, a Guatemalan entomologist, asked Mayan farmers about their pest problems. Surprisingly, they replied that they do not have pest problems. Yet when questioned about what insects they have, farmers provided a long list, including the characteristic maize and bean pests. Pushing further, Morales discovered that they did not see these insects as pests, but as other members of the ecosystem in which their farms existed. Of course the crop loss due to them was not desirable, but this was relatively small due to agroecosystem management such as promoting the pests' natural enemies (Vandermeer, 19).

After this experience, Morales developed a new outlook on pest management. Instead of focusing on how to eliminate pests, she researched why pest infestations occur; she switched from agronomy, the science of soil management and crop production, to agroecology, the study of the ecosystem in which agriculture exists. The distinction here is much like the argument for preventative practices instead of curative medicine. By creating a system that does not require external inputs, one

that fosters the biological pest controls already in place, resources can be saved. Rethinking the basic philosophies that have created systems that crave fertilizer and pesticide inputs is an important step in moving away from these inefficient practices.

Marginalization of Farmers

We have focused mostly on the biological factors that control the efficiency of agricultural systems. While farming practices may differ drastically from plot to plot, soil fertility and pests' ability to destroy a crop are characteristic of all agriculture, whether it is a large monoculture operation in Iowa, a family providing for itself, or a small scale farmer selling their goods in market (Vandermeer, 312 - 313). The efficiency analysis of this chapter focuses on these ecological consistencies. However, it is necessary to also discuss the social consequences of land use; agriculture is growing food for humans and therefore intrinsically tied to social and economic issues.

During the Industrial Revolution at the end of the 19th Century, capitalist entrepreneurs attempted to scale industries like textile and other goods production by using factories. Since farmers could not be placed under one giant roof, agriculture was difficult to factory-ize. The solutions for these capital-seekers were to appropriate farming's inputs and substitute its outputs (Vandermeer, 314). We have already discussed these two strategies, but not yet in this way. Industrial corporations created artificial fertilizer and began to sell it to farmers. Since the farms that adopted this practice were more productive, soon, to keep up with their neighbors,

all farmers used fertilizer in their fields. Thus corporations appropriated soil fertility and their product became necessary for agriculture in the United States. The story of mechanized tractors and pesticides is analogous.

In Chapter 1 I discussed how corporations took control of the end product of agriculture. When people moved away from their food sources, distribution companies became the main consumers of farmed produce. These dealers therefore had the power to choose how to sell their products. As discussed, they used natural advertising techniques to alter the definition of edibles. At first the goal of canning and selling processed goods like bread instead of the raw wheat was better preservation during the trip from farm to mouth. However, even today with advanced refrigeration and other techniques for keeping produce fresh, the majority of food consumed is processed. Typical consumers do not buy produce from industrial farmers; the sticker labels on fruit and vegetables tell us which corporation distributed the food to the store that we purchase it from. Buying food from its producers, the farmers, has become a rare sight mostly saved for those who can afford farmer's market wares, and due to government subsidies of corn and soy production, a large portion of a poorer consumer's diet is comprised of processed food instead of the healthier ingredients.

Farmers too have been marginalized. They have been forced to buy petroleum products from monopolized sellers, who raise prices artificially, to grow large quantities of a single, genetically modified crop that is inedible by their family and sell it to a monopsony that buys artificially low (Vandermeer, 314). Since giant corporations are the buyers of produce, farmers have no say in what happens to their product

after they sell it or even in how it is grown. In addition, corporations only desire a few select crops, and within these, only a few varieties. Thus, the choice of crop has been taken from the farmer. The techniques described in this chapter are in practice because of the control that profit-maximizing capitalists have over food production; like corporations, industrial methods focus on short-term increases in profit. Corporate domination over food production is failing to provide the world with food, despite producing enough, and continues to use inefficient practices that will fail in the long term. The solutions in the next chapter aim to solve both of these issues by bringing food production back to the communities it supports and by giving agency to farmers. Most importantly, this chapter shows examples of systems other than the industrial farm performing equally as well with less environmental and social degradation. That alternatives exist is vital to this movement.

Chapter 3

The Alternatives

"To be worried about making money, expanding, developing, growing cash crops and shipping them out is not the way of the farmer. To be here, caring for a small field, in full possession of the freedom and plenitude of each day every day - this must have been the original way of agriculture."
- Masanobu Fukuoka[1]

Sustainability

Solutions to the agricultural crisis revolve around acting sustainably. Unfortunately the word sustainable' has become a buzz word in advertising and has lost some of its meaning. Labels usually fall into the dichotomy of sustainable' or unsustainable,' each of which without context has little meaning. Yet many products and processes are defined in this way. Sustainability is a spectrum, not a dichotomy. Actions can be less sustainable than others, but there are none that bound the interval of worst to best. In the context of this thesis sustainability is easily defined, it is the antithesis of uninformed economics as described in Chapter 2, complete economics;

[1](Fukuoka, 112)

to act sustainably is to act as efficiently as possible for a long period of time. Like we saw with the diminishing returns of chemical farming, for longevity to be feasible, knowledge of all factors leading to production is paramount.

A key input of sustainability calculations that must be taken into account, and one that is often forgotten, is the human gain from the action (De Koeijer et al., 2). Considering human utility gain from an action transforms the spectrum of unsustainable to sustainable to be from profit maximization to environmental preservation; the interval is now defined as a function of how efficiently benefit is derived from resources and how well the use of these resources avoids their degradation. To not enter the contradiction of removing humanity from the environment, this concept is best thought of as planning a new action. Again, in the apple orchard example, we had the spectrum of choices from not expanding to the surrounding area to using some of its resources to using all of its resources. If this development were necessary for human survival, then somewhere in that spectrum would be an optimal decision.

Figure 4 graphically describes this understanding of sustainability by plotting these two concepts, profit efficiency and environmental efficiency, on the vertical and horizontal axes respectively. The main assumption here is that the more profit we derive from the land, the less we are able to take care of it. For the most part this is true, but, as we will see later, natural farming does not seem to fall within this constraint. The boundary arc on the graph, called the sustainability frontier, indicates the maximum profit and environmental preservation an action can achieve under this assumption. Therefore the point within the frontier could theoretically better allocate its resources to either gain more profit from the same level of environ-

mental degradation or keep its profit level constant while better managing the land. The two ends of the spectrum are the intersections of the frontier with the vertical and horizontal axes; if one maximizes profit completely, all resources are used and no environmental longevity is taken into account and vice versa. The sustainability frontier is a great tool that will be used in conjunction with the efficiency analysis from this chapter to analyze potential agricultural progress.

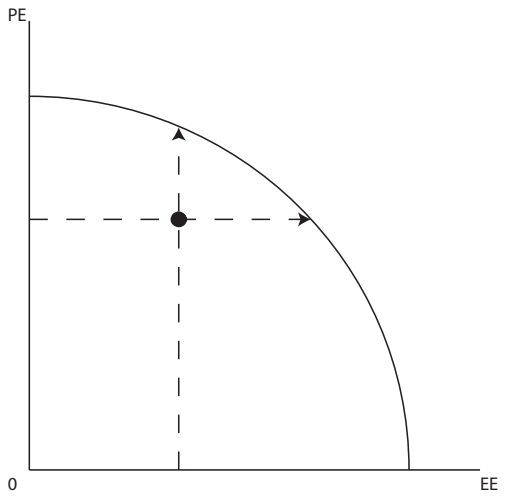

Figure 4: Graph of Environmental Efficiency verus Profit Efficiency. See text for explanation. Adapted from (De Koeijer et al., 2002).

The Productivity of Organic Farming

From the analysis of industrial agriculture, it is easy to see that we can no longer sustain industrial farming. The point on the sustainability graph above may represent this system; in Chapter 2 we discussed how industrial farmers could easily decrease their chemical inputs and simultaneously be more profitable and environ-

mentally conscious. A clear step away from industrial agriculture is to disallow all chemical inputs, what we call "organic". There are many myths surrounding organic farming. The most pervasive is perhaps that it cannot achieve the same yields as its industrial counterparts. Chemical proponents do a great job of popularizing this fallacy, but in reality many studies have found that there is no discrepancy between organic and industrial yields. In fact one study about these studies concluded that from 2000 to 2008 there had been 98 papers published on whether or not organic agriculture was a viable way to feed the world and that these researchers unanimously agreed that it was (Hewlett & Melchett, 2008).

One impressive investigation due to its length and scope is still being carried out in Kutztown, Pennsylvania at the Rodale Institute. Beginning in 1980, researchers there have explicitly examined the myths surrounding organic and industrial agriculture. They do this by growing three plots of land, each with its own distinct farming technique. One of the experiments is a livestock operation so we ignore that one for the sake of this paper. The second plot represents a typical cash-grain industrial farming unit, which used a 5-year crop rotation of corn, corn, soybeans, corn, and soybeans to mimic commercial conventional operations in the region and throughout the Midwest. To accurately simulate this method, standard amounts of fertilizer and pesticides are used and no cover crop is planted for the off-season months. The third plot uses no agricultural chemicals and is a certified organic cash-grain operation. Its purposes are the same as the conventional plot, but in this one no synthetic fertilizers or pesticides are used. It instead used nitrogen-fixing cover crops like the hairy vetch as a nutrient source (Pimentel et al., 2005).

From 1981 to 2002 the researchers recorded each farm's yields in addition to its soil composition, plant vigor, and the amount of labor and energy they needed to put into the system. For the first five years of the study the industrial plot was significantly more productive than the organic plot. Yields for organic corn were recorded to be 4743 kg per hectare while the industrial plots averaged 5903 kg per hectare (Pimentel et al., 2005). In percentages, these numbers point to organic agriculture as being 80% as productive as the industrial analogue. The researchers deem this period as a transition period, the time where the crops and soil microorganisms worked to fertilize the soil. Successful plants change the soil underneath them to suit their needs best; microorganisms are attracted and nutrients are fixed. After the transition period each plot had similar yields. Now corn yields were respectively 6368 and 6553 kg per hectare for the organic and industrial plots (Pimentel et al., 2005). The organic system is now operating at 97% of the capacity of industrial farming. The missing three percent is equivalent to 185 kg of food. Although this study is robust, it is important to note that these results are not unique and can be found from other reputable researchers as well (Vandermeer 322).

The rise in relative productivity for both plots at Rodale is evidence that as plants adapt to a location, they are able to produce more, but the organic system's higher rise in productivity may suggest that it is effectively supporting soil vitalization. However, agricultural success can vary significantly based on locale and so to trust these results as leading to a global solution, they must be reproducible worldwide.

Catherine Badgley et al. sought to answer the question, "Can organic farming

feed the world?" (Easton, 276) To do this they looked at percentages similar to the ones I calculated above comparing the yields of organic farming to industrial. These yield ratios were calculated separately for developed and developing nations and then applied to global agriculture yields. First note that current food systems generate about 2786 kcal for each person every day and that a healthy adult needs between 2200 and 2500 kcal a day. The study looked at production in many food categories: milk, citrus, vegetable oils, meat, etc. In developed countries, the productivity of organic agriculture for all the food groups analyzed of the 160 sample farms averaged to be 92% as productive as industrial agriculture. The average productivity of the 133 farms sampled in developing nations was twice this figure, 180%. In calorie count, they estimate that the figure of 2786 kcal could be raised to 4381 kcal with a world-wide switch to organic methods (Badgley et al., 92). These numbers are averages, and therefore only estimates, but the significant ranges found show that organic agriculture has potential to support current, and even larger, population sizes.

The results of the Rodale Institute and this global comparison are intuitive if we look at the inputs of plant growth again. Since irrigation is the same with both methods and we cannot control sunlight, fertilizer and pesticide use is the distinction between organic and industrial. Many proponents of organic agriculture argue that there are additional benefits of adding nitrogen, phosphorus, and potassium from compost or manure that help soil microorganism colonies and prolong soil health (Vandermeer, 323). Artificial fertilizer has no such prescribed benefits. However, even if it did, there is no insight that adding inorganic fertilizer is any better than

organic. Nitrogen is nitrogen; industrial fertilizer can only be as good as organic fertilizer and never better. There are differences in soil strength as seen again at the Rodale Institute. The organic plots displayed a considerable advantage over industrial ones during drought; they generally did about 30% better (Pimentel et al., 2005). Percentages can be hard to discern, pictured in Figure 5 is organic and industrial plantings side by side during drought. These ideas were found in the organic farms of developing nations in Badgley et al.'s study: "High yields [were] obtained when farmers incorporated intensive agroecological techniques, such as crop rotation, cover cropping, agroforestry, addition of organic fertilizers, or more efficient water management" (Badgley et al., 92). They go on to say that they found specific instances when organic methods displayed higher yields than industrial methods "for the same crop in the same setting," e.g., the system of rice intensification in ten developing countries (Badgley et al., 92).

<http://www.rodaleinstitute.org/files/Rodale_Research_Paper-07_30_08.pdf>

Figure 5: Organic (left) next to industrial (right) during drought (LaSalle et al., 4).

Another difference between these two systems that must be noted is the energy they use. Although the organic plots at the Rodale Institute used 30% less fossil fuel energy than the industrial plots, they required more labor throughout the year (Pimentel et al., 2005). Organic farmers must keep track of the health of their crops throughout the year to ensure that pests do not take over and the plants are healthy so as to generate a good harvest. Industrial farmers mostly work in the spring and fall harvest and planting seasons. While more labor is needed in organic farming,

there is a significant argument that when labor is required it is spread throughout the year. This allows farmers and laborers to have a more stable job environment, which in turn supports the rural communities they live in (Badgley et al., 94). In a British study, shifting 20% of farmed land in the United Kingdom to organic techniques would create 73,200 jobs (Patel, 164). Labor in large-scale organic farms can also be reduced with the use of mechanized tractors, harvesters and seeders.

A Problem System or a System With Problems?

Despite the Green Revolution's stark increase in per capita food production in the past half-century, more than an eighth of the world's population goes hungry. Therefore it seems that the problems of industrial agriculture are signals of unsustainable activity, but not directly involved in the key issue of food allocation. A corollary of this is the awareness that although switching to a chemical-free, organic agricultural system seems to be necessary in terms of efficiency and environmental health, it is not enough to only change what is inputted into farming if we hope to feed the world. Since it is able to produce as much as industrial systems, organic agriculture, to me, could simply replace the industrial and not create food security for those who need it.

In addition, while it is admirable that agricultural chemicals would no longer be used in food production, fossil fuels would still be in use if organic agriculture were to become the new, large-scale farming paradigm. Food processing, distribution, and storage are each dependent upon energy derived from coal, oil, and natural gas. The

prices of these fuels can vary based on many economic factors and therefore so can the availability of food (Quaiattini, 2008). Furthermore, their production is tied to large corporations with questionable attributes such as fracking' and oil spills (Gasland, 2010)(Fuel, 2008). Since food is vital for life, it is common sense that its production should be as stable as possible. We can lessen our dependence on fossil fuel for producing food and help create equitable allocation of food through a movement to smaller farming systems.

Smaller is Better

A study that examined fifteen developing nations concluded with statistical significance that smaller farms did better than larger ones (Cornia, 1985). A prevalent reasoning for this is that farmers who govern over smaller plots know the land better and therefore are able to farm it more intensively; due to scale, a farmer of a smaller plot is able to give more attention to each aspect of their plot. A useful technical definition is that of land use intensity, the ratio of area with crops to total farm area (Cornia, 517). By managing fewer resources more intensively, farmers are able to make more profit per unit of output, even if production of each commodity is less (Rosset, 1999). While the specific techniques used on these farms widely vary, small organic farms generally utilize concepts such as crop rotation and soil management while tilling less, allowing them to enjoy the benefits of the natural services of the biotic community (Pfeiffer, 68). Ecological services help reduce loss from weeds, insects, and diseases while also managing water and nutrients more effectively (LaSalle et al., 5). These findings have been duplicated in developed countries as well. In

1999, Peter Rossett noted that smaller farms are "more productive, more efficient, and contribute more to economic development" in both "Southern and Northern Countries" (Rossett, 1).

These results are displayed graphically in Figure 6, which shows the accumulation of the data for the two major trends of farming scale collected in Cornia (1985). Type I farms have been described above; as farm size decreases, productivity per acre increases. However, this algorithm does not take into account variable economic situations from different sizes of farm. In a country that has agricultural technology available for farmers to buy, most likely this technology will increase their productivity. Therefore, since these items cost money, the smallest scale farmer may not be able to purchase them. Even though smaller farms are more productive and profitable per unit area, the total revenue they generate may not be enough to justify an expansion in machinery (Rossett, 9). Thus, these technologies may only be feasible to mid-size farms and larger, allowing them to increase their outputs (Cornia, 526). Large farms are still less productive than these mid-range operations because of soil management issues (Chapter 2).

<http://www.foodfirst.org/files/pb4.pdf>

Figure 6: Graph of farm productivity as a function of size from 25 countries. Types I and II represent distinct trends in the data based on soil conditions and available technology (Rossett, 9).

Much like Cornia, Rossett attributes these gains to small-scale farmers' understanding of the ecosystem they work with, noting that small-scale processes have kept some family farms afloat in the United States despite the government subsidiz-

<http://www.foodfirst.org/files/pb4.pdf>

Figure 7: Farm output in USD as a function of farm size. Data is from (Rossett, 7).

ing large-scale industrial farms (Rossett, 10). Evidence of this is seen in Figure 7, which plots farm output per acre in dollars versus the farm's size. The downward arc of this information, taken from the 1992 USDA Agricultural Census, shows the United States as a Type I country (Rossett, 7). This relation shows that farmers can be more profitable per acre by changing the scope of their labor; the yield increase due switching from monoculture to polyculture is found to range from 20% to 60% (Altieri, 7).

Small farms in the US are actually found to be relatively less intensely farmed compared to other nations, especially those of the developing world (Rossett, 7). This seems to be because small farms in the United States are not as involved in national food production as in other countries. For instance in Latin America 35% percent of the land used in agriculture is comprised of peasant productions averaging 4.4 acres. For comparison, the average farm size in the United States is 418 acres (USDA, 2007). Small farms in Latin America produce half of the maize and more than two-thirds of the beans and potatoes produced for domestic consumption (Altieri, 5). Therefore a scaled down food production system has the ability to provide large amounts of food for nations. In a world where fossil fuel may become scarce, or climate change prevalent, small-scale organic farming can help because it uses less fossil fuel energy due to the reduction of machinery, fertilizers made through the Haber-Bosch process,

and petroleum-based pesticides. Soil conscious farming has also been estimated to be able to sequester almost 40% of atmospheric carbon (LaSalle et al., 2).

Finally, small-scale farming has great implications for the social structures that allocate food. Large industrial farms degrade the soil's organic matter, while regenerative farming practices, such as small-scale organic agriculture, build it (LaSalle et al., 2). Thus, instead of needing to buy and ship fertilizer to a farm, it can produce its own soil fertility and since food can be produced in the community, the need for food transportation is negated. Together these allow for the success of community-based food production systems.

Localized Food Systems

When I started this project, I never believed that I would end it by arguing for a more localized food system. However, after analyzing farming practices and scale, this system seems to be the most sensible. As we have seen, smaller organic farms are more productive than larger industrial ones and are able to not only sidestep fossil fuel use, but also ameliorate the effects of atmospheric carbon. Having these farms close to the communities would reduce even more energy use and carbon emissions. For example, a 10% increase in food purchased locally could decrease state carbon emissions by over 3,500 tons per year in Iowa and if the Japanese began to eat local food, the energy savings might be as much as the equivalent to a 20 percent savings per household (Patel, 165).

In addition to being rational on a climate change argument, there are economic

advantages to localized food. Since Amish communities are dependent upon sustaining themselves off of what they produce, they are a great example of community-based agriculture. One study that focused on the second half of the 19th century found that when compared to their non-Amish neighbors, the Amish were less productive at farming (Coşgel, 4). One hypothesis of the Coşgel's is that the Amish's renunciation, in contrast to their neighbors' use, of machinery lessened their potential for high yields. However, the 'tractor factor' seems not to be as crucial as the longevity of their religion.

The Amish are a devoted group of religious people who want their practices to continue on to the next generation. For this life to be viable for their children and their families, healthy land must be available to bequest (Coşgel, 10). Therefore, to reduce the risk of diminishing soil returns, the Amish consciously grew less (Coşgel, 11). Another important factor of their productivity was the crops the Amish chose to grow. Because they were providing for their family and their community, Amish farmers focused on growing a diverse selection of crops to supply the necessary variety of nutrients (Coşgel, 6). This is unlike farmers who grow a few select cash crops, which are mostly grains, because these are the easiest to sell. In the time analyzed by this study, all farming that occurred would be considered organic by modern standards. The success of small-scale farming again arises when we look at contemporary Amish communities. For example, Lancaster County in Pennsylvania, a largely Amish community, is the most productive of any farm county East of the Mississippi River (Rossett 10-11).

Most importantly, local food production puts the community's livelihood in

its backyard. If the status quo of agriculture and energy consumption continues until fossil fuel energy becomes more limited, the decline in available energy could have drastic effects on food supplies. In short, "food security is a matter of homeland security" (Pfeiffer, 67-68). Local food can provide this by building an agricultural ecosystem for humans to inhabit. Ecosystems like to form cycles of nutrients (Chapter 2). By shipping chemical fertilizer and pesticide to a farm, the food produced is dependent upon external production facilities. When the labor required lives on or near the farm, and the nutrients and seeds are byproducts of harvest, a farm can sustain itself indefinitely, even in the face of natural forces; there are many examples of agricultural societies who fit this model and have existed for more than four thousand years in South America, Africa, Southeast Asia, and Mesoamerica (Altieri, 8). A key component of these systems is that their longevity as a whole is a main goal. This is also seen in the Amish; their market structure is integrated and cooperative instead of fragmented and competitive, again due to their need for Amish traditions to survive (Ludwig and Anderson, 35). Across the United States, where family farms are healthy, there are "more local businesses, paved streets and sidewalks, schools, parks, churches, clubs, newspapers, better services, higher employment, and more civic participation" (Rossett, 10). The Food and Agriculture Organization of the United Nations (UNFAO) proclaims, "Sustainable agriculture and land use is not just a means to obtain more food and income, in socially acceptable ways which do not degrade the environment. Rather, it has an all-encompassing impact on communities, environments, and consumers" (FAO, 1998). Healthy communities correlate with healthy food supplies. Finally, if we think of the price of food representing all

of its costs, the production of a fresh, local meal is relatively cheap because little to no processing is necessary and the externalities have been reduced (Berry, 221). A switch to the local model would be drastic from our current, energy-rich infrastructure, but in lieu of a climate crisis due to the expanded prevalence of atmospheric carbon, it may be necessary.

Conclusion

"In nature there are neither rewards
nor punishments; there are consequences."
- Robert Green Ingersoll

I hope that this paper has been didactic and inspirational. We have seen the back-story to our modern predicament, critiques of our current food system, and the potential of small, organic, local institutions to provide enough sustenance while avoiding the use of fossil fuel as an energy source. The issue of food production and allocation is often overwhelming, and the broad implications of the changes necessary would upset many intact systems. Therefore this thesis would be incomplete without also explaining the possibilities for immediate action.

I sincerely believe that as people become more aware of the toxins that our production systems are putting in the air, water, land and even the food itself that the necessary changes for a more sustainable future will begin to be made. I urge you to tell someone, or everyone, for whom you care about what you learned in this paper. Inefficiency and injustice characterize the system that provides food for us, and with some simple changes, much could be ameliorated. As support for sustainable food production grows, governments and corporations will begin to change their policies.

In Chapter 2, ecosystem cycles were discussed in terms of nutrient cycles. In industrial agriculture, because nutrients from the biomass grown on the land is not returned to it, external fertilizer application is necessary to grow crops (Chapter 2). An easy way for governments to allow for the nutrients produced on these farms to be returned to the land they come from is to create city composting programs that can handle a variety of types of organic matter. "Every truck bringing a load of produce to town should go home with a load of compost" (Berry, 221). Programs like this could improve health of the rivers and fields surrounding a dense settlement while simultaneously lowering the cost of food due to taking advantage of this unused fertilizer. The concept of using human waste as manure, or *humanure*, is well developed (Jenkins, 1999).

While the size of governments and corporations gives them the ability to enact widespread change, it also creates bureaucracy that slows down their ability to act. Climate change and starvation are upon our species, and so we cannot wait for policy changes to be tweaked and debated on in congress. Begin to grow food, get friends together to start a community garden and learn of the delicious wonders of a freshly picked tomato or pepper. Community gardens can begin to dissociate food from industrial agriculture while teaching the valuable skills involved in growing crops. On a larger scale, to support local food production, one can shop at farmer's markets or participate in a Community Supported Agriculture (CSA) program in which a buyer links up with a farmer to receive fresh produce weekly or biweekly. Food waste from restaurants and supermarkets is also an important issue to tackle. Food Not Bombs is an organization that collects edible food that has been deemed

dirty or old, e.g. food in a dumpster, and gives it out to those who most need it. These actions are important in moving forward, but for this movement to succeed, we must also reevaluate our notions of health and regain knowledge of the impact of our actions. How is it that we act, and how are our actions affecting the world? As we have seen, small acts can have large consequences in our current system. Buying food that was grown on an industrial farm supports the pollution of the planet and the marginalization of the workers that grew it. By minimizing these impacts we can create more physical and mental health for each other and environmental strength for the world. Whether with scientific or spiritual reasoning, our relationship with nature must be adapted so that when we speak of health and of longevity, we are of course speaking of the wellness of all and not of just a few.

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