Sustainable and Diversified Agriculture – Not Optional but Absolutely Necessary

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A Global Food Crisis

According to current trends, experts predict that over nine billion people will inhabit our planet by the year 2050. The question naturally arises: how do we go about feeding nine billion people?

In many developed countries, food accounts for about 10 to 12% of the household budget. In Egypt food costs have already risen to more than 40% of the household budget. In India we see even bleaker statistics: over 40% of the children under the age of three are undernourished and underweight. In Spain, hit hard by austerity measures, many people regularly forage through garbage bins in search of their next meal.

Looking back over the last five years, we cannot help but conclude that we are in the midst of a global food crisis, and this crisis, according to the investment banker, Jeremy Grantham, is not going away any time soon.

Global grain prices have almost tripled within the last 10 years. During the summer of 2012, the price of corn, wheat and soy rallied 30 to 50%, despite heavily increased planting since 2008. If grain prices were to double within the next 20 years, hundreds of millions of people world-wide would starve.

Water is a finite resource, and it's getting scarce. About 300 million people in China and India are dependent on aquifers that will soon dry up. The Ogallala aquifer, considered the bread basket of America, covers parts of eight states and is predicted to dry up in as little as 25 years. Aquifers under Beijing, Delhi, Bangkok and many other major cities are drying up. Major rivers such as the Ganges, Jordon, Nile and Yangtze, at certain times of the year, are reduced to a mere trickle. Without water, vast areas of farmland throughout our planet will produce little or nothing at all.

Phosphorous too is a finite resource, and as much as 70% of all high-quality phosphorous lies in the hands of one country: Morocco. In a few decades from now, this hold on phosphorous could be, as Grantham explains, "the most important quasi-monopoly in the history of man!" Apatite reserves are becoming increasingly contaminated with pollutants such as cadmium. In as little as 25 years, many of these reserves will no longer be economically exploitable. Some predict that massive world-wide starvation will follow.

Pesticides, herbicides, chemical fertilizers, tillage and erosion are destroying the fertility of soils. Since 1997 about 8.3 million hectares of arable land in China has been lost to development and a variety of other causes. Each year about 75 billion tons of soil - the equivalent of nearly 10 million hectares of arable land - are being lost globally to erosion, water-logging and salination. Another 20 million hectares are being abandoned each year due to degradation of soil quality (see Soil Erosion Threatens to Leave Earth Hungry). At this rate, there will soon be a catastrophic shortage of arable land.

In 2010 we experienced global weather patterns of heat, cold, drought and flooding that take place once every 150 years. In 2011 we experienced global weather patterns that take place once every 50 years. In 2012 we saw weather patterns that come along once every 20 years. When we see three extreme years like this back-to-back, we know that our entire weather modeling system has unraveled. The only explanation for such off-the-chart weather patterns is global warming. Be sure and read this excellent article in the New York Times: Heat, Flood or Icy Cold, Extreme Weather Rages Worldwide.

Northern ice is melting far faster than anyone could have predicted. It's already at levels forecast for the year 2050. As ice melts, less heat is reflected into space, greatly increasing the rate at which ice melts. As heat rises, tundra melts, releasing large amounts of methane – a greenhouse gas 21 times more damaging to the environment than carbon dioxide. Two run-way cycles of warming spell big trouble for grain production. Rising temperatures in the next few decades are projected to reduce the productivity of grain in traditional areas by 20 to 40%.

More and more people in developing countries demand greater quantities of meat in their diets. But producing meat is not terribly efficient. In industrialized countries, for example, it takes 7 kg's of grain to produce one kg of dressed beef. But how to produce more grain when top-producers of wheat in Europe as well as top-producers of rice in Asia have failed in the last ten years to increase productivity?

We've got over 1.5 billion cows on our planet (about one cow for every five people), and they emit a lot of nasty methane. The livestock sector accounts for a significant amount human-induced methane, and it also generates a lot of human-related nitrous oxide, a really bad greenhouse gas. Livestock make use of a large portion of our planet's land surface. This includes pasture land as well as arable land needed to produce feed for livestock.

There are a few simple things that we might do. We might eat less meat, especially beef. We might stop wasting food (one third of food produced globally is wasted). And the United States should immediately stop making ethanol from corn (see Food and Energy Production from Biomass). The ethanol industry in the USA consumes 40% of its production of corn, and through substitution, this practice raises the price of most other grains. One gas tank of ethanol can displace enough calories to feed one poor person in India for an entire year. Fertilizer run-off from the cultivation of corn is a major contributor to the formation of the dead zone in the Gulf of Mexico.

Waste Transformation and Reintegration

Limiting population growth is imperative. But this alone is not enough. We must also look for solutions that address core issues relating to sustainability.

Therefore, the key to the sustainable production of food lies in the transformation of all of the waste surrounding the production, preparation and consumption of food – rigorously coupled to the return of all transformed products back to agriculture (in the broad sense). Put in the simplest of terms: *if it comes from agriculture, it has to go back to agriculture*.

I would like to highlight four types of waste along with a few simple methods (among many) of transforming them into valuable products:

	Types of Waste	Methods of Transformation	Products
1.	high nutrient content	pasteurization, drying, cooking, fermentation	feed
2.	medium nutrient content	black soldier fly and red worm bioconversion	feed/fertilizer
3.	low nutrient content	thermophilic and mesophilic bioconversion	fertilizer/soil amend...
4.	little nutrient content	gasification	fuel/soil amend…

The types of waste are listed in descending order of nutrient content. Types 1 and 2 are putrescent, and type 3 and 4 are non-putrescent.

Remember, one third of food produced globally is wasted. A large portion of this waste can be processed as type 1 waste. Here we might also situate slaughterhouse waste, shrimp waste, fish by-products, fish mortalities as wells as a lot of fruit and vegetable waste coming from farms, markets, supermarkets, packing houses and food preparation facilities. The idea here is quite simple: if waste has a high nutrient content, try to preserve it as feed.

A lot of type 1 waste could be pasteurized, blanched, cooked or dried, but it often turns bad before it can be processed in these intensive ways. Also cooking and pasteurization demand fuel, and why waste fuel, if there is a simple way to avoid its use? This brings us to an ancient way of preserving nutrients: lactic acid fermentation.

Lactic Acid Fermentation

Here lactic acid bacteria consume water-soluble carbohydrates and produce lactic acid. As the pH drops below 4.2, microorganisms that could degrade the waste, as well as a long list of pathogens, are killed. With the addition, often times, of no more than 5% molasses by weight, nutrients can be preserved for an indefinite period of time.

On the simplest of levels, a plastic sack or drum is all that is needed for both processing and storage. Both sack and drum cost very little. They can be used over and over again. Lactic acid fermentation works on a large variety of waste materials. Food waste can be fermented - even shrimp shells, crawfish shells, crab shells and dead fish. In this process proteins are not denatured, as when heat or chemicals are applied. Fermentation might require a bit of chopping, mixing and blending, but it is no more complicated in principle than the fermentation of vegetables for human consumption. Once the recipe is known for a particular type of waste, almost anyone could become an expert in fermenting it. As a monogastric, omnivore and scavenger, the pig excels as a recipient of the feed produced at this first level.

Organic acids, such as lactic acid, reduce gut pH, they increase the palatability of the feed substrate, they increase nutrient digestibility, they improve protein retention and mineral absorption, they regulate the balance of microbial populations within the gut, they control intestinal microbial growth, they stimulate the secretion of digestive enzymes, they improve growth performance, they prevent disease by inhibiting the proliferation of pathogenic bacteria, and they reduce animal mortality. They do all of these things to such a remarkable degree that they are now being promoted as alternatives to antibiotics (see The Use of Organic Acids in Monogastric Animals).

But rather than add organic acids to the diets of monogastrics as external inputs, the farmer can produce them via the fermentation of waste materials. Almost all of the diet of the pig, for example, might consist of fermented waste products.

Larvae and Worms

Type 2 waste consists of fresh putrescent waste that cannot be preserved as feed and yet is still too high in nutrients to be composted as type 3 waste. Examples of type 2 waste are pig and cow feces. When this waste is subjected to the combined action of black soldier fly larvae and red worms, we see one of the most efficient nutrient extraction and conversion processes on our planet.

BSF larvae digest fresh fecal material, something that red worms cannot do, and red worms digest the more recalcitrant cellulosic materials within the fecal material, something that larvae cannot do. Together they form a perfect partnership recovering all possible nutrients. Yes, the waste is actually digested twice: first by larvae and then by red worms. Red worms grow two to three times faster on BSF residue than on many of the waste materials normally fed to them. The larvae and red worms are exceedingly nutritious and are an excellent replacement for fish meal valued at over $1,000 US/ton.

BSF larvae are some of the most voracious eaters found within the natural world. In an area of only one square meter, they can eat up to 50 kg of fresh putrescent waste per day. They can digest food waste that is far too toxic to feed to pigs or other animals. It takes them roughly two hours to die when submerged in rubbing alcohol. They can be centrifuged at 2,000 g without harming them in any way. They are tough, robust and adaptable.

BSF larvae thrive on all types of fresh fecal material. To these hungry larvae, pig feces have roughly the same nutrient value as food waste. Dr. Craig Sheppard of the University of Georgia demonstrated that 18% of the weight of fresh pig feces is transformed into fresh BSF larvae. On food waste in the USA, by contrast, the percentage of conversion fresh-to-fresh is no more than about 20%.

Larvae can be grown quite inexpensively in what is called a biopod. When properly operated, a single biopod can produce up to 10 kgs of live larvae per day (see movie). The biopods are now made from 90% recycled plastic, and the heat needed to roto-mold them is supplied using gasifier heat.

BSF larvae contain a lot of high-quality nutrients: on a dry basis, about 42% protein and 35% lipids. The big value here is in the lipids. They contain about 54% lauric acid. By contrast, the lauric acid content of coconut oil is 50%, and the lauric acid content of palm kernel oil is 48%. About 3.5% of the calories found in human breast milk is lauric acid, and it is the main antiviral and antibacterial substance found there. Lauric acid is active against lipid-coated viruses, including HIV and measles, as well as many pathogenic protozoa and fungi.

The monoglyceride of lauric acid, known as monolaurin, has profound antiviral and antibacterial activity, as explained in A Review of Monolaurin and Lauric Acid. It is not clear just how humans and animals produce monolaurin from lauric acid. This amazing mono-ester kills several types of pathogenic bacteria that are resistant to antibiotics, and yet it does not appear to have an adverse effect on gut probacteria. In sum, it effectively combats many gram positive bacteria as well as a long list of deadly viruses. Several lauric acid mono-ester formulations even prove to be effective against MRSA, swine flu and bird flu.

Perhaps the high content of lauric acid in BSF larvae explains why mortality in catfish ponds has been noted to drop dramatically when catfish were fed live larvae as a supplement to their normal feed. Dr. Hein Van Le of Vietnam, when feeding live larvae to catfish, observed a drop in mortality from 45% to 5%. Making biodiesel out of BSF lipids, as some tend to suggest, is an extremely low-grade use of valuable nutrients.

Generally the larvae and worms are far more nutritious than any of the transformed products of type 1 waste, and the residue of the red worm (vermicompost) is at least 4 times more nutritive than conventional composts (type 3 products). Also vermicompost delivers 30% to 40% higher plant yields over chemical fertilizers. This is explained quite convincingly in this excellent paper on vermicomposting. Also see this more recent article, Worms Produce Another Kind of Gold for Growers.

Ideally we should not feed type 1 waste to type 2 transformers (except, of course, when type 1 waste turns bad and toxic). Nutrients are lost at each trophic level introduced. Likewise we should not feed type 2 waste to type 3 transformers. And finally in an ideal world, we should not take type 2 waste and transform it into biogas (see A Cool Way of Raising Pigs), since type 2 products (larvae and worms) have a far greater value than biogas. If it's fuel we need, we should turn to type 4 waste, as will be explained shortly. Whenever possible, wherever possible - since we are in the midst of a global food crisis - *our overriding goal should be to maximize food production*.

Mesophilic and Thermophilic Composting

The third type of waste is presented to thermophilic or mesophilic microorganisms (mainly bacteria and fungi). Generally thermophilic composting is quicker and more efficient than mesophilic composting. But the latter is needed when the quantity of waste produced in a given area is too small to be collected and processed on a frequent or regular basis. Through mesophilic storage and reduction, the daily collection and land-filling of household waste can be entirely eliminated. In this way, all of the biodegradable waste from the farm that makes it into the household can be transformed and returned to the farm. The residue of mesophilic bins, once reduced to an appropriate grain size, serves as an excellent substrate for red worms.

The logic of waste transformation should be extended to include the whole of human waste.

On a yearly basis a human produces roughly 500 liters of urine and 50 liters of feces. These two products contain enough nutrients to grow all of the grain that this person needs as food. But instead of utilizing these 550 liters as a resource, we do something amazingly foolish: we mix it with roughly 15,000 liters of water, and all goes down the drain. This end-of-pipe solution recycles nothing. It takes valuable resources and transforms them into pollutants. As fertilizer prices rise throughout the world, and as water becomes an increasingly scarce resource, this approach is totally nonsensical.

In recycling human waste, we should not mix urine with feces. Within the human body these two wastes are produced and stored separately, they are excreted separately, and afterwards they should be contained and processed separately. A double-outlet toilet, one for urine and the other for feces, is all that is needed. The feces receptacle, except for the lid, is the same device used for the mesophilic storage of household biowaste.

In tropical and semi-tropical countries, the feces storage bin is inhabited by BSF larvae within about 15 days after its construction. Before the flush toilet was invented, the black soldier fly was commonly referred to in the USA as the "privy fly". BSF larvae eat human feces within an hour or two after it is introduced. This is a powerful factor in eliminating odor. These incredibly active larvae also keep the contents of the bin well aerated. Biochar and effective micro-organisms can also be added to the storage bin from time to time to further eliminate odor. The residue of this bin should be fed to red worms. They have the means to sanitize it.

Most of the nutrients absorbed by the human body from food are excreted in the form of urine. The nutrients in urine are easily taken up by plants. Generally the urine of one person is enough to keep 300 to 1,000 square meters of agricultural land well fertilized.

In Vietnam, farms are typically small. The average size of a farm in the Mekong is 1.2 hectares; while in the Red River Delta it is much less (Farm Size and Land Use Changes in Vietnam). If all of the urine produced by an average farming household were diverted, collected and applied to the soil, this alone would effect a significant reduction in fertilizer use. If the farming household could get access to the urine of four or five other households, it would have just about all of the fertilizer it would need.

There are many simple ways to transform or concentrate nutrients within human urine. Urine can be processed by means of duckweed in small household ponds. The protein content of duckweed reaches as high as 45%. Or urine can be diverted into a receptacle filled with dry biochar and a small amount of magnesium oxide (see Removal of Nutrients from Wastewater using Biochar). Urine can be applied to a dry biomass rich in carbon, such as rice straw, where it mesophilically composts.

We talk a lot about sustainable food production, but we will never achieve true sustainability in this regard if we fail to understand the importance of every gram of human waste produced world-wide. Imagine what marvelous things could be done with the waste of nine billion people! *Giving back to nature all of the nutrients within our own waste is perhaps our first and most important duty as citizens of planet Earth.*

Gasification

Finally there is lingo-cellulosic material (type 4 waste) that does not decompose very easily. Good examples of this are the rice hull and the coffee husk. These recalcitrant materials can be transformed quite inexpensively in top-lit, updraft gasifiers. The economics here are quite unbelievable: one ton of rice hulls acquires a value in syngas and biochar of more than $300 US. This means that one ton of rice hulls has a higher value on average than one ton of paddy rice. The line between product and by-product becomes blurred. Nothing in terms of solar or wind power comes even close.

- Without a pot, the flame looks like this.
- With a pot, it looks like this.

The biochar produced in these gasifiers has excellent cation exchange and water-holding capacities. Biochar aerates the soil, and once in the soil, it does not easily degrade. A substantial portion of it remains there for hundreds, if not thousands, of years. Its incorporation into the soil is an excellent way of sequestering carbon (Bio-Char Soil Management on Highly Weathered Soils in the Humid Tropics). "It also appears that adding biochar to the soil may be one of the only ways by which the fundamental capacity of soils to store and sequester organic matter could be increased." Like worm castings, biochar promotes the growth of beneficial soil microbes and reduces the need for fertilizer.

Biochar greatly increases the ratios of methanotrophic to methanogenic abundances in paddy soils (Feng et al 2012). This results in reduced methane emissions. Biochar is now being used in the reclamation of soils degraded through the use of chemical fertilizers. Rice hull biochar with a bit of compost has been shown to increase rice productivity in degraded soils in Cambodia by as much as 300% (see Preliminary Trials). The addition of rice hull biochar increases substantially the yield of water spinach (paper 1, paper 2 and paper 3) and maize. Anyone doubting the benefits of biochar should go the website of the International Biochar Initiative.

Dr. Thomas Reginald Preston has done important research in demonstrating that biochar can play an important role in the reclamation of about two million hectares of acid sulfate soils in Vietnam located in both the Red River Delta in the north and in the Mekong Delta in the south. These soils tend to be quite acidic, and consequently the yield of many crops grown on these soils has declined. Two million hectares represents about 21% of the land in Vietnam currently used for agriculture.

Dr. Preston demonstrated that when rice hull biochar is added to these soils, normal plant growth and yield are obtained. Because Vietnam's security in food production comes into play, he states that the reclamation of these two million hectares is not a luxury but a necessity. The gasification technology described in this essay is inexpensive, and Vietnam has enough type 4 biomass to carry out this reclamation in a relatively short period of time.

Sangkhom Inthapanya, together with Preston and Leng, conducted an experiment in Laos wherein 0.62% rice hull biochar (DM basis) was incorporated into cattle feed as a means of reducing enteric methane emissions and enhancing feed conversion. They discovered that the rice hull biochar produced in the TLUD gasifier explained above reduced methane production by as much as 22%. When nitrate was added to the biochar, the total reduction in methane was 41%. But there is even more: live animal weight gain increased by 25%. No doubt, this has to be one the greatest advances in bovine nutrition in the last few decades.

More recently Dr. Chhay Ty of Cambodia did another study on the incorporation of rice hull biochar into the soil. He applied 5 kg of rice hull biochar per m2 to a plot of mustard greens. To a second plot of mustard greens he applied no biochar. But this second plot received the same water, fertilizer and management as the first. The plot with biochar yielded four times more weight in mustard greens than the plot without biochar. But the improvement here was not merely quantitative. The mustard greens with biochar had 40% less fiber and 35% more protein than the mustard greens without biochar. At the same time experiments with other vegetables were carried out. With water spinach there was a 39% increase in growth. With Chinese cabbage there was a 100% increase. With celery cabbage there was a 300% increase. In light of such research, what then is the value of biochar?

There is no greater advocate of sustainable agriculture than Dr. Preston. The thousands of articles that he has authored, co-authored, mentored and inspired are an incredible resource for anyone interested in sustainable agriculture.

An exciting application for biochar lies in water treatment. Josh Kearns has written a paper explaining how biochar can be used to remove synthetic organic compounds (SOCs), such as pesticides and herbicides, from drinking water. The herbicide, 2,4-D is one of the most widely used herbicides in the world, and this carcinogen is hard to remove from water. If a particular biochar can remove 2,4-D from water, then it can remove most other SOCs. Kearns discovered that the removal rate of 2,4-D by means of certain biochars produced in a fan-assisted, high temperature, gasifier cookstove situates at about 100%. He then explains how to construct simple and inexpensive water filtration systems that make use of biochar in a final stage. Such a simple water filtration system is desperately needed in many developing countries. In Laos, for example, 40% of the children in certain minority villages die before the age of five.

The small-scale gasification of biomass is a powerful concept (see this essay), and this technology should be engineered for widespread use even in the developed world. To view this technology as a technology only for poor people in developing countries is dreadfully short-sided. Alongside microwaves and toaster ovens, there is definitely a place for gasifiers in modern kitchens. In large portions of the developed world, the wood pellet and the wheat straw pellet become obvious sources of gasifier fuel. No one, rich or poor, either in developing or developed countries, should rely exclusively on fossil fuels to cook a meal or boil water. Hopefully within the next ten years, engineers throughout the world will give small-scale gasification the attention it deserves.

Making Waste our Greatest Resource

This listing of the types of waste, as well as the means to transform them, should not be viewed in a rigid and definitive manner. What needs to be emphasized, above all else, is that there should not be a single approach to waste transformation that overrides all other approaches. Imagine the incredible short-sightedness of those who promote the incineration of biodegradable waste. It is precisely the integration of many waste transformation technologies that results in the most beneficial environmental impact and the highest economic return. We must remain open to multiple approaches and to whatever works best in a particular situation. For example, certain agricultural residues, such as wheat and rice straw, defy easy categorization and can lead us in many exciting directions.

There's money to be made in growing mushrooms on straw. Nothing could be better than this, for the main product of this fungal transformation is food for humans, while the spent mushroom substrate can be fermented and fed to cows and even pigs.

When rice straw is harvested at full-ripening stage, it is relatively moist and contains more nutrients than straw that has been dried in the sun. This green straw can be chopped, fermented by means of lactic acid bacteria and transformed into cattle feed of substantial value (see Effects of Treating Whole-plant or Chopped Rice Straw Silage).

Dry straw can be shredded and pelletized. Pelletizing increases the bulk density of loose straw at least ten-fold, and into this pellet, a small percentage of biochar can be added. The pellet could then serve as cattle feed. The shredding and pelletizing make the straw more palatable to the cow, and with the addition of biochar, the feed conversion ratio of the straw should improve substantially, as the Inthapanya/Preston research indicates. Adding urine to this pellet should also improve palatability.

Pelleted straw can be used as bedding for cows, pigs and other animals. A small percentage of biochar can be incorporated into the pellet to prevent the volatilization of ammonia. This urine-soaked bedding of a high bulk density is easy to handle. It can be used to fertilize plants. It can serve as a substrate for red worms. Pelleted straw that served as bedding for pigs can be mixed with a bit of molasses and fed to cattle.

Straw can be shredded and composted thermophilically along with materials of a low C:N ratio.

And finally straw can be pelleted to serve as gasifier fuel. The compost, vermicompost and biochar from all of the above processes can be mixed together in the right proportions to form an exceptional growing medium for plants. Each of these products contributes something unique to the soil. On the synergism between compost and biochar, see Synergisms between Compost and Biochar for Sustainable Soil Amelioration.

From this one agricultural residue we can produce food, fuel, feed and fertilizer. The tonnage of straw produced globally each year is phenomenal. China alone produces annually 340 million tons of straw. The transformation of straw could become a global business worth hundreds of billions of dollars US each year. It seems that the agricultural community has yet to learn the value of the many types of waste it generates (Cereal Straw: a Wasted Resource).

One notable exception in this regard is Shangqiu Sanli New Energy Ltd of China. But unfortunately this company sees itself as faced with the "daunting challenge" of trying to scale up its transport, pelletizing and gasification operations. The real challenge here, of course, lies not in scaling up but in scaling down, and in adopting a multifaceted approach that integrates and combines all of the value chains that straw represents.

Beyond Waste Transformation

But if we really want to produce a lot of food, it's not enough to focus on how to transform waste and route it back to agriculture. We have to take things one step further. This next step is best explained by means of an example - an example that I often use when addressing farmers in the south central highlands of Vietnam.

There's a coffee farmer who typically grows nothing but coffee, and right next door, there's a pig farmer who only raises pigs. The coffee farmer dumps coffee pulp and coffee husks into a valley near his farm, and is totally reliant on chemical fertilizers; while the pig farmer flushes pig waste into a nearby stream, and buys all of his feed from Cargill.

In contrast to this total nonsense, let us imagine that the coffee farmer is at the same time a pig farmer. Instead of dumping coffee pulp in valleys, he ferments it and feeds it to his pigs – pigs located on the same farm where his coffee is cultivated. The crude protein content of fermented coffee pulp is about 14%.

The feces from his pigs are processed by larvae and red worms, and the urine from his pigs flows into a dense granular bedding comprised of rice straw pellets laced with biochar. This strategy eliminates the odor, flies and virtually all of the disease normally associated with raising pigs. The use of antibiotics on his pig farm, an extremely dangerous practice, is completely eliminated (see Breeding Bacteria on Factory Farms). The yearly income from the sale of pigs eventually matches, and at times surpasses the yearly income from the sale of coffee beans.

The farmer understands what lauric acid can do for his pigs. He feeds small amounts of coconut and BSF oil to them each day (even Eli Lily has caught on to this). The pig metabolizes lauric acid to produce antibacterial and antiviral compounds that effectively combat an array of swine diseases, especially those caused by bacteria such as MRSA and Clostridium *difficile*. At his farm, pharmaceutical companies pushing antibiotics have nothing to sell.

Let us suppose further that this same farmer plants perennial peanut throughout his coffee plantation. This beautiful, lush ground-cover controls weeds, prevents erosion, fixes nitrogen and increases the availability of phosphorous. Earthworms proliferate in this nitrogen-rich environment, and as they burrow through the soil, they eliminate the need for tillage. These worms greatly increase the availability of all essential plant nutrients, and as they repeatedly rework the soil, it is continuously transformed into vermicompost.

The farmer cuts and feeds fresh perennial peanut stems to his pigs and cows. But most of the perennial peanut serves as forage for free-range chickens. Chickens feast on insects within the peanut vines as well as on the live larvae and red worms cultivated on the pig and cow feces. The yearly income from the sale of free-range chickens eventually matches, and at times, surpasses the yearly income from the sale of coffee beans. Chicken droppings continually fertilize the coffee plants. In between the coffee and perennial peanut, the farmer plants taro as an additional source of fermentable biomass for his pigs.

The coffee farmer soon realizes that, in order to have a more regular supply of fermentable biomass for his pigs, he should also cultivate bananas. After the banana fruit is harvested, the farmer chops and ferments the massive pseudostem of the banana plant. The farmer gradually expands his efforts in the direction of rabbits, which also forage on the perennial peanut, and in the direction of bees, which feed upon the nectar produced by the coffee and peanut flowers. The farmer then stocks his irrigation pond with ducks and fish.

Next he installs on his farm two top-lit updraft gasifiers: a small one for all of his household cooking and hot water needs, and a larger one initially for the distillation of rice wine (the mash is fed to pigs). His total investment in gasifier equipment is less than $100 US. He gasifies, of course, the dry coffee husk, which he has in abundance. He stops buying bottled gas altogether.

He then realizes that he can use gasifier heat to dry the coffee cherry and even the more delicate coffee bean. In this way he is no longer solely dependent on sunshine, which is often unreliable, especially if the dry season is late in coming. This eliminates spoilage due to fungi and mold. His coffee bean dryer with gasifier might look something like this.

He ends up with a lot of coffee husk biochar - a biochar quite rich in potassium. This biochar has roughly the same volume as the original coffee husk that he gasified. He mixes some of this biochar into his fermented pig feed, he mixes some into his pig bedding, and he uses some directly as a soil amendment around his coffee and banana plants. Finally he sells some of it at a high price. The moment he starts selling biochar, he becomes a consumer of energy at a cost less than zero.

So our farmer ends up cultivating a variety of plants, animals, poultry and fish. They all complement one another in increasing efficiency, reducing cost, maximizing profit and minimizing environmental impact. The one fairly uneducated farmer produces with ease the four basic commodities of food, fuel, feed and fertilizer. Big Ag, Big Oil and Big Pharma come nowhere near his farm. *He finally breaks free of the commercial slavery they impose upon hundreds of millions of poor farmers throughout the world.*

Farmers world-wide should be taught the *ancient wisdom* of raising plants to feed animals and animals to fertilize plants. In such a strategy, all waste by-products become essential inputs. The imbalance created by the continuous outflow of food products that the farmer brings to market is corrected in large part by the continuous inflow of materials that the farmer receives from mesophilic bins, urine-diverting toilets, gasifiers, as well as small-scale composting and fermentation facilities.

The farmer can grow two or more plants in proximity to one another in such a manner that they do not compete in terms of physical space, nutrients, water or sunlight. Such biodiversity is important in limiting the outbreak of crop pests and diseases. Beneficial insects, earthworms and other beneficial soil organisms thrive in such an environment. They limit the proliferation of harmful insects and soil pathogens. Pesticides and herbicides are no longer required. In any one space and at any one time, a lot more is grown, harvested and sold.

The farmer does not manage a single crop such as coffee, rice or bananas. Rather he manages relationships between living systems that mutually support one another. *The ability of a plant or animal to enhance the growth of something else becomes paramount in agricultural planning.* This approach enables the farmer to have a highly diversified basket of products that protects him against market fluctuations and assures a predictable and steady stream of income. His strategy resembles that of an investment banker who always maintains a well diversified portfolio for his clients. The farmer's annual revenue and profitability per hectare, therefore, is at least three to five times more than that of a conventional farmer.

Objections

There are those who think that Big Ag has got it all figured out.

On the one hand, they argue that the ideas presented in this essay are too brain-intensive for farmers in developing countries, and that it would take an army of agricultural extension agents to train and advise them.

But they overlook the fact that the economics of a sustainable and diversified agriculture are so appealing that agricultural extension agents would not be required. Here we call upon brokers who are at the same time social and environmental entrepreneurs. These brokers would contract farmers to grow plants and animals on their behalf. They would train farmers in the use of all of these waste transformation technologies, and they might even supply equipment to them. They would buy at fair market prices all that the farmers under them are contracted to produce. Farms would remain small and intensive, while brokers could operate on a larger scale.

The broker would certify to the consumer that all farm products conform to the highest standards of sustainability. Brand names would be established, and brokers would vigorously compete with one another in offering consumers the healthiest and tastiest farm products. Once the consumer understands the danger of eating meat loaded with antibiotics and hormones, and the danger of eating vegetables sprayed with herbicides and pesticides – the broker should have no problem selling his products. Already small-scale farms produce about half of the world's food, and with a bit of assistance, they could produce a lot more.

A single farmer does not have to close the loop all on his own. He can work together with other farmers in a waste transformation exchange program. For example, one farmer only grows coffee and ferments all of his coffee pulp into feed, while the other farmer only grows pigs and processes all of his pigs waste into fertilizer (vermi-compost). The two farmers exchange feed for fertilizer in a highly profitable and efficient manner.

On the other hand, someone might argue that these ideas are only for relatively poor people in developing countries. But they overlook the fact that there are many urban agriculturists in the USA who clearly understand the benefits of an agriculture that is small-scale, intensive and local. This new generation of farmers has the brain power to totally reinvent agriculture in the context of a developed world where labor is not cheap.

Already about 15% of Americans are involved in growing some of the food that they eat. As Mark Bittman explains, if 10% of the lawns on the USA were converted into gardens, this would supply about a third of the fresh vegetables needed there. The USA has some 50,000 square miles of lawn on which a colossal amount of food could be grown. Back in 1943 there were some 20 million "victory" gardens which produced about 40% of the fruit and vegetables consumed in America. One of the best articles against modern, industrialized agriculture can be found here. The United Nations recently issued a report, entitled "Wake Up Before It Is Too Late" wherein it forcefully argues for a return to agriculture that is sustainable and small-scale.

Conclusion

Rich or poor, developed or underdeveloped, it makes no difference. Waste transformation and polyculture are not optional. As the price of fertilizer derived from fossil fuels continues to rise; as phosphorus becomes increasingly contaminated and expensive; as aquifers and rivers throughout our planet begin drying up; as the cost of importing grain and other feedstuffs from America and Brazil becomes prohibitive; as our oceans become critically depleted and can no longer provide the protein needed to make feed; as the price of oil rises continues to rise; as farmland becomes contaminated with chemicals, depleted of carbon and thoroughly unfit for cultivation; as immense tracts of arable land are lost to agriculture year after year; as hundreds of millions of people world-wide begin to starve and die; as food insecurity increasingly undermines the stability of nations – such an approach becomes an absolute necessity.

To understand what farming should be, we should deeply reflect upon the rich diversity within the natural world where a large numbers plants and animals within an ecosystem mutually support one another, each occupying a niche that is spatially or temporally distinct. Once we understand that in nature there is no such thing as waste, that all living systems are characterized by a symbiotic relationship with at least one other living system, and that all of life defines itself in a tight and critical interdependency, we cannot help but devise food production systems that mimic the natural world and are totally self-sustaining.

In this approach humans learn to give to nature far more than they take. For it's not simply a question of feeding a lot of people. It's not simply a question of making a lot of money. It's above all else a question of living in harmony with the whole of the natural world.

If you would like to see a condensed version of this essay in PowerPoint format with a lot of pictures and drawings, please see this link.