In Search of a Sustainable, Nature-based Agriculture:
Identifying Problems, Defining Goals, Envisioning Solutions, and Measuring Success

By

Abigail Hood

Table of Contents

Acknowledgements

This project started with a conversation in a beautiful barn on the Teal Farm, Camel's Hump looming just outside the window. Sitting with Melissa Hoffman and Amy Seidl, I began a series of fascinating conversations that would guide and support my work for the following year. I am grateful to Melissa and Amy, as well as their organization, LivingFuture, for supporting my work.

The permaculture community was welcoming and generous with their time. Thank you to Dave Jacke, Keith Morris, John Patrick Hayden, Ben Falk, and Claude Genest for taking the time to share your impressive knowledge with me. Thanks also to Josie Hannon, Rick Paradis, Mike Klein, Christina Goodwin, Ellen Sibret, Kari Dolan, Chuck Mitchell, Erica Gaddis, Marla Emery, Bill Kropelin, and Adam Sherman.

I am grateful to my friends and family for all of their support, to V6, and especially to my committee: Deane Wang, Deb Neher, and John Todd.

Prologue

In the spring of 2005, I began working on a project for my master's degree through the University of Vermont's Rubenstein School of the Environment and Natural Resources. Sponsored, encouraged, and inspired by LivingFuture, a non-profit organization located in Huntington, Vermont, I set out to examine current agricultural practices and to imagine alternative methods for food production – methods that would rely on nature as a model.

LivingFuture's Mission Statement: *LivingFuture is a 510(c) 3 non-profit organization assisting healthy planetary change. Our mission is to promote a new ethic for global survival through ecosystem conservation, and through innovation that works at the intersection of ecology, economy, and culture. LivingFuture's vision is founded on the conviction that human enterprise can ultimately enrich-rather than deplete- Earth's life systems. Our fundamental purpose is to mobilize the inquiry, collaboration, and innovation necessary to make such human presence a reality*.

LivingFuture is a think-tank, research institute, and a seed-organization for conscience-based design. We collaborate with entrepreneurs, activists, scientists, students and others to create localized food, energy and waste-cycling systems that harmonize with biological principles, that are perpetually self-renewing, and that will contribute to the long-term vibrancy of human and natural communities.

LivingFuture is located on the Teal Farm, a 1300-acre preserve in Huntington, VT with a facility-in-development modeling living-systems design. Our buildings are designed to mimic ecosystem processes by harvesting their own energy and cycling their own wastes and are constructed with materials that are sustainably procured and locally-sourced.

One of LivingFuture's primary goals is to "create localized food…systems that harmonize with biological principles, that are perpetually self-renewing, and that will contribute to the long-term vibrancy of human and natural communities." Simply put, they seek to develop agricultural systems that are both sustainable and sustaining, that do not degrade, but instead enrich, natural systems and human communities. Such an approach to agriculture is not simply a set of adjustments to the status quo. On the contrary, this approach relies on a process: an examination of the current systems producing our food supply, a definition of how we want our agricultural systems to look, and an exploration of innovative approaches that could solve our agricultural problems.

LivingFuture's approach is predicated on the belief that the time has come to shed the unwieldy infrastructure and institutional memory of conventional, degrading agricultural systems – to free ourselves to build new systems based on the wisdom inherent in the natural world. In this paper I document a four-fold approach: I begin by *identifying the problem*, move on to *defining sustainability*, then *envisioning sustainable agriculture,* and finally *measuring our success*. Throughout this document, I address global issues in a local context. For each facet of this four-fold approach, I begin by *looking out* to the global community, the challenges and victories that are shared across the country and the planet. Then I ground that understanding by *bringing it home* to the forested hillslopes of Vermont's Green Mountains.

Introduction

All in all, I think nature-based agriculture will be nourishing in the best sense of the word—an honest and honorable way to take our place in the food web that connects all life. We have lived too long by hubris, imposing disruptive patterns on the land, squaring the circle. If we as a country, or as a global net of communities, are truly committed to sustainability in all things, agriculture must be first on our agenda, the first meal of the new day.

*from **Biomimicry** by Janine Benyus 1997*

Agriculture is a disturbance to the natural landscape. As we seek out ways to reduce our collective impact on the environment we are faced with a quandary: we must eat, yet our food production systems are at best a disturbance to natural systems, and at their worst cause massive soil erosion, pollute water, emit greenhouse gases, and reduce and fragment wildlife habitat. In many areas, this disturbance has been maintained for over a century and its impacts have compounded over time resulting in dramatically reduced ecological function on the landscape.

Fortunately, many farmers are natural conservationists, intimately aware of "fundamental ecological processes, including energy flow, nutrient cycling and erosion control, year in and year out" (Badgley 2003). Many are searching for methods that will reduce their negative impacts on the landscape and thereby make it possible to sustain the productivity of their land into the foreseeable future. Organic practices, integrated pest management, and a return to small-scale farming are all ways in which farmers are working to lessen agriculture's harmful ecological impacts. All of these methods, however, represent adjustments to abate the negative impacts of conventional agricultural systems. Proponents of more radically different agricultural methods argue for creative agricultural approaches using natural systems as the model. Model natural systems are conservative of water, nutrients, and soil, are self-renewing, and productive.

In Vermont, the model is forest. Though it takes on many forms in both structure and composition, the forest is the dominant ecosystem on this landscape. In order to capture the ecological services provided by native systems, agricultural systems in Vermont will have to integrate trees. The various disciplines within the field of agroforestry have the potential to make meaningful contributions to a sustainable, nature-based agriculture for Vermont. The under-explored practice of forest gardening has particular promise and deserves further practice and study.

Identifying the Problem

Modern agriculture is astonishing in both its successes and its failures. Large, highly mechanized farms produce huge amounts of food, enough to fill produce bins and cereal boxes at supermarkets across the country and around the globe. In the sheer volume of food they produce, our agricultural systems are a remarkable success. However, vegetables are not the only products coming off of modern-day farms. Pollution in the form of excess nutrients, chemicals, and greenhouse gases is a less welcome result of some farming practices. In addition, many agricultural practices accelerate soil erosion, a dangerous oversight for an enterprise that is completely dependent on the soil for its continued success.

The first step in solving a problem is correctly identifying it. How do we know how we want to change if we do not first assess our current conditions? This chapter highlights some of the problems with modern, conventional agriculture. Looking out, it examines and details some key challenges faced by agricultural systems around the world. The second section of the chapter brings the conversation home to the Vermont landscape, identifying some of the pressing concerns for food production in this region.

LOOKING OUT

Conventional agricultural systems pose social, economic, and ecological problems the world over. In this chapter, four problems are presented in detail: pollution, soil erosion, forcing of global climate change, and oversimplification of agricultural systems. While this list is by no means inclusive, it represents a line-up of some of the more serious offenders – and certainly gives cause for major departure from the agricultural status quo.

How nutrients became pollutants

In the eighteenth and early nineteenth centuries, agricultural systems in Europe and the United States were based on subsistence. The majority of plants produced on a farm were either eaten by people on that farm or by animals that were consumed by people on the farm – wastes and residues returned to the land, effectively cycling harvested nutrients back to the soil (Magdoff 1997). Urbanization in the latter half of the nineteenth century and early twentieth century created a break in the nutrient cycle, as food was shipped from producer to consumer (Magdoff 1997). Another break in the cycle occurred with the industrialization of agriculture. Animal production had formerly occurred as one facet of diversified farming; grain crops had to be rotating with nitrogen-fixing forages to maintain soil fertility and animals were raised to make use of those forages. When nitrogen fertilizer became readily available at low cost, it severed the link between grain and forage production and created the potential for large-scale animal production farms, separated by long distances from feed-producing farms (Magdoff 1997). In this modern system, nutrients flow off of feed-production farms and accumulate on animal-production farms. The decline in soil organic matter and nutrients on crop farms leads to extensive (and often excessive) use of synthetic fertilizers, while the build-up of nutrients on animal production farms leads to water pollution (Magdoff 1997).

The disruption of nutrient cycling is not isolated to animal production farms. Fertilizers are synthesized and then moved from where they are produced to the site of application. Once incorporated into foodstuffs, nutrients are shipped from farms to population centers (Carpenter et al. 1998). At this point, the nutrients are embodied in food scraps and human waste, and are not harvested for re-use. Instead, more fertilizers are synthesized. Nutrients flow from site to site, rather than cycling through a more closed system. “Globally, more nutrients are added as fertilizers than are removed as produce” (Carpenter et al. 1998), resulting in an accumulation of nutrients in the soil, aquatic ecosystems, and the ocean.

Excessive nutrient loading from agricultural land use has dire implications for water quality and aquatic ecosystems. The two most serious offenders are nitrogen and phosphorus. Normally one or the other are in limited supply, but nitrogen and/or phosphorus levels are elevated it leads to the excessive growth of algae and other plants, a process known as eutrophication (Bennett et al. 2001; Carpenter et al. 1998). Excessive nutrient loads causes a shift toward bloom-forming algal communities. Algal blooms can, in turn, deplete the water of oxygen resulting in large-scale fish kills. Some algal blooms are toxic to other organisms, including humans. Eutrophication often results in a loss of aesthetic and economic values and can render drinking water unpalatable. In addition to these cultural problems, eutrophication can contribute to the extirpation of native plants and the loss of biodiversity (Bennett et al. 2001). A potential link has even been drawn between eutrophication and amphibian malformations; Johnson and Chase (2004) suggest that the complex changes in eutrophic wetland food webs may increase populations of a parasite that causes malformations in amphibians. Eutrophication accounts for around 50% of impaired lakes and 60% of impaired river reaches (“impaired” waters are those that are unsuitable for drinking, irrigation, industry, recreation, or fishing) in the United States, according to the Environmental Protection Agency (1996).

While these impacts of phosphorus pollution are frightening enough, the story is not yet complete. The movement of phosphorus through a watershed is complicated by the nature of this particular nutrient, which adsorbs to soil particles and can accumulate in the soil and remain there for long periods of time(Bennett et al. 2001). Whenever these over-enriched soils erode, they bring phosphorus with them; even years after the phosphorus was applied, its mobilization by a major storm event can lead to eutrophication.

On a global scale, phosphorus storage in soils and aquatic ecosystems has increased at least 75% since pre-industrial times – a significant portion of that being stored in agricultural soils (Bennett et al. 2001). Prior to the 1960s, phosphorus accretion was a problem only of developed nations, but the export of the industrialized world’s agricultural practices is leading to an increase in P accretion in developing countries (Bennett et al. 2001). In areas where access to safe, clean, palatable drinking water is already uncertain or limited, excessive application of fertilizers threatens the long-term availability of potable water. Thus, the ecological impacts of modern agricultural practices are not only a local issue, but a global social welfare issue – an issue of equity and human health.

Nitrogen behaves differently from phosphorus and so its accumulation has different implications. Though elevated phosphorus levels cause toxicity only indirectly through algal blooms, both nitrate and nitrite in high concentrations can be toxic to people and livestock. In addition, increased fertilization results in increased emissions of nitrogen gases into the atmosphere, including nitrous oxide, a potent greenhouse gas (Vitousek et al. 1997).

Our diminishing soil

Soil is literally at the roots of agriculture. Without it, agriculture cannot exist, and neither can our human populations. However, "this precious soil from which we have our physical being is only a very thin skin upon the earth" (Smith 1950), a thin skin which is rapidly eroding. Annual erosion rates of fertile soil from croplands average about 30 tons/hectare (Pimentel et al. 1995). The World Resources Institute estimates that over the last 40 years, 30% of the world's arable land has been rendered unproductive due to erosion.

Of course, erosion is a natural process. Water and wind, the two primary agents of erosion, have always and will always move soil from place to place. However, in most natural systems (deserts being one notable but irrelevant exception), vegetation serves to secure soil in place, keeping erosion to low levels. Erosion rates from soil covered in sod have been measured at under 0.1 tons/hectare/year (U.S. Forest Service 1936), while erosion in stable, forested ecosystems has been found to be between 0.004 and 0.05 tons/hectare/year (Bennett 1939; Roose 1988; Lal 1994). These values are substantially lower than the average rate of natural soil formation, 0.5 to 1 ton/hectare/year (Troeh and Thompson 1993; Lal 1994; Pimentel et al. 1995), which indicates a net gain of soil in most natural ecosystems. Agricultural lands in general, however, are losing soil much faster than pedogenesis (soil formation) occurs. The result is a rapid loss of soil that threatens the viability of agriculture for future generations, thereby threatening future generations themselves.

Soil erosion also has implications for global equity of food availability and quality. Erosion is most severe in developing countries where much agriculture takes place on marginal lands with steep topography and poor soils (Pimentel and Kounang (1998). Thus, where residents are most dependent on their local resources, the productivity and fertility of the land is being most rapidly degraded. Agricultural methods that conserve soil resources are desperately needed to ensure secure food supplies for all people now and in the future.

Though loss of soil is troublesome enough, erosive processes also degrade the remaining soil, decreasing its fertility and productivity. In their informative review of the soil erosion literature, Pimentel and Kounang (1998) cite evidence for the negative effects of erosion on remaining soil quality, including decreased water infiltration and absorption rates, decline in fertility, loss of organic matter, and decreased soil depth. These effects further result in decreased productivity, increased need for irrigation and fertilization, and loss of soil organism biomass and biodiversity.

Global climate change

The relationship between climate change and agriculture has three facets: first, modern agricultural practices are contributing to climate change through their reliance on fossil fuels and excessive chemical fertilization; second, agricultural practices may be modified to mitigate the accumulation of greenhouse gases in the atmosphere; and finally, future agricultural practices will have to be adaptable and resilient to weather the unknown alterations that climate change will bring.

Conventional agricultural systems emit three different greenhouse gases (GHGs), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Agriculture contributes a small amount of CO_2 to the atmosphere, mostly because tillage increases soil oxygenation and therefore enhances the microbial activity that converts soil organic matter (SOM) into CO_2 (Smith and Almaraz 2004). Methane production is of more serious concern for agriculture, as anthropogenic methane emissions constitute almost 20% of the radiative forcing potential that causes climate change and more than half of that methane is produced through agricultural practices (Smith and Almaraz 2004). Nitrous oxide is particularly problematic because it has 310 times the warming effect that carbon dioxide has. Agriculture is responsible for up to 70% of the anthropogenic nitrous oxide emissions. Taken together, the emissions of these GHGs from agriculture contributes 7% of the total GHGs emitted by the United States (U.S. EPA 2002).

In addition to the greenhouse gases contributed directly by agriculture, modern food production and distribution systems are heavily reliant on fossil fuels. The machinery used in preparing the soil, planting, harvesting, and processing use fossil fuels, contributing to pollution and the accumulation of greenhouse gases in the atmosphere. Finally, large-scale, centralized food production facilities are often large distances from the consumers who use the products. Thus, fossil fuels are burned in the transportation of food from farm to processing facilities and finally to consumers.

It is clear that agriculture is contributing to climate forcing, and it is likely that climate change will, in turn, have substantial implications for agriculture. These effects are difficult to predict. According to a review by Smith and Almaraz (2004), we can expect changes in soil organic matter content as higher temperatures accelerate SOM breakdown, wind speeds may increase thereby worsening soil erosion, increased concentrations of carbon dioxide may change the carbohydrate to protein ratio in our crops, nitrogen fixation rates are likely to increase, and pest species will move. In addition, the intensification of storm severity is likely to increase the rate of erosion by water, which, due to the accretion of phosphorus in upland soils, could increase the severity and prevalence of cultural eutrophication (Bennett et al. 2001). Thus, the effects of climate change on agricultural systems are likely to be complex and synergistic with other environmental problems. It is essential for agriculture to be diverse and adaptable to face the unknowns of the future; modern agricultural systems, characterized by simplification rather than complexity, may not be able to respond dynamically to climatic change.

Despite the potential for serious negative implications, predictions about the effects of climate change on agriculture are not altogether pessimistic; increases in carbon dioxide levels and temperature are expected to increase productivity in areas of the world where drought is not expected. In fact, one model predicts that by 2080, North America will have experienced a 40% increase in land area suitable for cultivation, while northern Europe will have a 16% increase (Fischer et al. 2005). In contrast, sub-Saharan Africa, a region where a substantial proportion of the population is already undernourished, models project losses of cereal-production potential of up to 12%. Even within this region, effects are anticipated to be highly variable, with some countries seeing increases in production, while others (some of the most undernourished) lose production potential (Fischer et al. 2005). Climate change effects are likely to be extremely regionally variable, with areas of the world that are already undernourished potentially the most vulnerable to losses in production potential. As such, climate change may have dire implications in terms of global hunger, with potential for equity of food distribution to be an ever-growing concern.

Simplification of agricultural systems

As farms get bigger and more specialized, the agroecosystems on which they rely become much simpler. While such simplification might streamline productivity, it comes at a cost in terms of energy, habitat fragmentation, and biodiversity loss.

In their 1998 paper, Vandermeer et al. discuss complexity in agroecosystems. They point out that complexity can exist on many different scales. One way of viewing agroecosystem complexity is by recognizing that land use systems provide different functions including production of food and tree products, soil conservation, and carbon sequestration, among others. In more complex agroecosystems, various functions may be integrated, while the trend toward simplification results in the segregation of functions. “A central research question is which functions can be combined and which ones are better served separately” (Vandermeer et al. 1998). One example of the choice between integration and segregation pertains to biodiversity conservation and agricultural production. The segregated option results in “national parks and separate zones for intensive agriculture”, whereas an integrated system could include agroforests, multifunctional forests, or prairies.

The specialization and simplification taking place on our farms is subsidized by the oil industry. Vandermeer et al. (1998) note that “specialization is based on the externalization of functions of farm components.” Examples include the replacement of traditional plant varieties with modern, hybrid cultivars, chemical rather than ecological pest control, chemical fertilizer rather than on-farm nutrient cycling, market supply of animal feed rather than local fodder production, mechanization replacing human labor, and insurance policies replacing the "stabilizing effect of farm diversity." In a world in which liquid fuel is no longer readily, inexpensively available, an agricultural system based on specialization and simplification becomes untenable. Without chemical fertilizers and pesticides, without inexpensive fuel for farm machinery and for transportation of animal feed and crops, large-scale factory farming is unimaginable.

BRINGING IT HOME

Agriculture is an important part of Vermont's culture and economy. In 1999, one-sixth of Vermont's workforce was employed in agriculture or related industries (Pelsue 2002). Vermont cows produced 2.7 billion pounds of milk, and the state was the nation's number 1 maple syrup producer (Pelsue 2002). Despite its value, Vermont's agriculture has an ecological cost.

Vermont is bordered on its northwestern side by Lake Champlain, the sixth largest freshwater lake in the United States. The lake is undergoing cultural eutrophication resulting from high levels of phosphorus in its waters. In fact, according to a 1997 report by the Vermont and New York State Departments of Environmental Conservation, "human activities in the Lake Champlain Basin have increased phosphorus loading to the lake four-fold over natural background levels." Some of this pollution comes from point sources such as wastewater treatment facilities; however 71% is attributed to nonpoint sources. The DEC study demonstrated a strong correlation between land use and phosphorus load, with concentrations particularly high in those rivers that drain heavily agricultural regions. These findings implicate agriculture as a major offender, one of the greatest causes of high phosphorus levels and the resulting eutrophication.

Dairy farming is a major component of Vermont agriculture; in 2002 agriculture contributed $556 million to the state economy and $400 million of that came from milk sales (New England Agricultural Statistics). Dairy farms are an integral component not only of Vermont's economy, but also its rural heritage. However, livestock grazing in the riparian zone is a serious environmental concern, as is nutrient runoff from milk producing farms. Dairies are considered to be some of the biggest sources of phosphorous pollution in the Lake Champlain watershed (Anon. 1998). Many Vermont dairies have more cows than their land can support, so they import feed. Importation of feed creates a net flow of nutrients into Vermont, since all the manure is being spread locally, rather than being transported back to where the feed was produced. Magdoff et al. (1997) point out the geographic separation of crops and animals, which results in two problems: the decline of nutrients on crop farms (resulting in the need for synthetic fertilizers) and the excess of nutrients on animal farms (resulting in nonpoint source pollution).

Though Vermont has a strong agricultural community, the vast majority of food eaten by Vermonters is produced out of state, even outside the country. This problem exists throughout the United States and other industrialized nations. One study, based on data from 1980, estimated that fresh produce traveled an average of 1,500 miles between where it was grown and where it was eaten (Hendrickson 1996). Another study determined that an average American meal contains ingredients from five countries outside the United States (Lang 2001). The Vermont Agency of Agriculture promotes consumption of locally grown food, estimating that if Vermonters shifted as little as 10% of their purchases to locally grown foods, it would add more than $100 million to Vermont's economy (VT Agency of Agriculture 2005). It is difficult to quantify the difference that shift would make in fossil fuel consumption and greenhouse gas emissions. However, a study done in Iowa found that on average conventional food traveled 27 times further than locally produced food (Pirog and Benjamin 2003). The difference in travel distance between conventional and local varied depending on the food item, with conventional pumpkins traveling only 8 times farther, but broccoli traveling 92 times farther (Pirog and Benjamin 2003).

Vermont faces the challenge of a short growing season, meaning that agricultural self-sufficiency would require careful planning and extensive food preservation. The current simplification of Vermont farms (apparent in the percentage of Vermont's agriculture industry that is dominated by dairies) does not support the nutritional diversity required in a self-sufficient system.

Defining Sustainability

Agricultural practices that accelerate erosion, degrade soil, pollute water, and contribute to global climate change cannot be sustained. The limited resources available for food production are currently being depleted, undermining the ability of future generations to provide sufficient food for the world's expanding population. We must find a way to feed ourselves without making it impossible for future generations to do the same. We must make our agricultural systems sustainable. An important step in this effort is defining what constitutes success: what is sustainability? Many definitions of the term have arisen and its connotations have shifted over time, making sustainability something of a moving target. Given the extent of the discourse on the subject, a clear, precise, and universally-acceptable definition of sustainability may be an unattainable goal. However, conditions mandate that a *working* definition be developed. We cannot afford to wait for consensus; we must grapple with the term to the extent possible, then operationalize the concept so that it can guide our efforts.

This chapter begins with a discussion of the concept of sustainability and the ways in which the term has been used. The focus then shifts to establishing a set of principles to serve as guides when we venture into the realm of building solutions to our agricultural problems. Finally, we return to our home landscape, tailoring those principles to the specific conditions that constrain Vermont's agricultural systems.

LOOKING OUT

By its most literal definition, sustainability is the ability to be maintained into the future. From this perspective, agricultural sustainability is a *system property*, or a characteristic of an agricultural system (Hansen 1996). Marten (1988) includes sustainability as just one of many system properties, defining sustainability in a simple and literal way: the maintenance of a certain level of productivity in the long term. He includes productivity, stability, and equitability in his list of properties for agroecosystem assessment. However, if sustainability is viewed in a holistic way, it encompasses all of these other properties; a system must be productive, stable, and equitable if it is to be sustained in the long term. On the farm-scale, a system that is not sufficiently productive will not support the farmer and the system will not be sustained. Similarly, if a farm is abundantly productive in one year, then unproductive for a couple of years, it is unlikely to be sustained by the farmer, who needs to make a living every year. Finally, on a broader scale, if a region's food supply is directed only to a subset of the population while other people are undernourished, the system is socially unsustainable; undernourished people would be forced to seek subsistence by any means available, potentially including civil unrest.

As such, sustainability must be an over-arching system property, one that encompasses the long-term maintenance of all the functional components of the agroecosystem. This definition includes everything from soil quality to the equity of food distribution. Altieri

(1987) captures this concept in his definition: “sustainability refers to the ability of an agroecosystem to maintain production through time, in the face of long-term ecological constraints and socioeconomic pressures.”

Another definition of sustainability is as a philosophy. The concept of sustainable agriculture “emerged as the most agreed-upon term to synthesize a variety of concepts and perspectives associated with agricultural practices that differ from those associated with conventional production agriculture” (Neher 1992). Schaller (1990) argues that its origins as a critique of conventional agricultural systems make agricultural sustainability difficult to define; it represents the alternative to an ill-defined concept – conventional agriculture. From this basis, sustainable agriculture has at times been defined as a set of agricultural practices. This definition has been called means-based or means-oriented, referring to the fact that the approach focuses on the means of improving agricultural systems rather than on the end results desired.

Using the concept in this way is problematic, argues Hansen (1996), because it relies on circular logic. “It is logically impossible to evaluate the contribution of an approach to sustainability when adherence to that approach has already been used as a criterion for evaluating sustainability” (Hansen 1996). Von Wirén-Lehr (2001), on the other hand, suggests that sustainability can be defined as a set of agricultural practices: “means-oriented concepts a priori determine which agricultural measure is sustainable and provide defined prescriptions on how to achieve sustainable agricultural production…” This suggests that once an agricultural practice has been demonstrated to contribute to sustainability, it is safe to use its adoption as an indicator of the sustainability of agricultural systems. However, von Wirén-Lehr (2001) also points out that this approach does not incorporate the case- and site-specific circumstances that affect the success of an agricultural practice. Due to the high degree of heterogeneity in global agricultural landscapes, there can be no single set of practices that is optimal everywhere. This is exemplified in a study of the environmental impacts of organic farming in Denmark, where research found that on certain soils there was little difference in nitrogen leaching between organic and conventional practices (Hansen et al. 2001). Thus the means-oriented concept of sustainability falls short on two fronts: it is often difficult to evaluate and it may be insufficiently adaptable to local conditions.

Agricultural sustainability can be defined as a philosophy without being simplified into a list of methods. Neher (1992) described sustainable agriculture as a philosophy that “integrates land stewardship with agriculture.” Similarly, Schaller (1990) described it as “a marriage of agricultural productivity and profitability, resource conservation and environmental protection, and the enhancement of health and safety.” These definitions represent a concept of sustainability that focuses on the process of developing adaptable, site-specific agricultural practices with the ultimate goal of sustaining the land’s productive potential for future generations.

Even as the definition of sustainability becomes clearer, an important question remains: how can agricultural sustainability be operationalized? How do we know what we are striving for and how can we measure our success in achieving it? Agricultural sustainability can be broken down into three components: environmental, economic, and social. These distinctions are somewhat artificial as overlap exists between each of them, yet dividing it into components may be useful for identifying where action is needed (Goodland 1995). A similar triumvirate of sustainability emerged from Neher (1992): "plant and animal productivity, environmental quality and ecological soundness, and socioeconomic viability." Sustainability requires all three. Without productive soil and clean water, or in the event of excessive accumulation of pollutants and toxins, agriculture will fail. The economic and social viability of agriculture are both dependent on the existence of a natural resource base sufficient to support the production of food, thus neither of them can be sustainable without environmental sustainability (van der Werf and Petit 2002). Similarly, if a system is not sufficiently profitable, it will not be economically sustainable even if it is ecologically sound (Neher 1992).

The relationships between the three components of sustainability differ regionally. The concept of environmental sustainability in agriculture developed in regions of the world characterized by food surpluses, where, because their basic needs are amply met, consumers and farmers are able to plan for a distant future and consider their impacts on the well-being of future generations. In poorer regions characterized by food shortages, people's behaviors must be ruled by their current needs; without adequate food supply, ecological degradation is the likely result as desperation forces people to try to eke out a living on marginal lands. In these areas, increasing production and the equity of distribution are of the foremost concern (Hansen 1996). This concern is expected to become even more pressing in the future as climate change impacts agriculture, potentially resulting in droughts in areas already afflicted by food shortages (Slingo et al. 2005). The philosophy of sustainable agriculture must be flexible enough to accommodate such regional differences.

Principles of Sustainability

In order to successfully operationalize sustainability, the concept is often further broken down into a set of goals (Hansen 1996; von Wirén-Lehr 2001). Using a goal-oriented approach encourages empirical evaluation of the success of projects, avoiding the pitfall of circular logic that can sometimes hinder approaches that view success as the adoption of particular practices. The challenge of the goal-oriented approach is setting goals that are sufficiently rigorous but are still adaptable to local conditions. Any set of goals designed to be universally applied must be broad, thus it is advisable to set up goals at the region and/or farm level in addition to global-scale goals. In order to distinguish between the two scales, I will refer in this paper to broad, universally applicable *principles* and to more localized and specific *goals*. In order to formulate a list of principles, it is useful to glean from the work of scientists, farmers, designers, and other thinkers who have already taken up this challenge.

William McDonough is an architect and designer renowned for his work in sustainable development and green technologies. He believes that human

The McDonough Principles
(McDonough 1993)

1. Waste equals food
2. Rely on current solar income
3. Respect diversity

design should be modeled after "certain fundamental laws that are inherent to the natural world" (1993). The first principle that he recognizes is drawn from the field of physics: matter cannot be created or destroyed. McDonough points out that all the raw materials we will ever have to work with are already here on the planet. Therefore, if we want to have materials in the future, we must recycle everything. Every item that we currently view as "waste" is simply a raw material for another process. In agriculture, it is easy to see how this principle can play out; human waste, food waste, yard waste all contain nutrients and energy that can be cycled back to enrich the soil. In addition, cow manure can be used to generate power, pest insects can help nourish chickens, and a myriad other cycles within a complex farm system can reduce the need both for external inputs and for disposal of waste.

McDonough's second principle is to "rely on current solar income." This principle draws on two observations: that global oil supplies are near or at peak production and are therefore expected to decline in the coming decades; and that greenhouse gases produced through the burning of fossil fuels are accumulating in the atmosphere and forcing global climate change. For both of these reasons, current reliance on fossil fuels is clearly unsustainable. McDonough's answer to this challenge is to rely on solar energy. Other solutions include increases in energy efficiency and use of alternative energy sources including wind and hydro.

The third challenge issued by McDonough's Principles is to respect diversity. McDonough writes that "the characteristic that sustains this complex and efficient system of metabolism and creation is biodiversity. What prevents living systems from running down and veering into chaos is a miraculously intricate and symbiotic relationship between millions of organisms, no two of which are alike" (McDonough 1993). Stated another way, this is the diversity-stability hypothesis, an important and much-discussed topic in ecology. The relationship between diversity and ecosystem function is complex and surprisingly difficult to pin down experimentally; studies of it have produced mixed results (Chapin et al. 1998). Even so, it is widely believed that biodiversity plays an important role in stabilizing ecosystems. The implications of this for farming are many, ranging from choices about which crops to cultivate to management decisions on a farm's woodlot. Diversity can be incorporated for economic reasons – a farmer who cultivates twenty crops has less to lose if a pest wipes out one crop altogether – or for ecological ones, as in designing farms in order to maximize on-farm wildlife habitat and connectivity (Smeding and Joenje 1999). In addition to on-farm diversity, agricultural practices can affect species beyond the farm's boundaries. For example, runoff from farms can pollute waterways with chemicals and excessive nutrient loads, degrading even distant terrestrial and aquatic habitats. This habitat degradation can contribute to the loss of biodiversity in those distant habitats.

In summary, according to the McDonough Principles, by encouraging tight nutrient cycling (with the common definition of "nutrient" expanded to include all that which we generally consider "waste"), eliminating the use of fossil fuels, and supporting on- and off-farm biodiversity, farmers would be working toward a sustainable agriculture.

Another set of principles (termed "system conditions" by Brukardt (1997)) comes from The Natural Step, an international organization devoted to promoting sustainability. While there is some overlap between these system conditions and McDonough's principles, this approach also adds to them. The first principle is that "substances from the Earth's crust must not systematically increase in nature." The term "substances from the Earth's crust" refers to metals, fossil fuels, and other substances that are mined and accumulate in greater and greater quantities above ground. Though the wording of this principle is not completely clear (the earth's crust is not part of nature?), it captures an important idea – that metals are concentrating at toxic levels in natural systems and the burning of fossil fuels results in the accumulation of GHGs in the atmosphere. The use of the word "systematically" seems to imply that the problem lies in the continued and indefinite accumulation of these substances beyond the environment's capacity to assimilate them.

The Natural Step's Four System Conditions (Brukardt 1997)

- Substances from the Earth's crust must not systematically increase in nature.
- Substances produced by society must not systematically increase in nature.
- The physical basis for the productivity and diversity of nature must not be systematically diminished.
- Just and efficient use of energy and other resources.

The second principle states that "substances produced by society must not systematically increase in nature." Chemical pesticides and fertilizers are examples of such substances.

"The physical basis for the productivity and diversity of nature must not be systematically diminished." As human populations increase and agriculture follows suit, a greater and greater proportion of global net primary productivity is harnessed for human use, leaving less available to natural systems. On a smaller scale, this principle can be interpreted as a mandate to conserve soil, which is the physical basis for productivity and diversity in agroecosystems.

Fundamental principles of productivity and theoretical sustainability (Ohlander et al. 1999)

- Life-supporting ecosystems must be preserved or enhanced
- Agricultural land, other land, water and air must be… used in such a way so that they are maintained or upgraded
- Renewable resources must be used…such…that their use does not cause a degradation of the environment.
- The degradation of non-renewable resources must be kept within acceptable limits. This requires recycling.
- Non-renewable fossil fuels should not be used to a larger extent than is permitted by the ability of the global ecosystem to recycle the residual products through environmental work into biomass or rock deposits. For instance, the carbon dioxide generated must be absorbed by the ecosphere.

Finally, in order for agriculture to be sustainable, Brukhart (1997) claims it must make "just and efficient use of energy and other resources." This principle includes two separate issues, justice and efficiency, both of which derive more from values than from laws, theories, or observations. The term "just" is highly value-based and is subject to individual interpretation. I equate it with equity and posit that systems that do not result in equitable distribution of food are not socially sustainable. Efficiency has two implications for sustainability: efficient use of resources implies minimal waste and it also suggests lower levels of consumption of limited resources.

In a 1999 journal article entitled "Visions for ecologically sound agricultural systems," Ohlander, Lagerberg, and Gertsson lay out five principles particular to the sustainability of agricultural systems. Similar themes arise, but with a particularly agricultural bent. Ohlander et al. call for the preservation or enhancement of "life-supporting ecosystems." This is a more holistic approach to biodiversity – rather than focusing at the level of the species, they approach the issue from a landscape scale, emphasizing healthy, functional systems. In addition, these principles emphasize recycling; conservation or improvement of land, water, and air quality both on and off the farm; and a decline in the use of fossil fuels.

Nature's laws, strategies, and principles
(Benyus 1997)

- Nature runs on sunlight.
- Nature uses only the energy it needs.
- Nature fits form to function.
- Nature recycles everything.
- Nature rewards cooperation.
- Nature banks on diversity.
- Nature demands local expertise.
- Nature curbs excesses from within.
- Nature taps the power of limits.

Another set of guidelines comes from Janine Benyus in her book, *Biomimicry* (1997). Benyus outlines what she calls "laws, strategies, and principles" underlying the way nature works. She contends that human designs should obey them. Among this list, we recognize some common themes: reliance on contemporary solar energy ("nature runs on sunlight"); waste equals food ("nature recycles everything"); preservation of biodiversity ("nature banks on diversity"); toxins must not accumulate in nature ("nature uses only the energy it needs" and "nature curbs excesses from within").

Perhaps the most important addition to the sustainability principles to come out of Benyus's list is "nature demands local expertise." Agricultural systems will be most likely to retain diversity and minimize fossil fuel use if they serve the local community. Since community demands are diverse, the agricultural system that supplies those demands will be diverse as well. In addition, locally produced food requires less transportation and thus results in less fossil fuel use to get it from the farm gate to the consumer. In addition, the "local" principle demands that farming practices be adapted to the land where they are being used. As the writer, philosopher, and farmer Wendell Berry put it, "the land is too various in its kinds, climates, conditions, declivities, aspects, and histories to conform to any generalized understanding or to prosper under generalized treatment… Kindly use depends upon intimate knowledge, the most sensitive responsiveness and responsibility" (Berry 1977). Benyus's principle promotes this view.

In his paper on environmental sustainability, Goodland (1995) emphasizes the importance of local expertise. He suggests a very simple definition of sustainability that obeys biophysical laws, and then leaves the rest up to individual nations or regions (and we might further recognize that agricultural systems must be locally-adapted at a much finer scale). Goodland's definition is appealing in that it is based on a literal understanding of the word *sustainable*, meaning "able to be maintained over time." He argues that "two fundamental environmental services—the source and sink functions—must be maintained unimpaired" for a system to be sustainable. From this basis it is possible to develop three principles of sustainability: systems must produce no more waste than can be assimilated by the environment; renewable resource harvest must stay within the regenerative capacity of the system that generates the resource; and nonrenewable resource depletion must be set below the rate at which substitutes become available.

Rules for environmental sustainability (Goodland 1995)

- Waste emissions should be kept within the assimilative capacity of the environment
- Harvest rates of renewable resource inputs should be within regenerative capacities of the natural system that generates them
- Depletion rates of nonrenewable resource inputs should be set below the rate at which renewable substitutes are developed by human invention and investment

These three principles encompass many of the other principles listed above. For example, several of the previous lists pointed to the unsustainability of relying on fossil energy. Reliance on fossil fuels violates two of Goodland's principles: waste (e.g. greenhouse gases) is emitted at a higher rate than it can be assimilated into the environment and non-renewable resources (oil, coal, etc.) are depleted faster than substitutes are developed. Goodland's approach addresses the root of the problem, rather than its mechanism. With some modifications and additions, Goodland's rules can form the basis for our list of broad-scale principles for agricultural sustainability:

- Waste emissions should be kept within the assimilative capacity of the environment (including greenhouse gases and nutrients)
- Harvest rates of renewable resources should be within the regenerative capacities of the natural system that generates them (for example, erosion rates should not exceed rates of pedogenesis)
- Depletion rates of nonrenewable resources should be set below the rate at which substitutes are developed (including biodiversity as a nonrenewable resource for which there is no substitute)

In addition, for agricultural systems to be socially sustainable they must meet the nutritional requirements of the planet's human populations. As such, the following two principles should be added to the list:

- Food production should be maintained at a level sufficient to feed all people
- Food should be equitably distributed

These principles provide a conceptual framework for agricultural sustainability, but when applied to a specific region or system, more specific goals are needed, goals that will be highly variable depending on local environmental conditions and threats and the community's needs. Climatic, geographical, and socioeconomic conditions can all influence the suite of goals that comprise sustainability for a given region (Liebig et al. 2001). In addition, the relative importance of the same goals will differ regionally, resulting in different prioritization of evaluative criteria.

BRINGING IT HOME

The above list of general sustainability principles become more specific and informative when set in the context of Vermont's economic and natural environment.

- Waste emissions should be kept within the assimilative capacity of the environment (including greenhouse gases and nutrients).

As discussed earlier, phosphorus loading is a serious problem in Vermont, resulting in cultural eutrophication of Lake Champlain. The problem takes on added complexity due to the nature of phosphorus, a nutrient that adsorbs to soil particles and as a result concentrates at higher and higher levels in the soil over time. Many areas of Vermont's Champlain Valley have been in agricultural production for many decades, resulting in accumulation of phosphorus. Even without further application of nutrients, soils may continue to be a source of nonpoint pollution. As a result, achieving the goal of **keeping phosphorus runoff levels within the assimilative capacity of the environment** may require efforts to actively remove phosphorus from soils and lake-bottom sediments.

Vermont farms also emit waste in the form of greenhouse gases (GHGs). This occurs directly on the farm through soil emissions of carbon dioxide and nitrous oxide, livestock production of methane, and exhaust from fossil-fuel burning farm equipment. In addition, some Vermont farms contribute to GHG emissions indirectly through their purchase of fertilizers (mineral nitrogen fertilizer production is extremely energy-intensive) and pesticides and through their reliance on imported feed, the transportation of which results in GHG emissions. In addition, many Vermont farms produce food for distant markets, increasing the GHG emissions associated with transporting food from the farm gates to the consumer. Thus, the goal of **keeping GHG emissions within the assimilative capacity of the environment** is a priority. Fortunately for farmers, opportunities exist for increasing carbon storage on agricultural lands, both in the soil and in woody biomass. In addition to reducing their GHG emissions, farmers may be able to increase carbon storage on their land, thereby offsetting some of their emissions.

- Harvest rates of renewable resources should be within the regenerative capacities of the natural system that generates them (for example, erosion rates should not exceed rates of pedogenesis).

Wind, which is responsible for large-scale, rapid erosion in the plains of the mid-western United States, is much less problematic in Vermont, where the best agricultural land is situated in valleys. Even so, agricultural practices that leave bare soil exposed can accelerate topsoil loss. Water erosion is also a concern. For example, bank erosion is occurring along the Huntington River, particularly on reaches that were historically straightened and channelized, and where there is no woody vegetation to help secure the soil. A goal for sustainable agriculture in Vermont should be **minimizing erosion such that it does not exceed pedogenesis.**

- Depletion rates of nonrenewable resources should be set below the rate at which substitutes are developed (including biodiversity as a nonrenewable resource for which there is no substitute).

One nonrenewable resource on which many farms heavily depend is fossil fuel. Many farms in Vermont are already hard at work to reduce their dependence on oil. Solar and wind energy as well an anaerobic digestion of livestock manure and on-farm production of biofuels are all methods that some Vermonters are using to power their farms. These technologies, as well as increases in energy efficiency, are all effective ways for farmers to **reduce or eliminate their use of fossil fuels.**

Vermont's native biodiversity is threatened by habitat loss and fragmentation, by invasion of non-native species, by pollution (including excessive nutrient loading and the resulting eutrophication), and by global climate change. Viewed on a macro-scale, it may seem that climate change does not threaten the existence of species, but will merely shift species' ranges further north. Certainly, Vermont's flora and fauna have migrated in response to climate change many times over their evolutionary history. However, it is the synergistic effects of environmental problems that is the most alarming; given the degree of habitat loss and fragmentation, some species' migrations are likely to be greatly inhibited, which could result in the loss of species that are unable to adapt quickly or migrate freely in the face of changes. As a result, loss of biodiversity is associated with GHG emissions, pollution, and habitat fragmentation. To the extent possible, Vermont farms **should maintain wildlife habitat on the farm as well as habitat connectivity across the landscape.**

- Food production should be maintained at a level sufficient to feed all people.

Vermont's agriculture industry, though robust and important to the state's economy, does not produce the volume or variety necessary to support its population. This is not surprising, nor is it a problem, as Vermonters are able to buy inexpensive foods produced all over the world. In turn, Vermont exports large volumes of the foods that the landscape is well-suited to producing, including maple syrup and dairy products. These industries are profitable and serve as Vermont's niche in the world of specialized agriculture, suggesting that it may make sense to develop sustainability standards for these two industries.

Viewed on a longer time scale, however, the specialized nature of Vermont agriculture may not be sustainable at all. As oil reserves deplete, fuel prices may skyrocket. Given that agricultural specialization is contingent on long-distance transportation of food products, rising fuel prices could render current levels of specialization economically unsustainable. In addition, global climate change potentially threatens the viability of the maple sugar industry in Vermont; a number of studies have suggested that sugar maples

(*Acer saccharum*) will decline in the northeastern United States as their range shifts northward in response to climate warming (Whitney and Upmeyer 2004). It appears likely that in the future, Vermont agriculture will need to shift its emphasis from specialization to diversification in order to supply more of its residents' food needs, and that within a few generations, maple sugaring may no longer be a viable industry in Vermont. As a result, an important strategy for increasing the long-term sustainability of Vermont agriculture's may include **increasing the productivity and variety of Vermont crops to more nearly fulfill the nutritional requirements of the state's population**. In addition, diversification of farms may be necessary to ensure their long-term viability in the face of unpredictable change.

Another constraint that affects Vermont's ability to produce sufficient food for its population is its short growing season. Though climate warming is expected to lengthen that season to some extent, Vermont's food systems will still be constrained by the region's long winters. If Vermont is to become more locally self-sufficient, its food systems will have to be heavily reliant on food preservation. Maintaining historic food preservation methods, as well as developing new ones, may be essential elements of a fossil fuel independent agriculture for Vermont.

- Food should be equitably distributed

It is possible, of course, that rising fuel prices will not compromise the current system of specialized, simplified food production and long-distance transportation, but that instead the increased cost will be passed to the consumer in the form of higher food prices. The likely result of this shift would be increasing inequity in the distribution of food as lower income people were less and less able to afford nutritious food. Again, localized food systems look like a good solution; as petrochemical-derived fertilizers and transportation costs drive up the price of conventionally-produced foods, the economic viability of local food systems may increase. Building a local agriculture that is more productive and more diverse looks like a potential solution to the possibility of increasing inequities in food availability.

In summary,

- keeping phosphorus runoff levels within the assimilative capacity of the environment,
- keeping GHG emissions within the assimilative capacity of the environment
- minimizing erosion such that it does not exceed pedogenesis,
- reducing or eliminating the use of fossil fuels,
- maintaining wildlife habitat on the farm as well as habitat connectivity across the landscape, and
- increasing the productivity and variety of Vermont crops to more nearly fulfill the nutritional requirements of the state's population

are goals that derive from a broader set of sustainability principles, but are specific to the constraints and challenges faced by Vermont's farmers. In the context of an individual farm or a specific agricultural practice, these goals will have to be further narrowed and prioritized; one farm may need to focus almost exclusively on phosphorus control while another might prioritize fossil fuel independence. There is no simple formula that can guide every system onto a sustainable path.

Envisioning Sustainable Food Systems

Agroecosystems are overwhelmingly complex.
The numerous ecological processes that tie people, crops, weeds, animals,
micro-organisms, soil, and water together into a functioning, on-going ecosystem are so intricate that they can never be fully described, nor can they be fully comprehended."
Gerald Marten (1988)

The intellectual exercise of defining sustainability and setting standards for its implementation is a challenging one, but is straightforward when compared to the realities of plants in the soil. The armchair farmer dwells in a garden of ideas and numbers and when he stands up from his work, his knees are clean. The real farmer encounters reality in all its messy incarnations: "large and rapacious animals, hegemonies of weeds, a few billion examples of every insect in the field guide, killing frosts in June and September, and boulders of inconceivable weight and number" (Pollan 1991). A set of principles takes us only so far in providing useful information to the farmers who actually grow our food.

This chapter focuses on envisioning solutions, developing food systems in a new model in which sustainability is built into the design, rather than addressed as an afterthought. This approach is rooted in the idea of structuring agricultural systems to mimic natural systems. This method is in use on the prairies of the Midwest and in the tropics. Bringing the concept home to Vermont, a number of manifestations are possible, three of which are discussed. Forest gardening is one very promising possibility that has the potential to yield a diverse array of foods with minimal inputs. A forest garden is currently under development for the Teal Farm property; the garden will serve as a site for demonstration and experimentation, as well as a source of food.

LOOKING OUT

The truth is, it is extremely difficult to make agriculture sustainable. Of course it is a challenge to break old habits: we have a massive infrastructure and institutional memory in place, perpetuating highly degrading agricultural practices. However, there are two reasons, fundamental to agriculture, that agricultural problems are so difficult to fix. First, as Wes Jackson often points out, agriculture is an extractive practice; it is the harvesting of energy and nutrients from the environment for our own use. Perpetual extraction leads to depletion. As human population levels increase, that extraction accelerates and depletion follows suit.

The second challenge is that living systems are complex. Rich with interacting organisms and ecological processes, ecosystems are difficult to control and predict. Agricultural systems are living systems, termed agroecosystems. They are simplified, often highly so. While they are usually made up of a smaller number of species than analogous natural systems, they also represent a reduction in the number of interacting ecological processes, for it is one process and one process alone that most farmers seek to enhance: production. The speedy and efficient conversion of carbon dioxide into energy-rich carbohydrates is the primary goal and agroecosystems are simplified and refined to accelerate that process. As a result, other ecosystem functions decline and the soil-conserving, water-retaining, nutrient-cycling, biodiversity-supporting properties of highly functional ecosystems are sacrificed. It is easy to jump from this understanding of the problem to a pat solution: we must build complex agroecosystems that perform these multiple functions. This is probably true. At the same time, however, we must recognize that, by its simplest measure, productivity may decline as other ecological processes become more robust.

Due to the extractive nature of agriculture, the complexity (and accompanying unpredictability) of ecosystems, and the power of habit and existing infrastructure to direct our actions, the challenge of creating truly sustainable food production systems is a great one. It will require numerous initiatives and innovations. While some solutions to agricultural problems will come from within the status quo, as farmers discover that nutrient conservation can be cheaper than fertilization, for instance, other solutions need to come from fresh approaches, from systems that are radically different. One such approach is ecosystem mimicry – agricultural systems that mimic natural systems. This approach, which is being tested and promoted by Wes Jackson, John Ewel, and Janine Benyus, relies on the wisdom inherent in nature to teach us how systems work best. It will not be easy to perfect, but it is worth the effort.

Biomimicry

This concept – looking to nature for inspiration in solving our own human problems – is not new. Indigenous cultures have been learning from and copying their environment for as long as they have existed, and now scientists are using the latest technological advances to mimic the processes that occur within a single cell. With her 1997 book, Janine Benyus coined a name for this phenomenon – biomimicry – and wove together the inspiring stories of biomimics in a range of fields, from biochemistry and materials science to primatology and computer science. Biomimicry can work on any of three levels: mimicry of form, such as copying the hooks on seeds to make Velcro; function, for example studying photosynthesis to learn to capture solar energy; or ecosystem, including mimicking wetlands in order to purify water (Benyus, pers.comm.). Biomimetic agriculture is an example of that third level: ecosystem mimicry. It requires an understanding of the ecological processes at play in productive ecosystems, in order that we can capture that productivity, even amplify it, in our agricultural systems.

Mimicry and disturbance

Disturbance is a natural phenomenon. Our ecosystems have adapted to their respective disturbance regimes and are able to bounce back after disruption. When we understand the disturbance indigenous to a particular place we can shape the disturbances we cause to minimize their permanent impact. Without this understanding, our disturbances tend to be far more degrading.

Precolonially, the rangelands of the American west were home to massive herds of large ungulates. These animals moved over the landscape in a thundering disturbance, grazing the plants and trampling the soil. The rangeland evolved to be resilient to that disturbance, perhaps even depended on it. Despite their similarity to native ungulates, cattle degrade the plains, impacting native species and increasing erosion. Allan Savory (1988) introduced ranchers in the American west to rotational grazing, a method of high-intensity, short-duration livestock grazing that mimics the effects of natural herds of large ungulates. Though results have been mixed, some ranchers have used this method with great success, using intensive grazing to improve the health of the rangeland (Badgley 2003).

When Vermont's hillslopes were cleared for agriculture some 200 years ago, the disturbance was unnaturally intense and sustained, resulting in extensive soil loss that permanently altered the landscape's condition. Our current logging and farming practices are an immense improvement, but we might be able to do even better. The disturbances native to our region are generally small and transitory: in the mature northern hardwood forest, treefall produces small openings which soon succeed back to forest. On a somewhat larger scale, beavers create impoundments, beginning a wetland cycle moving from pond to meadow to forest again, until the beavers eventually return. These disturbances give our forests a patchy and dynamic structure.

The agriculture of Native Americans in the northeast was a similarly patchy disturbance: they cleared small tracts for farming, then abandoned those sites after eight to ten years, allowing natural revegetation to restore soil fertility (Soule and Piper 1992). Soule and Piper (1992) recommend using nature as a structural model for agriculture. In the northeastern United States, a region dominated by temperate deciduous forests, the model is a forested landscape with patchy, transitory clearings filled with annuals.

Mimicry and succession

Natural systems that have been disturbed undergo succession, a progression of communities leading eventually to a metastable condition. Though there has been much debate about the mechanics and nature of succession, it is generally accepted that, in our region, an area that has been cleared of vegetation will be colonized first by annual, herbaceous plants, followed by perennials and woody vegetation. Fast-growing trees move in, shading out their competitors. Eventually, they too will be replaced, this time by the slower-growing, often longer-lived species that make up the mature community.

Our conventional agricultural system relies almost entirely on annual plants, those earliest of early-successional species. Annuals require extensive and frequent disturbance of their environment in order to persist – the soil must be tilled and all competitors removed. This phenomenon, a disturbance so persistent as to maintain a community in a perpetual early successional state, is unnatural to our environment and it leaves the soil vulnerable to erosion and leaching. Plants that remain in the ground for year after year serve to stabilize and protect the soil and its teeming microbial community.

The World Resources Institute estimates that over the last 40 years, 30% of the world's arable land has been rendered unproductive due to erosion. These catastrophic losses inspired Wes Jackson to found The Land Institute, an organization that researches and promotes the concept of "natural systems agriculture," a perennial-based, no-till agricultural system that mimics the structure and function of the mature prairie ecosystem. Work that has come out of The Land Institute so far includes study of the breeding of perennial grain crops (Cox et al. 2002), including assessing the genetic variability of wild perennials that may be suitable for breeding as perennial grains (DeHaan et al. 2003), as well as work on the development of perennial types of annual crops, such as wheat (Scheinost et al. 2001). The process of breeding to produce new crops is a gradual one, that will take many plant generations to, as it were, yield fruit. The Land Institute is chipping away at the problem of modern food production, laying the foundation for an agriculture reliant on perennials.

Mimicry and the polyculture

> *Polyculture is not music to a breeder's ears. When you are working in a polyculture, you take all the difficulties that you encounter in monoculture breeding and multiply them. You are not only selecting for high yields, large seed size, uniform maturation time, easily threshed seeds, low shattering, winter hardiness, disease and pest resistance, and climate tolerance, but also for compatibility – a plant's ability to perform well or even exceed performance when grown next to other plants. Janine Benyus (1997)*

Another component of the prairie ecosystem that The Land Institute seeks to mimic is its diversity. While modern agricultural practices rely on monocultures, natural systems everywhere are built of complex assemblages of species. The biomimetic alternative to the monoculture is the polyculture, a mixture of species planted together. The main drawback to polyculture planting is in harvesting, since our machinery cannot sort out one crop from another. The rewards of the polyculture, though, are in its control of insect pests and disease. Arthropod-plant interactions are extremely complex, and it is dangerous to make sweeping generalizations about their ecology. However, it has been empirically demonstrated that well-chosen polycultures usually receive less pest damage than monocultures (Andow 1991; Gurr et al. 2003). Certain plants that are especially attractive to pests can be planted among crop plants, effectively drawing the herbivores away from the crop. One example is the yellow rocket which draws the diamondback moth away from cabbage plants (Badenes-Perez et al. 2005). Agroforestry has the potential to maximize the pest control benefits of polycultures, as tree and crop combinations have a high degree of niche diversity and complexity, encouraging a greater insect diversity and reducing the risk of outbreaks of individual pest species (Stamps and Linit 1997).

Biodiversity and ecosystem function – a closer look

One of the key assumptions underpinning the use of polycultures and other complex agricultural models is that biodiversity is good for these systems. Though it has often been posited that biodiversity yields ecological function, and that more diverse systems are more productive, resilient, stable, and/or sustainable, this hypothesis has not been upheld during testing (Chapin et al. 1998). Instead, the results have been mixed and we find it impossible to make sweeping statements about the ecological ramifications of biodiversity. It may be the case that each species in a diverse system functions slightly differently and that as a result the whole system functions at a higher level than any individual species (or less diverse grouping of species) functions. On the other hand, ecosystems tend to have a great deal of redundancy built into them, with different species overlapping in function. From that point of view, a simplified system could simply reduce redundancy without reducing function, depending on which species are eliminated. Alternatively, redundancy may be viewed as an insurance policy, buffering an ecosystem against changes over time (Vandermeer et al. 1998).

In fact, there may be no overarching rule about the relationship between biodiversity on agroecosystems and ecological function. Rather, localized solutions and adaptive management may be the best approaches for maintaining high ecological function. In fact, careful tending by an attentive farmer may strengthen the link between diversity and function. "Existing complex agroecosystems are not random combinations of components. They have survived under continuous selection by the farmer to improve on low-value components" (Vandermeer et al. 1998). Localized adaptive management is likely to increase diversity on the landscape scale, though at a smaller scale, different farms may end up with different levels of diversity due to constraints imposed by their land or by their goals and values.

Despite the lack of conclusive evidence in the literature, it is still widely accepted that highly simplified systems are more vulnerable to catastrophe than are complex systems. "Intensive arable monocrops are potentially more susceptible to perturbations in climate and global economics but are buffered by technology, such as irrigation, and financial capital"(Vandermeer et al. 1998). Perhaps, then, biodiversity on the farm offers an opportunity to move away from agrotechnology, with its high inputs of fossil fuels and chemicals, and toward a reduced dependence on unsustainable use of energy and chemicals (Smeding and Joenge 1999).

The Land Institute is less concerned with pest control than it is with disease. Given the perennial nature of the cropping system they are working to develop, the typical pathogen control practices of tillage and crop rotation are not feasible. Polycultures of different species with varying resistance functions will be an important component of their disease control strategy (Cox et al. 2005).

BRINGING IT HOME

The landscapes of Vermont are naturally forested ones, with few exceptions. Trees thrive here, and the land thrives under them – its soils guarded from excessive erosion, its nutrient cycles tight. As we seek the services a forested ecosystem provides, we will be integrating more and more trees into our agricultural system. Fortunately there is already a farming system designed on this concept: agroforestry.

Agroforestry integrates woody plants with crops and/or livestock, and it takes many forms including alleycropping, silvopasture, windbreaks, riparian buffer strips, and forest farming (Beetz 2002). In Vermont, a variety of opportunities exist to improve the sustainability of agricultural systems by incorporating agroforestry practices. For example, forest gardens represent a biomimetic agricultural alternative that can provide a variety of foods with low environmental impact. LivingFuture is preparing to implement a forest garden on the Teal Farm. In addition, other forms of agroforestry may provide a way for farmers to control erosion and nutrient fluxes while making productive use of marginal farmlands. Many riparian areas in Vermont are used for agricultural purposes from row cropping to cattle grazing. Many of these areas suffer from erosion and contribute to nutrient loading in streams, rivers, and lakes. Growing tree crops in the riparian zone, whether in a forest garden, as livestock fodder, or for biomass energy production, may provide a way for farmers to maintain productive use of riparian areas while preventing excessive erosion and controlling nutrient flows.

Agroforestry and Climate Change

Forest management is one important mechanism by which atmospheric carbon can be reduced. According to Montagnini and Nair (2004), this reduction can be achieved through a combination of carbon sequestration (e.g. afforestation and reforestation), carbon conservation (conservation of existing forests), and carbon substitution (e.g. conversion of forest biomass into durable products or increased use of biofuels). Agroforestry has the potential to play an important role in carbon sequestration as it increases the carbon storage on agricultural lands.

Forest Gardening

In 1950, J. Russell Smith published *Tree Crops: A Permanent Agriculture.* In this book he argues for a multi-layered agricultural system with herbaceous crops growing under a canopy of trees. The reasoning is based largely on the importance of soil preservation. An agriculture more suited to the land would rely on trees, which naturally grow there.

The concept of permanent agriculture was re-envisioned by Bill Mollison and David Holmgren in 1978, when they coined the term permaculture. “Permaculture (**perma**nent agri**culture**) is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems” (Mollison 1990). Permaculture describes an agricultural system that integrates trees, shrubs, and herbs with livestock to create managed, productive ecosystems, but the concept has grown to represent a self-sufficient, sustainable, agrarian way of life. A worldwide movement has developed, promoting and living by the complex and rich system that is permaculture.

Forest gardening is a common practice in the tropics. Surprisingly, the consistently warm, wet climate can be a hindrance rather than a help to agriculture, causing acceleration of chemical weathering and more severe infestations of pests. These constraints make it ever more necessary to mimic the natural structure and function of the forest to preserve fertility and control pests (Ewel 1986). Tropical homegardens yield a diverse array of fruits, nuts, and other products. Application of this model in temperate climates has been more rare. Robert Hart (1990) created a forest garden on his property in England to demonstrate that the concept was viable in temperate climates as well as in the tropics. He describes his own temperate forest garden as a closed ecosystem, structurally diverse and rich in species and varied products. Some examples of foods grown in his garden are apple, plum, gooseberries, blackberries, and blackcurrants.

Forest Gardens Everywhere?

"As one component within a landscape mosaic…diverse agroforests and prairie mimics can play an essential role – perhaps not a substitute for other modes of agriculture, but a complement to them" (Ewel 1999).

Smeding and Joenje (1999) discuss the importance of integration of farms into the greater landscape. Farms should be planned, they argue, in part on the basis of their landscape context, in order to promote similarity to surrounding habitat types, connectivity with ecologically related habitats, and to express the potential for variation inherent in abiotic conditions. The authors call these the "ecological keynotes" and suggest that applying them will lead to "compatible green infrastructures that will positively influence each other and may also restore characteristics of the landscape" (Smeding and Joenje 1999). Thus with planning and attention to the biotic and abiotic character of the land, agriculture can become a compatible component of the whole landscape rather than a blight.

Forest gardens offer a way to accomplish this goal; integrated with other farming methods, they increase structural diversity, offer ecological services, and provide wildlife habitat.

As forest farming is becoming more common, resources are appearing that highlight specific plants. *Uncommon Fruits for Every Garden* (2004) devotes a chapter each to 23 fruits, describing each plant and giving instructions for its cultivation, propagation, harvest, and use. A paper by Josiah and colleagues (2004) offers estimates of market values for many of the same fruits, as well as for decorative woody plants.

For diversified organic farms, incorporating a forest garden could be a way to maintain productivity while protecting the landscape's natural resources. This idea was explored in a study in the Chesapeake Bay watershed (Robles-Diaz-De-Leon 1999). Researchers designed a theoretical riparian forest garden, calculating the area per acre occupied by different crop plants including filbert, pecan, blueberries, elderberries, and more. From these estimates, projected gross income was calculated to be $60,694.30/ha/year. This value does not include any maintenance, harvesting, or marketing costs; obviously, net income would be much lower. An additional caveat is that the model assumes a steady market, but the market for most non-timber forest products is highly volatile (Marla Emery, pers.comm.). Farmers expecting to make money from a forest garden would have to devote significant time and energy to marketing, and would not be able to depend on their forest garden for a predictable income. Despite these challenges, the estimated gross income demonstrates that a forest garden could be of significant economic value to a farmer.

LivingFuture's Forest Garden

Currently, a forest garden is being planned for the Teal Farm in Huntington, Vermont. The garden site is about a half acre in size adjacent to the farm's driveway and was formerly part of a sugarbush. Currently, however, sugar maples are no longer regenerating on the site; beech saplings dominate the understory. Potential is low for sustained use of the site for maple syrup production, so management of the site exclusively as a sugarbush no longer makes sense. The site is poorly suited to traditional methods of intensive agricultural use due to its rocky soils and pit and mound topography. In addition, the site is located about a quarter mile from the buildings and so is best suited for low-intensity usage; according to the principles of permaculture, the highest-intensity use of land should occur closest to the home, where maintenance is convenient and requires less energy and attention. Despite these drawbacks, the site has the potential to play an important role in the farm's food production system. The vegetation on the site, including sugar maple (*Acer saccharum*), basswood (*Tilia cordifolia*), blue cohosh (*Caulophyllum thalictroides*), plantain-leaved sedge (*Carex plantaginea*), and silvery spleenwort (*Deparia acrostichoides*), suggests that the site is nutrient-rich with good potential for productivity. A low maintenance forest garden is an excellent use for this site. Vegetation will be steered toward a suite of native edibles and medicinals including juneberry (*Amelanchier* spp.), elderberry (*Sambucus canadensis*), ramps (*Allium tricoccum*), ostrich fern (*Matteuccia struthiopteris*), American ginseng (*Panax quinquefolius*), goldenseal (*Hydrastis canadensis)*, red raspberry (*Rubus idaeus*), and wood nettle (*Laportaea canadensis*). In addition, the sugar maples on the site will be tapped as long as they are vigorous enough. The desired result is a low-input garden that yields a nutritionally diverse array of foods.

Due to the location of the forest garden, one of the primary constraints on its design is that it require few inputs, either of labor or soil amendments. As a result, the garden is designed to sustain itself to the maximum extent possible. The most intensive inputs a garden requires are: control of competition, control of pests, fertilization, planting, and harvesting. In a typical garden, competition is controlled through tilling, weeding, and sometimes even herbicide use. Tilling is impossible in the rocky, root-filled soil of this site, and is undesirable as it disrupts soil structure and can accelerate erosion and nutrient leaching. Instead of controlling competition through manual and chemical means, the forest garden is designed to manipulate competition to minimize its negative effect on crop plants. This is done by planting a dense polyculture, wherein little space is left for weeds. When a weed appears, it can be removed once and replaced with a crop plant or a groundcover plant to prevent the weed's return. While planting densely means that crop plants will be competing with one another, potentially suppressing the yield of all of the crops, the hope is that careful management and adaptation can yield polycultures that do not compete directly. Dave Jacke (pers. comm.) explains that competition between a shrub and an herb is less severe than competition between two herbs since they use resources in different ways. Thus, plant pairings can be chosen based on their ability to effectively partition a resource, rather than compete for it directly. There is no way to determine *a priori* which polycultures will thrive and which will not, thus constant adaptation is the forest gardener's most important tool.

Instead of relying on pesticides, pest control in the forest garden is hopefully achieved passively. The diversity of plants is expected to support a diversity of arthropods, thereby keeping individual herbivores in check. In practice, however, polycultures are not always less vulnerable to pests; again, constant adaptation is required to develop polycultures that effectively reduce pests. In the event that pests do attack a crop, polycultures have an advantage in that they produce many crops; damage to one represents less of a hardship.

Fertilization is an expensive, time-consuming, and potentially environmentally damaging agricultural input. The forest garden is being designed to minimize fertilization requirements. This is done in a number of ways. First of all, because the crops grown in the garden are perennial, there is no tilling and roots stay in the soil year-round. This prevents erosion and maintains soil structure, hopefully minimizing nutrient leaching. In addition, the pit and mound topography of the site will remain undisturbed, capturing water and organic matter and allowing infiltration and decomposition to occur on the site. Many of the crops in the garden, particularly the woody species, will produce a great deal of unharvested biomass; all of this nutrient-rich organic matter will remain on-site, allowed to naturally decompose. Of course, harvesting will remove nutrients from the site. Compost may be added to amend the soil. However, some soil enrichment can be accomplished without any amendments. Incorporating plants known as "dynamic accumulators" in the forest garden can help maintain nutrient levels in the soil (Jacke 2005). These plants bring nutrients up from their roots and concentrate them in their leaves, effectively drawing the nutrients up higher in the soil profile. Sugar maple is a dynamic accumulator; its prevalence in the forest garden should help to maintain the site's richness. In addition, including nitrogen-fixing plant species in a forest garden increases levels of available nitrogen. Though no nitrogen-fixers are currently included in the design, they can be added to the garden in the event that nitrogen levels become limiting. Including a lot of nitrogen-fixers where they are not needed may actually be detrimental, as high soil nitrogen levels increases nitrous oxide emissions from soil.

Planting is another energy-intensive component of gardening. Utilizing perennials obviously reduces planting time, as plants live anywhere from a few years to several decades. Self-seeding plants further reduce planting time, as long as the gardener is not overly concerned with the garden's layout. Ramps (*Allium tricoccum*), for instance, self-seed and form dense mats that outcompete other plants in a small area. Given good growing conditions, this species is expected to sustain itself once it is established. In addition, some areas of the garden may be planted via spreading a seed mixture. Individual plants are then able to germinate wherever conditions are right, rather than the gardener having to alter conditions in order to place plants in particular locations.

The main drawback to this method is in harvesting; polycultures, particularly those comprised of a disorderly layout of crops, require attention, time, and energy to harvest. Large-scale monocrop production enables the use of mechanized harvesting and processing equipment, thereby minimizing the human effort required to achieve high yields. However, that decrease in labor is compensated for by the increased dependence on fossil fuels. Harvesting in the Teal Farm's forest garden will require regular checking during the growing season to monitor the readiness of crops for harvest. Plants will not be arranged in orderly rows or sections, but scattered throughout the garden in the microsites that best suit them. As a result, the harvester will need to wander through the garden attentively. Harvesting from the forest garden will resemble harvesting native edibles from the wild, except that they will all be concentrated within a half-acre plot.

The challenges of forest gardening may be balanced by the ecological advantages of this farming method. The characteristic that makes a forest garden different from any other polyculture is its structural diversity. Forest gardens can be structurally diverse in two ways. Vertical diversity is created through the integration of tree, shrub, and herb crops resulting in a multi-layered canopy. Two of the benefits of vertical structure are carbon sequestration (as large volumes of biomass are stored in forests) and wildlife habitat. The multi-layered garden provides shelter and habitat for foraging and nesting. There is some danger in creating wildlife habitat within a garden; the gardener ends up sharing the harvest with whatever creatures utilize the site. Again, constant adaptation is necessary to minimize herbivory; fencing or netting at certain times of year may be required to keep deer away from greens or birds out of a berry crop.

Structural diversity does not refer only to the multiple layers of natural forests (referred to as *vertical* structure). Forests are often patchy, their structure differing from site to site (*horizontal* structural heterogeneity). In Vermont's forest, one dominant natural disturbance is wind-throw, which creates open patches of varying sizes distributed across the landscape. Over time these patches close through the in-growth of adjacent trees' canopies and the upward growth of young trees. Native American agricultural practices are thought to have resembled these fleeting disturbances. The land, after its fertility decreased due to several years of cultivation, was left fallow for a decade or two, allowing the natural vegetation to restore its fertility (Soule and Piper 1992). Although that model is of limited use given our much higher food demand, it can inform our thinking about reducing our energetic inputs in the effort to maintain fertility. Less interference (in other words, less work) would be required if succession were allowed to occur. As gaps naturally close, we can open new ones by harvesting a tree and planting in the gap its removal creates.

A Second Alternative: Livestock Fodder

Dairy farming is a major component of Vermont agriculture; in 2002 agriculture contributed $556 million to the state economy and $400 million of that came from milk sales (New England Agricultural Statistics). Dairy farms are an integral component not only of Vermont's economy, but also its rural heritage. However, livestock grazing in the riparian zone is a serious environmental concern, as is nutrient runoff from milk-producing farms. Dairies are considered to be some of the biggest sources of phosphorous pollution in the Lake Champlain watershed (Anon. 1998). Reforesting riparian zones on dairy farms should be a priority, but making ends meet with a small dairy is hard enough without losing valuable land. In addition, nutrient cycling on dairy operations is fairly complex, and nutrient flow attenuation may not be achieved with a traditional buffer.

A major concern facing dairy farmers in Vermont is phosphorus runoff. Many Vermont dairies have more cows than their land can support, so they import feed. Importation of feed creates a net flow of nutrients into Vermont, since all the manure is being spread locally, rather than being transported back to where the feed was produced. Magdoff et al. (1997) point out the geographic separation of crops and animals, which results in two problems: the decline of nutrients on crop farms (resulting in the need for synthetic fertilizers) and the excess of nutrients on animal farms (resulting in pollution). Given this fact of modern agriculture, simple riparian buffers (those that are delineated and then left alone) do little to attenuate nutrient flows on dairy farms. Though the riparian buffer takes up nutrients initially, once it is established it is in a nutrient equilibrium, returning as much as it takes up (Lowrance et al. 1984). In fact, such a buffer could result in an increase in nutrient loading, as removing acreage from grazing to establish the buffer might result in the importation of a greater quantity of feed, thereby increasing the nutrient flow into the system.

Thus, in order for a dairy farm buffer to be effective at removing nutrients, it must be harvested regularly. With a regular removal of biomass, a buffer could remain a net sink for nutrients. The most effective buffer on a dairy operation would be one that produced livestock fodder. This system would minimize the need to import feed and would maintain its function as a nutrient sink through the regular harvesting of biomass. The simplest form would be hay, which provides more ecosystem services than row-cropping or over-grazed pasture. However, without woody vegetation, such a buffer would not stabilize eroding banks or provide the shade and woody debris required by stream fauna.

One possible solution is coppice-growing woody plants as livestock fodder. Admittedly, judging by the literature, woody livestock fodder is used mainly in harsh climates where herbaceous livestock feed is in short supply. For example, hill farmers in the Himalayas typically rely heavily on uncultivated woody fodder species, some of which have leaves of comparable digestibility and nutritive value to cultivated leguminous fodders (Singh and Bohra 2005). A study in New Zealand looked at willow as a supplement for cattle during the dry season, finding that willow supplementation was effective at reducing weight loss during prolonged drought conditions (Moore et al. 2003). Additional work in New Zealand demonstrated that willow and poplar tree fodders were similar in digestibility and metabolizable energy content to good quality lucerne hay (McWilliam et al. 2005). In West Africa, a study found that home garden production of leguminous fodder, including trees, was much more cost-effective than purchasing feed for dairy cattle (Agyemang et al. 1998).

Studies in the United States have looked at cattle browsing of willows. Pelster et al. (2004) looked at steers' effect on willows in montane riparian communities, finding that during certain times of year steers browsed willows so enthusiastically that it was best to exclude the steers from the riparian areas to minimize willow damage. This demonstrates that willow is palatable for cattle – at times even a preferred food source. In fact, cattle browsing of willow improves the forage quality in the following year, according to work by Phillips et al. (1999) in a montane riparian community. Though they did not observe an increase in nutritive value, they found that willow plants that had been grazed the previous year had 11% higher digestibility than ungrazed plants.

Willows are fast-growing and naturally occur in the riparian zone. Their nutritional value and digestibility also makes them good fodder for livestock. It is possible that dairy farmers could grow willows along rivers and streams on their properties and harvest the trees to feed to their cows, thereby helping to curb nutrient pollution by creating a cycle of nutrients within the farm, rather than allowing nutrients to flow through the farm into our waterways.

A Third Alternative: Biomass Energy

Another alternative land use that offers environmental benefits is the production of biomass fuel. Already popular in Europe and growing in popularity in the United States, biomass fuel provides a carbon neutral source of renewable energy (Volk et al. 2004). Woody plant species, especially poplar (*Populus* spp.) and willow (*Salix* spp.), are grown and harvested in short rotation cycles. The trees are planted in double rows and coppiced (or cut off at their base) after one year of growth. The stumps sprout, producing multiple trunks. After three years of growth, the aboveground biomass is harvested and the roots and stumps left in place to resprout. A single planting can be harvested seven to eight times (Volk et al. 2004).

In order to quantify the environmental benefits of converting cropland to hybrid poplar biomass production, Updegraff et al. (2004a) modeled three hypothetical conversion scenarios in a Minnesota watershed. Their findings suggested that conversion could contribute substantially to erosion control and reduction in forest harvesting. They were able to estimate the economic value of some environmental benefits. For example, projected savings in sediment-related maintenance costs for roads in the watershed over five years totaled between $236,171 and $359,761 depending on the amount of land converted (Updegraff et al. 2004a). These values are of limited value as they are simulations modeled for a particular watershed; however they serve to demonstrate the scale of potential benefits from conversion of cropland to biomass fuel production.

Modeling has also demonstrated the potential of biomass production to reduce peak flows and nitrate delivery, though the model predicts the opposite effect on phosphorus, possibly due to leaf litter decomposition (Updegraff et al. 2004b). The possibility of increased phosphorus yield must be further explored.

One of the potential drawbacks to short rotation woody crops (SRWCs) is the lack of diversity in a field of biomass crop. With careful planning, however, both structural and species diversity can be increased, thereby improving the habitat for wildlife. There are multiple species and hybrids of SRWCs that can be grown in polyculture (Volk et al. 2004). Though the diversity of a mixed stand of SRWCs would likely be lower than that of a native riparian natural community, planting a variety of species increases the stand's resistance to disease and pests. In addition, the farmer can rotate harvesting year, so that any given year there are three different age classes represented in patches on the landscape. This system provides a regular source of income for the farmer, who can harvest every year rather than every three years, and also provides consistent breeding habitat for shrub-nesting birds (Volk et al. 2004). A study in upstate New York found that nesting success in willow plantations was similar to natural habitats (Dhondt and Wrege 2003 in Volk et al. 2004). This suggests that strategically placed biomass crop fields could provide corridors for wildlife between forest fragments.

One of the important environmental benefits of SRWCs is their impact on global carbon cycles. According to Timothy Volk and colleagues (2004), SRWC biomass used to generate electricity is carbon neutral, meaning "that the amount of carbon released during the production, harvest, transportation, and conversion of the biomass is equal to the amount taken up by the growing crop." It is important to note that other greenhouse gases are produced during portions of the willow production system, though compared with fossil fuels these emissions are very low – on the same order of magnitude as wind and building integrated photovoltaic systems (Heller et al. 2004). Updegraff et al. (2004) took a slightly different approach in examining SRWCs role in carbon cycling: they calculated the amount of fossil carbon offset by biomass energy and added that value to the residual carbon left after SRWC harvesting (roots, stumps, and leaf litter) to come up with total sequestered carbon. For their study watershed, the model predicted sequestration rates ranging from 44,546 Mg for 4665 ha of land in SRWC production to 159, 848 Mg for 14,645 ha. However the numbers are calculated, it is clear that biomass crop production offers a sustainable alternative to fossil fuel derived energy.

Biomass crops are not a panacea, however. At this time, their cost is not competitive with that of fossil fuels such as coals. This is due in large part to the failure of the market to reflect the environmental and social costs of fossil fuels. Woody crops will not become widespread without some correction for that market failure, in the form of societal willingness to pay more either for renewable energy or for the negative effects of fossil fuels (Volk et al. 2004). In addition, start-up costs for biomass farming are high; three years in a row, farmers must invest in field preparation and planting, and harvest does not begin until after year four. Harvesting equipment is also a substantial investment that must be made before the farmer receives any income from the crops.

One approach to this challenge is the formation of cooperatives (Downing et al. 1998), which can lower planting costs. Cooperatives can also purchase planting and harvesting equipment and rent it out to members as needed, at cost. Collaborating enables growers to secure a more reliable market, as energy producers demand a steady fuel supply which an individual grower might not be able to produce. In Vermont, the McNeil power station is involved in the Salix Consortium, a New York-based group of researchers, power companies, and others working toward a viable commercial willow biomass industry (Downing et al. 1998). The involvement of Burlington's McNeil power station may enable Vermont communities to become involved in biomass energy production.

Biomass fuel presents a powerful opportunity for rural communities to work together to support local energy production and make a significant contribution toward global sustainability. As landowners look for ecologically sound, profitable land uses for their riparian zones, biomass production may become an exciting option, allowing a farmer to make a contribution to global environmental health through supporting alternative energy and to local water quality by protecting waterways with woody vegetation.

Measuring Our Success

Innovative approaches to agricultural sustainability are of little use without methods to measure their success. Because climate, soil, landform, and culture vary so greatly from place to place and even from decade to decade, there is no such thing as a universal answer to achieving sustainability in agricultural systems. As a result, we are forced to constantly assess and adapt our agriculture so that it fits the land and our needs. This chapter reviews the literature on assessment of agricultural sustainability before making recommendations for the assessment of LivingFuture's forest garden.

LOOKING OUT

A dizzying array of assessment methods exist, and, just as no agricultural practice fits on every landscape, no single assessment method fits every system. Understanding a broad spectrum of methods is essential to being able to select the most appropriate one.

Scale of Assessment

Assessment of agricultural sustainability can happen at a broad range of scales, all of which are useful in their own way. When considering the sustainability of agricultural systems in the context of global climate change, as well as the contribution of agricultural systems to greenhouse gas emissions, appropriate scales for inquiry include the global and national (Fischer et al. 2005; Parry et al 2005; Smith and Almaraz 2004). The global scale may also be appropriate for assessment of broadly applied agricultural technologies. Organizations such as the International Federation for Organic Agriculture Movements (IFOAM) specialize in the wide and rapid dissemination and promotion of broadly applicable agricultural information and methods; assessment on a similar scale would be useful to inform the continued development and refinement of those efforts. However, assessment on that scale is difficult and may tend to fall back on adoption of practices as a metric for success. This does not represent a true assessment of the sustainability of systems (Hansen 1996; Hansen et al. 2001; Payraudeau and van der Werf 2005).

Agricultural sustainability can also be evaluated at the regional level. While this level of assessment is primarily used to evaluate economic sustainability (Payraudeau and van der Werf 2005), it is also useful for the study of environmental impacts as it allows for the inclusion of the relationships between farms. In his review of region-level environmental impact assessment methods, Payraudeau and van der Werf (2005) point out the importance of including inter-farm relationships in assessment, as they can influence pollution emissions and resource consumption for a region. Despite this reasoning, some of the assessment methods they review fail to incorporate inter-farm relationships; the effect of these relationships may be difficult to assess.

A third scale for sustainability assessments is the farm scale. "The farm is the main management unit of the agricultural system" (Payraudeau and van der Werf 2005) and the farmer is the main manager of agroecosystems, so it is a logical and useful scale for evaluation. As a result, there are many different assessment methods in use at the farm level (Halberg et al. 2005; van der Werf and Petit 2002). With assessments at this level, farmers may be educated about the impacts of their practices and encouraged to improve their practices. Such encouragement is sometimes enhanced by subsidization of farms that perform assessments. This may represent a supplement to region- or nation-scale rules and regulations, or may be a voluntary alternative (Halberg et al. 2005). In any case, farmers are likely to be able to respond to the results of an assessment with localized solutions, tailored to site-specific conditions, which may be more effective and appropriate than observations or recommendations made at a courser scale.

Within the farm, assessments can be performed on a field-by-field basis. This scale is useful to the farmer who wants to isolate a problem area on his/her farm. Thus, as a component of a farm analysis, field-scale studies can provide a useful level of detail and can inform a farmer's management choices. The utility of this scale of study is limited for any other purpose.

Once the spatial scale of the area of assessment has been determined, another issue of spatial scale comes into question: the scale of the impacts themselves. The impacts of a farming system can be considered only on a local level or they can be expanded to include regional and global effects. For example, a farm that pollutes a stream with nutrient-rich runoff may be contributing to eutrophication of a lake many miles away. In addition, an over-fertilized field could be emitting high levels of nitrous oxide, a potent greenhouse gas, from its soils, thereby contributing to climate forcing. Any assessment, no matter the scale of the agroecosystem it focuses on, should consider even far-reaching impacts. This allows for the detection of "problem shifting," which Payraudeau and van der Werf (2005) define as "reducing a local impact at the cost of an increased global impact."

In addition to considerations of spatial scale, questions of temporal scaling are also important in assessing the sustainability of agriculture. Impacts can not be assumed to result immediately from the actions that caused them. For example, there is a delay between the emission, deposition, and effects of pollutants (von Wirén-Lehr 2001), so assessment must include impacts that occur at a later time.

Assessment Methods

A number of means-based methods have been used to evaluate agricultural sustainability. These methods tend to be adopted because they are easy to perform, so they are frequently used for certification programs (van der Werf and Petit 2002). Examples of means-based approaches include: the farmer sustainability index (FSI), which developed in Malaysia for use by policymakers and emphasizes farmer improvement; Ecopoints (EP), an Austrian program designed to promote preferred agricultural practices; and indicators of farm sustainability (IFS), a method developed in France to promote sustainable agriculture (van der Werf and Petit 2002). IFS is unique among these methods in that it can incorporate social and economic aspects of sustainability, while the others focus exclusively on environmental sustainability. None of these methods evaluates actual impacts of farming practices; rather they all aim to promote particular agricultural practices without attention to their suitability to the landscape and community in which they are being used. Another means-based method, environmental management for agriculture (EMA) improves upon the more typical model by integrating site-specific information into the analysis (van der Werf and Petit 2002). Thus, practices are considered with respect to their suitability for a given site.

With the exception of EMA, these means-based methods result in a farm receiving a single, unitless score. While this approach expedites assessments for the purposes of certification and funding programs, it does not provide useful feedback for farmers. There is no way for farmers to learn about problem areas on their own farms and there is no built-in incentive to farmers to adapt and localize existing practices or to develop innovative new approaches in the effort to become more sustainable (van der Werf and Petit 2002). Effect-based assessment methods are necessary to truly evaluate farm sustainability.

Many different assessment methods fit under the umbrella of effect-based approaches. One of these is environmental impact assessment (EIA), which was developed to assess the environmental impacts of a particular human action, generally focusing on pollution and the sensitivity of the environment (Payraudeau and van der Werf 2005). This method has been adapted for application to agricultural systems and has been useful in alerting farmers to particular impacts their practices have on the environment (Payraudeau and van der Werf 2005). A drawback to this approach is its inability to detect problem shifting; it emphasizes local impacts above regional impacts and rarely accounts for global effects (Payraudeau and van der Werf 2005). Thus it may be particularly useful in areas where acute degradation is occurring on a local scale, but does not offer the necessary scope to be more widely used.

Another effect-based method is life cycle assessment (LCA). LCA is unusual in that it evaluates the sustainability of a product, rather than an agricultural practice, agroecosystem, or farming region. Thus, the farm is viewed as a production system rather than a type of land use (van der Werf and Petit 2002). This method is primarily used to assess environmental impacts, but can be modified to incorporate some elements of social and economic sustainability (Payraudeau and van der Werf 2005). This approach is advantageous in that it is inclusive of all scales of impact from local to global, but it is information-intensive and costly (van der Werf and Petit 2002) and so may not be feasible in many cases. LCA is not geared, as many of the other assessments are, to informing policy or farmer decisions. Rather, this method may be particularly important for influencing consumer decisions. Wilkins (2005) introduces the concept of "food citizenship," wherein individuals have the right to thorough and truthful information about their food choices and the responsibility to make choices that support ecological, social, and economic sustainability. LCA is an important mechanism for informing responsible consumer choices.

Multiple goal linear programming methods (LP) address two deficiencies common to other evaluation techniques: they can be flexible in scale from the field level to the region level, and they integrate the biophysical sciences with economics (Bouman et al. 1999). As a result, these methods can "illustrate trade-offs among economic and biophysical sustainability parameters at different levels of scale" (Bouman et al. 1999). The site-specific integration of economic and biophysical data is aimed at enabling the simultaneous optimizing of production and minimizing of environmental impacts (Payraudeau and van der Werf 2005). This method is not necessarily thorough in its accounting for environmental impacts – it can focus on a single impact or incorporate many (Payraudeau and van der Werf 2005). In addition, though it may include several scales within a specific project (Bouman et al. 1999), it can also focus at a single scale, such as the farm scale (van der Werf and Petit 2002). Thus, this method is highly variable and can be adapted to accommodate the goals of different assessment projects.

One widely used indicator-based assessment of environmental sustainability is known as input-output accounting (IOA) or Green accounts. IOA systems are designed to elucidate a farm's environmental impact based on the use of external inputs in relation to production or the use of specific farming practices (Halberg et al. 2005). These methods tend to focus on fertilizer and pesticide use. In some cases, the indicator used is simply the amount of active ingredient applied, and other systems rely on more complex indicators that account for the different toxicity/environmental impact levels of different pesticides. In addition to pesticides and fertilizers, many IOA systems also address energy use on the farm. Systems vary, with some accounting only for direct energy use, and others accounting for indirect energy as well, such as the energy required to make nitrogen fertilizer, which is substantial (Halberg et al. 2005). The most useful component of IOA systems seems to be the fact that the impact is measured per unit of productivity. This allows the assessment to be scaled, enabling meaningful comparisons between farms of different sizes.

Many assessment systems, including some already listed above, rely on indicators. Most of these indicator-based methods, with the possible exception of the ones listed above, use a similar framework. This was described by von Wirén-Lehr (2001) as a four-step strategy: first is the "formulation of a case-specific perception of sustainability," which includes defining the goals for the system being assessed; second, the desired condition is characterized and an appropriate indicator or set of indicators is developed; third, the sustainability assessment is performed; and finally, strategies are developed for the implementation of improved agricultural practices (von Wirén-Lehr 2001). An earlier paper by Stockle et al (1994) outlined a similar approach using different terminology. They suggest a set of nine attributes of a sustainable farming system, analogous to von Wirén-Lehr's goals. Next, they identify constraints to sustainability within each of the attributes; all of these constraints are measurable indicators of unsustainability. Each constraint is scored and weighted to determine attribute scores, which are scored and weighted to give a unitless, numerical score for the farming system as a whole (Stockle et al. 1994). This is only useful as a relative measurement; the value is meaningless on its own.

Of all the approaches reviewed here, effect-based approaches that rely on indicators have the most potential to be flexible to different scales and site concerns, as well as informative without being overly complex. Some indicator approaches integrate scoring systems such that the final result of assessment is a single number or grade. This is useful for structured assessment programs that need to analyze and rank a large number of farms; however, there are significant drawbacks to scoring systems as well. First, the scoring process may not be entirely transparent to the farmer, resulting in a lack of clarity about what steps should be taken to improve conditions. Instead of compiling a single score, separate scores for each indicator point specifically to the problems that need to be addressed. The second problem with scoring systems is that they impose a particular set of sustainability priorities on all farms. Working toward environmental sustainability while maintaining the economic viability of a farm can be a delicate balancing act. A single sustainability score represents an oversimplification of a complex and nuanced management challenge. The assessment approach that is likely to be the most informative and useful to farmers is a suite of carefully selected indicators.

Selecting Indicators

For each of the sustainability principles developed in the *Defining Sustainability* section of this paper, indicator(s) are suggested for assessment of the sustainability of farming systems.

- Waste emissions should be kept within the assimilative capacity of the environment (including greenhouse gases and nutrients)

Nitrogen is an important nutrient to monitor, as it has implications for both greenhouse gas emissions and water pollution. Excessive nitrogen fertilization can increase nitrous oxide emissions and elevate nitrogen levels in farm run-off. A widely used indicator to capture these effects is "N-surplus per ha," calculated as the balance between inputs and outputs in products (Halberg et al. 2005). Other nutrients, such as phosphorus, can be calculated in the same way. However, this method may not fully capture a farm's contribution to phosphorus pollution because phosphorus binds to sediment particles and can therefore accumulate in the soil over time. Once that has happened, the phosphorus-saturated soil can act as a source of phosphorus for a long time. Farms that have accumulated phosphorus in their soils may contribute to phosphorus pollution even if their present-day application rates are at or below their harvest rates. This may be difficult or impossible to capture with an indicator.

Another waste that needs to be monitored is greenhouse gas emissions (GHGs). It is difficult to develop a suitable indicator for GHGs, though GHGs can be partially captured through other indicators. For example, energy utilization is often monitored, and can offer an approximation of GHGs. Considerations of scale are particularly important in the monitoring of GHGs and energy use; the simplest calculations are on-farm energy use, and a number of assessment methods use on-farm energy as their indicator (Halberg et al. 2005). However, this measure fails to capture some of the most energy intensive processes in our food systems. For example, nitrogen fertilizer production requires very high energy inputs; Refsgaard et al. (1998) found that nitrogen fertilizer accounted for close to 30% of the total energy use on some farms. In addition, transportation of food from farm to table requires energy inputs and results in GHG emissions. Most studies fail to incorporate data about energy costs after food leaves the farm gate. This is unfortunate, as a farm that tailors its production to serve the local community has a lower energy and GHG cost than a farm that serves a market thousands of miles away; this distinction is usually lost in farm-level assessments, but would be captured in a LCA of the farm product.

- Harvest rates of renewable resources should be within the regenerative capacities of the natural system that generates them (for example, erosion rates should not exceed rates of pedogenesis)

Typical rates of pedogenesis are typically so low that soil can be viewed as a nonrenewable resource. However, weathering rates are variable and some sites receive sediment deposition, so soil processes should be considered on a site-by-site basis. Net topsoil loss may be used as an indicator of unsustainable erosion rates.

- Depletion rates of nonrenewable resources should be set below the rate at which substitutes are developed (including biodiversity as a nonrenewable resource for which there is no substitute)

This goal essentially states that agriculture should not contribute to the loss of biodiversity. Biodiversity in agriculture is a complex and multi-faceted concept, and one that is difficult or impossible to quantify. On the farm, biodiversity can be a planned component of the system; farms that produce a broad array of crops are more diverse than monoculture farms. Native biodiversity may also be planned into a farm system; riparian corridors and farm woodlots can contribute to wildlife habitat and native floral diversity. Agricultural practices also affect biodiversity beyond the farm's boundaries; nutrient run-off and sedimentation from farm erosion can impact native aquatic flora and fauna downstream. In addition, application of pesticides can affect fish and amphibian populations downstream and downwind. While some of these effects can be captured in indicators, some cannot. For instance, two hayfields may appear nearly identical, but one may be managed with attention to nesting songbirds and may therefore contribute to healthy populations of grassland birds, while ill-timed harvests on the other field can result in a population sink for the same species. It is impossible to capture all of the complex relationships between biodiversity and farm practices. Simple indicators like riparian buffer width, surplus nutrients, and pounds of active ingredient (AI) of pesticide may be the best approximations available.

Fossil fuels are another nonrenewable resource that must be monitored. Fossil fuel consumption can be measured directly, though, as mentioned above, it is extremely important that indirect energy use also be accounted for. Ideally, farm-to-table energy costs should be included.

- Food production should be maintained at a level sufficient to feed all people

Given our current global food market, this goal is difficult to measure. In a region where agricultural systems are localized, it would be possible to identify the community that a farm or group of farms must feed. However, in the industrialized world, widespread food transportation erases the boundaries around agricultural communities. Production is driven by the market, rather than by the mandate of producing nutritionally complete diets for the community. As fuel prices rise in the coming decades, we may be headed for more localized agricultural communities, in which case food production can more readily be scaled to local need. Farmers who are moving in that direction already may measure their success as the percentage of total food purchases that are locally produced.

- Food should be equitably distributed

This goal is also difficult to quantify, yet it is important to do so. Various indices of global hunger can indicate large-scale effects. On a local scale, social programs such as food pantries, soup kitchens, and food stamp programs may be able to provide data about food availability and the equity of its distribution.

BRINGING IT HOME

The three agroforestry alternatives discussed in the last chapter – forest gardening, livestock fodder, and biomass fuel production – all should be subject to assessment to determine their productivity and sustainability. Individual assessment of these practices requires field-scale measurements. Some of the indicators listed above are well-suited for field-scale measurement, including surplus-nutrient per acre and pounds of active ingredient applied. Other indicators, including those for biodiversity and production, are more useful when measured at the farm- or region-scale.

In fact, farm- and region-scale assessments are generally more appropriate for the three agroforestry alternatives presented, as all three of them are intended as components of diverse farm systems. Forest gardens have particular potential as productive uses of marginal or ecologically-sensitive lands. LivingFuture's forest garden is a perfect example: located in a declining sugarbush with moist, rocky soils, the location has no potential for conventional agriculture but can still offer a valuable contribution to the farm as a whole. Similarly, production of livestock fodder and biomass crops is suggested as an alternative for riparian areas – land where conventional production is excessively degrading. In these areas, the most important field-scale indicators would be soil loss and nutrient uptake by plants. Other sustainability goals would be better addressed on the farm scale, examining the complex system as a whole.

LivingFuture's Forest Garden

LivingFuture's garden is meant to be a demonstration of one of the many productive land use alternatives that can be integrated to build nutritionally complete and ecologically sound localized food systems. The forest garden is not intended to be as productive as a traditional field of row crops, and so comparing it to a standard garden does not make sense. However, it will be important to keep records of the forest gardens inputs and outputs, to get a sense of what can be achieved with this approach. Activities in the garden should be recorded, including work-hours spent, fuel used, and soil amendments added. Harvests should be measured by weight, which can then be converted to calories, nutrient densities, and/or dollar values for each crop. This modified input-output accounting method will allow for analysis of whether production levels justify the work required to maintain the garden, as well as assessment of the nutritional value of the gardens products. If the food produced in the garden does not make a meaningful contribution to the local food supply, it will not be a socially or economically sustainable endeavor.

In terms of biodiversity conservation, wildlife use of the garden should be monitored and recorded. Also, disturbing the soil for planting and harvesting could potentially open sites for colonization by non-native invasive plants. The presence of any invasive plants should be recorded. Invasive species can then be removed and replaced with crop plants or native groundcover plants.

LivingFuture's garden is designed to be managed adaptively, to be constantly adjusted and altered to increase its productivity and decrease its reliance on external inputs. It should be a site for experimentation and new ideas. Both successes and failures should be recorded and shared to help other forest gardeners develop their own systems.

The Work of John Ewel: hypothesis testing and forest gardens

While not suitable for LivingFuture's forest garden, rigorous hypothesis testing of forest gardening is possible. John Ewel has performed rigorous testing of forest gardening and returned to apply his results to theory. In his 1999 paper, John Ewel reviews the work that he and other researchers have done into agricultural systems that mimic natural systems. Ewel starts with theory, outlining three categories that he believes define the ecological underpinnings of sustainability (1999): responses to pests, productivity, and soil fertility. He and his colleagues performed experiments comparing tropical forest gardens to natural forests (after which the gardens were designed) and to monocultures of a few different crops. The results were mixed for all three of the sustainability categories that Ewel outlines. In the end, Ewel used the results of his experiments to inform a list of "Keys to success in mimicking natural systems for agriculture."

In terms of responses to pests, the mimetic system fared moderately well. Cassava plants received a high degree of herbivory by leaf-cutter ants – higher even than those in the cassava monoculture against which the mimetic system was being compared. Ewel posits that the ants may have been responding to shade or the complex structure that afforded them greater mobility in the mimetic system. Thus it is clear that diversity does not necessarily offer protection from predators. This conclusion apparently informs one of Ewel's "keys to success: …manage plants and herbivores to facilitate associational resistance and not associational susceptibility." It is impossible to predict and plan for all of the interactions that will occur in a complex system. Rather, it is the observant and responsive farmer who will gradually build and refine a complex system that works. From this research we are reminded that our agricultural systems must be literally grounded in place, the principles on which we base them adapted to the particulars of soil and slope as well as to our own needs. “Kindly use depends upon intimate knowledge, the most sensitive responsiveness and responsibility” (Berry 1977).

Cassava was not the only crop in the diverse system, and it is important to note that, despite the high level of herbivory on that one species, it did not result in a community-level loss of productivity. On the contrary, “in a diverse system, the resources freed by the loss of one species are taken up by another, thereby maintaining system-wide performance” (Ewel 1999). In this particular case, the function of diversity did not end up being protection from herbivory but protection from risk – an insurance policy.

In terms of productivity, Ewel (1999) found his mimetic system performed below the natural system he was mimicking. Interestingly, two trials were completed with a monoculture of maize, one that produced higher than any other trial and one with the lowest productivity. These results suggest that, though highly simplified agricultural systems have the potential for enormous yields, they are also very risky endeavors. This result informs Ewel’s second “key to success:…maintain adequate diversity to compensate for losses in a system simple enough to be horticulturally manageable.”

Soil fertility is the final category Ewel outlines for sustainable agriculture. The mimetic system was generally much more retentive of nutrients than the monocultures, with one exception. One tree monoculture increased greatly in nutrient retention over three years. The trees were very well matched to the site and grew well, but the most likely explanation for their success in maintaining soil fertility is one of duration – the trees had a chance to develop deep and extensive root systems. “Longevity, as much as diversity…, is the key to nutrient retention in the humid tropics” (Ewel 1999). This is a strong argument for integrating perennial, long-lived plants into complex agricultural systems.

There is a great need for more research and practice in the field of biomimetic agriculture. There is a tremendous amount of research done on modern agricultural methods, but there has been relatively little study of the complex agricultural systems that present the most promising alternatives to the status quo. Vandermeer et al. (1998) contend that the paucity of research on complex agricultural systems is due to the following: it is extremely difficult to compare complex systems, nearly impossible to model them, and finally, given the integrated suite of goals being simultaneously pursued, success can not be ascertained from a single measure of productivity.
Ewel’s work is a valuable study of forest gardens as complex agricultural systems. It is only through widespread experimentation, through the sharing of ideas and experience, that we can build a new institutional memory, a new infrastructure, around truly sustainable agriculture.

Conclusion

Conventional agricultural systems are contributing to dire ecological and social problems. We cannot afford to push blindly forward, clinging to the old, degrading systems we are used to. The effects are too great: the waste of nutrients and the resulting eutrophication of our waters, the accelerated erosion of our topsoil, the emissions of greenhouse gases. As we aim for more localization and regional self-sufficiency, we can no longer afford the segregating of functions resulting from the simplification of our agricultural systems. Rather, we must focus on building integrated systems that meet multiple goals.

A philosophy of sustainability can guide us in the direction of food systems that enrich our world, rather than deplete it. We can redefine waste so that our excesses become resources rather than pollutants. We can increase and diversify our production to support local communities. One place to start this endeavor is through mimicry of natural systems. By drawing on the wisdom inherent in the natural world, we can design productive systems that are also nutrient-retentive, soil-conserving, self-sustaining, and complex. A forest garden is a wonderful example of this, where every species makes multiple contributions to the whole. Consider the sugar maple, whose sap is boiled to produce syrup, whose wood is of superior quality, whose crown intercepts both rain and wind, lessening erosion, whose leaves amend the soil with calcium-rich mulch, whose fall beauty is unparalleled.

Literature Cited

Agyemang, K, D.L.Dogoo, and H.J. Makun. 1998. Profitability of forage production in smallholder peri-urban dairy production systems. *Experimental Agriculture* 34: 423-437.

Altieri, M.A. 1987. *Agroecology: The scientific basis of alternative agriculture*. Boulder, CO: Westview Press.

Andow, D.A. 1991. Vegetational diversity and arthropod population response. *Annual Review of Entomology* 36: 561-586.

Anonymous. 1998. America's Animal Factories: How States Fail to Prevent Pollution from Livestock Waste. Natural Resources Defense Council and the Clean Water Network.

Badenes-Perez, F.R., A.M. Shelton, B.A. Nault. 2005. Using yellow rocket as a trap crop for diamondback moth (Lepidoptera: Plutellidae). *Journal of Economic Entomology* 98(3): 884-890.

Badgley, C. 2003. The farmer as conservationist. *American Journal of Alternative Agriculture* 18(4): 206-212.

Beetz, A. 2002. Agroforestry Overview. Published by the National Sustainable Agriculture Information Service. Online at: http://www.attra.ncat.org/attra-pub/agroforestry.html.

Bennett, E.M., S.R. Carpenter, and N.F. Caraco. 2001. Human impact on erodable phosphorus and eutrophication: a global perspective. *BioScience* 51(3): 227-234.

Bennett, H.H. 1939. Soil conservation. New York: McGraw-Hill.

Benyus, J.M. 1997. *Biomimicry: Innovation Inspired by Nature*. HarperCollins Publishers, Inc.: New York.

Berry, W. 1977. *The Unsettling of America: Culture and Agriculture*. Sierra Club Books: San Francisco.

Bockstaller, C., Girardin, P., van der Werf, H.M.G. 1997. Use of agro-ecological indicators for the evaluation of farming systems. *European Journal of Agronomy* 7: 261-270.

Bouman, B.A.S., H.G.P. Jansen, R.A. Schipper, A. Nieuwenhuyse, H. Hengsdijk, and J. Bouma. 1999. A framework for integrated biophysical and economic land use analysis at different scales. *Agriculture, Ecosystems and Environment* 75: 55-73.

Brukardt, M.J. 1997. The Natural Step to Sustainability. In *Discussion Course on Choices for Sustainable Living.* Portland: Northwest Earth Institute.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* 8(3): 559-568.

Chapin III, F.S., O.E. Sala, I.C. Burke, J.P. Grime, D.U. Hooper, W.K. Lauenroth, A. Lombard, H.A. Mooney, A.R. Mosier, S. Naeen, S.W. Pacala, J. Roy, W.L. Steffen, and D. Tilman. 1998. Ecosystem consequences of changing biodiversity: experimental evidence and a research agenda for the future. *BioScience* 48(1): 45-52.

Cox, C.M., K.A. Garrett, W.W. Bockus. 2005. Meeting the challenge of disease management in perennial grain cropping systems. *Renewable Agriculture and Food Systems* 20(1): 15-24.

Cox, T.S., M. Bender, C. Picone, D.L. Van Tassel, J.B. Holland, E.C. Brummer, B.E. Zoeller, A.H. Paterson, and W. Jackson. 2002. Breeding perennial grain crops (section 1 of 3). *Critical Reviews in Plant Sciences* 21(2): 59-91.

DeHaan, L.R., N.J. Ehlke, C.C. Sheaffer, G.J. Muehlbauer, and D.L. Wyse. 2003. Illinois bundleflower genetic diversity determined by AFLP analysis. *Crop Science* 43(1): 402-408.

Dhondt A.A. and P.H. Wrege. 2003. Avian biodiversity studies in short-rotation woody crops. Final report prepared for the US Dept of Energy under cooperative agreement No. DE- FC36-96GO10132. Ithaca, NY: Cornell University Laboratory of Ornithology.

Downing M., C. Demeter, M. Braster, C. Hanson, G. Larson, and T. Volk. 1998. Agricultural cooperatives and marketing bioenergy crops: case studies of emerging cooperative development for agriculture and energy. Presented at BioEnergy '98: Expanding Bioenergy Partnerships, Madison, WI, October 4-8, 1998.

Ewel, J.J. 1999. Natural systems as models for the design of sustainable systems of land use. *Agroforestry Systems* 45: 1-21.

Ewel, J.J. 1986. Designing agricultural ecosystems for the humid tropics. *Annual Review of Ecological Systematics* 17:245-271.

Fischer, G., M. Shah, F.N. Tubiello, and H. van Velhuizen. 2005. Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990-2080. *Philosophical Transactions of the Royal Society* 360: 2067-2083.

Goodland, R. 1995. The concept of environmental sustainability. *Annual Review of Ecological Systematics* 26: 1-24.

Gurr, G.M., S.D. Wratten, and J.M. Luna. 2003. Multi-function agricultural biodiversity: pest management and other benefits. *Basic and Applied Ecology* 4(2): 107-116.

Halberg, N., G. Verschuur, and G. Goodlass. 2005. Farm level environmental indicators; are they useful? An overview of green accounting systems for European farms. *Agriculture, Ecosystems and Environment* 105: 195-212.

Hansen, B., H.F. Alrøe, and E.S. Kristensen. 2001. Approaches to assess the environmental impact of organic farming with particular regard to Denmark. *Agriculture, Ecosystems and Environment* 83: 11-26.

Hansen, J.W. 1996. Is agricultural sustainability a useful concept? *Agricultural Systems* 50: 117-143.

Hart, R. 1990. Tropical and temperature: the forest garden. *Appropriate Technology* 17(3): 17-19.

Heller, M.C., G.A. Keoleian, and T.A. Volk. 2003. Life cycle assessment of a willow biomass cropping system. *Biomass and Bioenergy* 25:147-165.

Hendrickson, J. 1996. Energy use in the U.S. food system: A summary of existing research and analysis. Sustainable Farming-REAP-Canada. Ste. Anne-de'Bellevue, Quebec 7(4).

Jacke, D. 2005. *Edible Forest Gardens.* Chelsea Green Press.

Johnson, P.T.J., and J.M. Chase. 2004. Parasites in the food web: linking amphibian malformations and aquatic eutrophication. *Ecology Letters* 7: 521-526.

Lal, R. 1994. Water management in various crop production systems related to soil tillage. Soil Tillage Research 30: 169-185.

Lang, T. 2001. Food safety and public health: will the crisis every end? Cardiff Law School Public Lecture Series: 4. Thames Valley University.

Lewis, K.A., and Bardon, K.S. 1998. A computer-based informal environmental management system for agriculture. *Environmental Modeling Software* 13: 123-137.

Liebig, M.A., G. Varvel, and J. Doran. 2001. A simple performance-based index for assessing multiple agroecosystem functions. *Agronomy Journal* 93: 313-318.

Lowrance, R., R. Todd, J. Fail, Jr., O. Hendrickson, Jr., R. Leonard, L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. *BioScience* 34 (6): 374-377.

Magdoff, F., L, Lanyon, and B. Liebhardt. 1997. Nutrient cycling, transformations, and flows: implications for a more sustainable agriculture. *Advances in Agronomy* 60: 1-73.

Marten, G.G. 1988. Productivity, stability, sustainability, equitability and autonomy as properties for agroecosystem assessment. *Agricultural Systems* 26: 291-316.

McDonough, W. 1993. Design, ecology, ethics and the making of things: a centennial sermon. In *Discussion Course on Choices for Sustainable Living.* Portland: Northwest Earth Institute.

McWilliam, E.L., T.N. Barry, and N. López-Villalobos. 2005. Organic matter digestibility of poplar (*Populus*) and willow (*Salix*) forage trees and its *in vitro* prediction. *Journal of the Science of Food and Agriculture* 85: 1098-1104.

Mollison, B. 1990. *Permaculture: A Practical Guide for a Sustainable Future*. Island Press: Washington, D.C.

Montagnini, F. and P.K.R. Nair. 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems* 61: 281-295.

Moore, K.M., T.N. Barry, P.N. Cameron, N. Lopez-Villalobos, and D.J. Cameron. 2003. Willow (Salix sp.) as a supplement for grazing cattle under drought conditions. *Animal Feed Science and Technology* 104(1-4): 1-11.

Neher, D. 1992. Ecological sustainability in agricultural systems: definition and measurement. *Journal of Sustainable Agriculture* 2: 51-61.

Ohlander, L., C. Lagerberg, U. Gertsson. 1999. Visions for ecologically sound agricultural systems. *Journal of Sustainable Agriculture* 14(1): 73-79.

Parry, M., C. Rosenzweig, and M. Livermore. 2005. Climate change, global food supply and risk of hunger. *Philosophical Transactions of the Royal Society* 360: 2125-2138.

Payraudeau, S. and H.M.G. van der Werf. 2005. Environmental impact assessment for a farming region: a review of methods. *Agriculture, Ecosystems and Environment* 107: 1-19.

Pelster, A.J., S. Evans, W.C. Leininger, M.J. Trlica, and W.P. Clary. 2004. Steer diets in a montane riparian community. *Journal of Range Management* 57(5): 546-552.

Pelsue, N. 2002. Vermont…The State of Agriculture: Agriculture, Food, and Community in Vermont. University of Vermont Extension.

Phillips, R.L., M.J. Trlica, W.C. Leininger, and W.P. Clary. 1999. Cattle use affects forage quality in a montane riparian ecosystem. *Journal of Range Management* 52(3): 283-289.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Sphpritz, L., Fitton, L., Saffouri, R., Blair, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science* 267: 1117-1123.

Pimentel, D.and Kounang, N. 1998. Ecology of soil erosion in ecosystems. *Ecosystems* 1: 416-426.

Pirog, R., and A. Benjamin. 2003. Checking the food odometer: Comparing food miles for local versus conventional produce sales to Iowa institutions. Leopold Center for Sustainable Agriculture, Iowa State University.

Pollan, M. 1991. *Second Nature: a gardener's education*. New York: Dell Publishing.

Refsgaard, K., N. Halberg, and E.S. Kristensen. 1998. Energy utilization in crop and dairy production in organic and conventional livestock production systems. *Agricultural Systems* 57(4): 599-630.

Reich, L. 2004. Uncommon Fruits for Every Garden. Timber Press: Portland.

Robles-Diaz-De-Leon, L.F. and P. Kangas. 1999. Evaluation of potential gross income from non-timber products in a model riparian forest for the Chesapeake Bay watershed. *Agroforestry Systems* 44: 215-225.

Roose, E. 1988. Soil and water conservation lessons from steep-slope farming in French speaking countries of Africa. In: Conservation farming on steep lands. Ankeny, IA: Soil and Water Conservation Society.

Sands, G.R. and T.H. Podmore. 2000. A generalized environmental sustainability index for agricultural systems. *Agriculture, Ecosystems and Environment* 79: 29-41.

Savory, A. 1988. *Holistic Resource Management*. Island Press: Washington, D.C.

Schaller, N. 1990. Mainstreaming low-input agriculture. *Journal of Soil and Water Conservation* 45: 9-12.

Scheinost, P.L., D.L. Lammer, X. Cai, T.D. Murray, and S.S. Jones. 2001. Perennial wheat: the development of a sustainable cropping system for the U.S., Pacific Northwest. *American Journal of Alternative Agriculture* 16(4): 147-151.

Singh, V., and B. Bohra. 2005. Livestock feed resources and feeding practices in hill farming systems: a review. *Indian Journal of Animal Sciences* 75(1): 121-127.

Slingo, J.M., A.J. Challinor, B.J. Hoskins, and T.R. Wheeler. 2005. Introduction: food crops in a changing climate. *Philosophical Transactions of the Royal Society* 360: 1983-1989.

Smeding, F.W., and W. Joenje. 1999. Farm-Nature Plan: landscape ecology based farm planning. *Landscape and Urban Planning* 46: 109-115.

Smith, D.L. and J.J. Almaraz. 2004. Climate change and crop production: contributions, impacts, and adaptations. *Canadian Journal of Plant Pathology* 26: 253-266.

Smith, J.R. 1950. *Tree Crops: A Permanent Agriculture*. Island Press: Washington, D.C.

Soule, J.D. and J.K. Piper. *Farming in Nature's Image*. Island Press: Washington, D.C.

Stamps, W.T. and M.J. Linit. 1997. Plant diversity and arthropod communities: implications for temperate agroforestry. *Agroforestry Systems* 39(1): 73-89.

Stockle, C.O., R.I. Papendick, K.E. Saxton, G.S. Campbell, and F.K. van Evert. 1994. A framework for evaluating the sustainability of agricultural production systems. *American Journal of Alternative Agriculture* 9(1&2): 45-51.

Troeh, F.R., Thompson, L.M. 1993. Soils and soil fertility, 5th edition. New York: Oxford University Press.

Updegraff, K., M.J. Baughman, and S.J. Taff. 2004a. Environmental benefits of cropland conversion to hybrid poplar: economic and policy considerations. *Biomass & Bioenergy* 27: 411-428.

Updegraff, K., P. Gowda, and D.J. Mulla. 2004b. Watershed-scale modeling of the water quality effects of cropland conversion to short-rotation woody crops. *Renewable Agriculture and Food Systems* 19(2): 118-127.

U.S. Environmental Protection Agency. 2002. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999. EPA 430-R-02-003. USEPA, Office of Atmospheric Programs. <www.epa.gov/globalwarming/publications/emissions>

U.S. Environmental Protection Agency. 1996. Environmental indicators of water quality in the United States. EPA 841-R-96-002. USEPA, Office of Water (4503F). U.S. Government Printing Office, Washington, D.C.

U.S. Forest Service. 1936. The major range problems and their solution. Washington D.C.: USFS.

Vandermeer, J., M. van Noordwijk, J. Anderson, C. Ong, and I. Perfecto. 1998. Global change and multi-species agroecosystems: Concepts and issues. *Agriculture, Ecosystems, and Environment* 67: 1-22.

van der Werf, H.M.G. and J. Petit. 2002. Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. *Agriculture, Ecosystems and Environment* 93: 131-145.

van der Werf, H.M.G. and C. Zimmer. 1998. An indicator of pesticide environmental impact based on a fuzzy expert system. *Chemosphere* 36: 2225-2249.

Vermont Agency of Agriculture. 2005. Buying Local Vermont Products. <www.vermontagriculture.com/buyvermont2.htm> last accessed 3/2006.

Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation. 1997. *A phosphorus budget, model, and load reduction strategy for Lake Champlain.* Department of Environmental Conservation, Water Quality Division, Waterbury, Vermont.

Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger, and D.G. Tilman. 1997. Human alteration of the global nitrogen cycle: sources and consequences. *Ecological Applications* 7(3): 737-750.

Volk, T.A., T. Verwijst, P.J. Tharakan, L.P. Abrahamson, and E.H. White. 2004. Growing fuel: a sustainability assessment of willow biomass crops. *Frontiers in Ecology and the Environment* 2(8): 411-418.

von Wirén-Lehr, S. 2001. Sustainability in agriculture – an evaluation of principal goal-oriented concepts to close the gap between theory and practice. *Agriculture, Ecosystems and Environment* 84: 115-129.

Whitney, G.G. and M.M. Upmeyer. 2004. Sweet trees, sour circumstances: the long search for sustainability in the North American maple products industry. *Forest Ecology and Management* 200: 313-333.

Wilkins, J.L. 2005. Eating right here: moving from consumer to food citizen. *Agriculture and Human Values* 22: 269-273.

World Resources Institute (WRI). 1994. World resources. New York: Oxford University Press.

Appendix 1. Forest Garden Design

As described in the body of the text, the forest garden on the Teal Farm is located on a half acre of forested land on the north side of the farm's driveway. The design of the forest garden began with two major considerations: it was guided by the goals of LivingFuture, who will be implementing and maintaining the garden; and it was constrained by the location and conditions of the site itself. The site is located in a declining sugarbush, and one of LivingFuture's primary goals with this effort was to increase the productivity of this part of the sugarbush. This is a particularly useful exercise given the anticipated effects of global change on sugar maple populations; within the next few generations, many Vermonters may be facing the challenge of determining how to use their declining sugarbushes. Another goal was to create a demonstration site utilizing the region's native flora to highlight forest gardening principles. Finally, a third (and obvious) objective was to produce food and medicinal herbs.

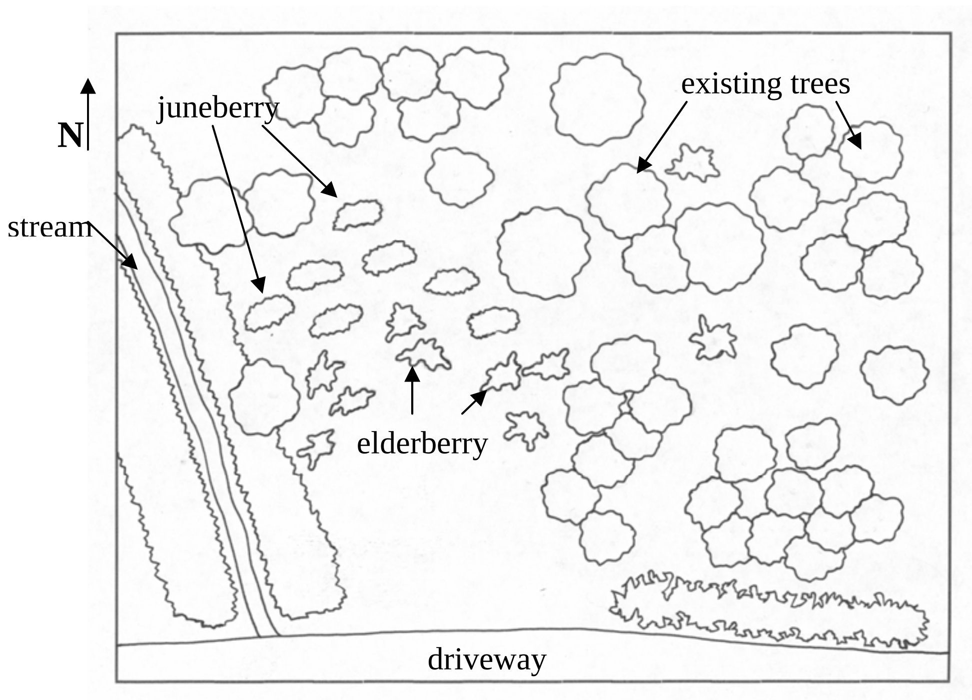
Design was constrained by a number of factors. First of all, the garden site is located partway down LivingFuture's long driveway, about ¼ mile away and not visible from the buildings. According to the principles of permaculture, an area this distant from regular traffic should be designed to require few inputs and little maintenance. This corresponded with LivingFuture's intentions for the site; they wanted the forest garden to be relatively self-sufficient.

Site conditions also constrained design. The site is fairly heterogeneous considering its small size; the eastern half of the garden has exposed boulders, pit and mound microtopography, and marked variability in soil depth. The western half is slightly higher and flatter with deeper soils. The site's soils are acidic, ranging from pH 5.0 to 6.0, but mostly between 5.0 and 5.5. Moisture levels vary with microtopography. Higher soils are drier while low areas and pits are wetter, often supporting the moisture loving plant species, sensitive fern (*Onoclea sensibilis*).

Shade was a major factor in design, as it must be in any forest garden. Given its gently north-facing aspect, sun is particularly limiting on the site. In addition, the site is already forested; while some trees will be removed as the garden is installed, most will stay. All sugar maples will be retained so that they can be tapped. Though many of the beech trees on the site are infected by beech bark disease, any that are not will be retained on the site. All trees provide valuable services, including wildlife habitat and carbon sequestration among many, so removal of trees has received careful consideration. The result is that the garden will be maintaining most of the trees already present on the site; shrub and herb species to be included must be tolerant of at least partial shade.

Another constraint limiting design was the decision to use only native species in the forest garden. This choice reduced the palette of potential species.

Design was also informed by the site's assets. The heterogeneity of the site is a boon in that, even without any modifications, it allows for the cultivation of a diverse suite of species. Microhabitats do not need to be engineered; they already exist. In addition, the site is naturally rich, a fact demonstrated by the presence of sugar maple, basswood, plantain-leaved sedge, silvery spleenwort, and blue cohosh. Finally, several of the species that will eventually be cultivated there already occur on the site in small numbers. These include wild leeks, ostrich fern, and sugar maple. This indicates that the site is appropriate for these species and also supplies a population that can be encouraged and added to as the garden is created.



Forest garden layout. The garden is bordered on the south by the farm's driveway, on the west by a small stream, and on the east by denser forest cover and a drop-off to a ravine. The east side of the garden is bordered to the north by a dense stand of pole-sized trees; to the north of the west side of the garden, the soil is more rocky and wet, making it less suitable for use. The boundary in this area is the least distinct

The drawing at left shows the basic layout of the forest garden. The design is roughly divided into four sections. The main two sections are: east (or *woodland*), characterized by patchy but fairly heavy forest cover; and west (or *suntrap*), characterized by a canopy opening to the south. Two smaller, elongate sections are the streamside and roadside sections.

The trees currently in the woodland section will be largely undisturbed by the garden, with only a few of the most diseased beech being removed. In the gaps left by these trees, elderberry bushes can be planted. Otherwise, the focus in this section will be on shade tolerant herbs. A vigorous patch of wild leeks is already present in the northeast corner of the garden; this patch can be divided and encouraged to spread by transplanting bulbs from within the established patch. In addition, wild leeks from elsewhere on the Teal Farm can be transplanted into the garden to establish additional patches. Harvesting should be minimal for the first few years, until a number of vigorous patches are present on the garden.

Ginseng and goldenseal will also be grown in the woodland section of the garden. Appendix 2 includes information about using test plots to establish ideal sites for wild-simulated ginseng cultivation. This approach is recommended as ginseng takes up to 9 years to be ready for harvest; it is worthwhile to invest some time in laying out ideal growth sites for both ginseng and goldenseal. Once these sites have been located, they should be demarkated to avoid trampling. Only after ginseng and goldenseal are established should the remaining areas of the woodland section be planted with other shade-tolerant herbs.

The suntrap section of the garden relies on more tree removals than the east side. This area already has a relatively sparse canopy cover, but to maximize light penetration, several beech, yellow birch, and hophornbeam trees near the driveway will have to be removed. The removal of these trees, paired with the location of the roadcut, should provide relatively abundant sunlight to plants in this section of the garden. The remaining trees will form a rough semi-circle within which juneberry trees and elderberry bushes can be planted, with the tallest trees planted furthest north to maximize sunlight interception by all of the plants. Once these trees and shrubs are established, plantings can begin in the herb layer. Planting herbs right beneath fruit trees/shrubs is not recommended, as they may be trampled during harvesting of fruits. Instead, plantings of shade-loving herbs (including wild leeks, ginseng, and goldenseal) can occur under the sugar maples at the northern edge of this section, and somewhat less shade-tolerant herbs (including wood nettle, Canada violet, sweet cicely, and ostrich fern in wetter microsites) can be included in the gap toward the southern edge of the section.

The streamside section, especially just to the west of the stream, has good potential for ostrich fern. Though some ostrich fern is present here already, it is minimal and should not be disturbed. Ostrich fern can be encouraged by taking rhizome divisions from off-site and planting them in this area. More details on ostrich fern cultivation are included in Appendix 2.

The driveway provides a canopy opening to the south that increases the availability of sunlight to the plants along the garden's southern edge. This roadside section has two zones; to the east, some areas are poorly drained and could be suitable for willow coppice. In these sections willow cuttings can be inserted into the soil, allowed to grow for a couple of years, and then cut back every two or three years and the harvest used for fuel. Higher areas may be planted with hazelnuts, which can be pruned to maintain the desired growth form. To the west, the roadside area is higher and better-drained and may be suitable for red raspberry cultivation. Some *Rubus* are already growing in this area; they could be replaced with a more productive cultivar. However, raspberries are somewhat labor intensive, and it is not definite that there is sufficient light penetration on this site to make their cultivation here worthwhile. As mentioned in Appendix 2, it is recommended to wait a year and assess site suitability further before proceeding with planting.

Appendix 2. Species Profiles

Primary Species

Sugar Maple (*Acer saccharum*)

A native species already present on the site, sugar maple is a late-successional tree of northern hardwood forests, tending to be dominant on richer sites. This species is shade-tolerant, so it can regenerate under a closed canopy. Several large and medium-sized sugar maples are present in the forest garden site; however, sugar maple is not actively regenerating. Over the last couple of years the stand has been thinned to encourage regeneration, with few signs of positive results. As the forest garden is developed, attention should be paid to sugar maple seedlings; they should not be disturbed. Beech saplings, on the other hand, are shooting up all over the site. These should be regularly trimmed back.

Sugar maple seedling. Photo by Charley Eiseman.

Sugar maple is a multi-purpose tree. It is best known for its sap that is boiled to make maple syrup. The trees on the forest garden site can be tapped. In addition, sugar maple produces high-quality wood, which can be harvested from the forest garden if any of the trees decline in sap production. Some people avoid tapping maples that they may want to harvest for timber, as tap holes create large scars in the wood. However, some people now view these scars as unique features rather than blemishes; consult with a forester to find a specialty wood products market for scarred logs. Finally, Jacke and Toensmeier (2005) cite sugar maple as a “dynamic accumulator,” a species that concentrates calcium and potassium in its leaves, enriching the soil with its leaf litter.

Source:

Jacke, D. and E. Toensmeier. 2005. *Edible Forest Gardens, Vol. 2: Design and Practice*. White River Junction, VT: Chelsea Green Press.

Juneberry (*Amelanchier* spp.)

Juneberry is also known as serviceberry, Saskatoon (a particular species, *Amelanchier alnifolia*), shadbush, and shadblow. This genus includes many hardy, native species of varying size and fruit quality (Jacke 2005). Species in this genus vary widely with respect to growth conditions, but generally are tolerant of sun or shade (though they will yield more fruit if they have more sun). Due to their early flowering time, growing juneberry on a north-facing slope is desirable (the trees will be less susceptible to spring frosts)

These small to medium-sized trees offer a beautiful display of white flowers early in the spring and fruit in early summer. Their fruits, which mature in June, resemble blueberries and some people feel that they are good substitutes for blueberries. The flavor of the fruits is variable and some may be more suitable to value-added processing rather than eating fresh.

Juneberry in bloom in the Vermont woods.

Juneberry trees are self-fruitful, meaning that a single tree can be planted alone and will still fruit. Each tree can be expected to yield 4-6 qts (Dana 2001). According to Laughlin et al. (1996) a high yield for a single plant is 10 lbs, but spring frost at the time of flowering can result in occasional years when no fruit is produced.

Juneberries can be propagated by crown division or from suckers, root cuttings, or seed. I recommend purchasing saplings from Elmore Roots, a nursery in Elmore, Vermont that sells cultivars that have been successful on their farm. Juneberries should be planted at the northern edge of gaps in the forest garden, where they can intercept the maximum amount of sun without casting too much shade into the gap itself.

Sources:

Dana, M.N. 2001. Fruits and nuts for edible landscaping. Landscape Horticulture HO-190-W. Purdue University Cooperative Extension Service, West Lafayett, IN.

Jacke, D. and E. Toensmeier. 2005. *Edible Forest Gardens, Vol. 2: Design and Practice.* White River Junction, VT: Chelsea Green Press.

Laughlin, K.M., R.C. Smith, and R.G. Askew. 1996. Juneberry for commercial and home use on the northern great plains. North Dakota State University Extension Service, H-938. http://www.ext.nodak.edu/extpubs/plantsci/hortcrop/h938w.htm; last updated, 4/96; last accessed, 4/06.

American Hazelnuts (*Corylus americana*)

Hazelnut is a native shrub that grows from 1 to 4 meters in height and forms colonial thickets. It grows under a variety of conditions, from moist to dry woods, on forest margins and roadsides, and other disturbed areas (Nesum 2000). The shrub produces a small, delicious nut. Hazelnut produces the greatest yields when in full sun, but can tolerate partial shade.

A hybrid of the European filbert (*C. avellana*) and the American hazelnut (*C. Americana*) combines the larger nut of the European species with the blight-resistance of the American species. This may be worth considering for the forest garden, as it might greatly increase yield. However, invasiveness should be considered; the aggressive colonial habit of the native hazelnut has caused woodlot managers to destroy it to minimize competition with timber species (Nesom 2000), so it is possible that the hybrid plant could have an invasive habit.

Hazelnuts can be purchased at Elmore Roots nursery. I recommend planting them as a hedgerow along the roadside at the south edge of the garden. The shrubs can be pruned to keep them low, which will minimize the shade they cast on the garden and will also facilitate harvest.

Source:

Nesom, G. 2000. American Hazelnut. USDA Natural Resources Conservation Service Plant Guide. http://plants.nrcs.usda.gov/plantguide/pdf/pg_coam3.pdf; last updated, 11/00; last accessed 4/06.

Elderberry (*Sambucus canadensis***)**

Common (or Canadian) elderberry is a native shrub with edible fruits and flowers. The berries generally do not taste good fresh from the bush, but are commonly used in jams and wines. Flowers can be eaten or made into teas. This species is also valuable in that it attracts beneficial insects and provides bird habitat (Jacke and Toensmeier 2005).

Elderberry generally grows in fertile, moist soils, but is a hardy and adaptable species that will tolerate a variety of conditions when cultivated. Considered partially self-fruitful, elderberry does best when planted near at least one other cultivar. Young elderberry plants can be

Young elderberry leaves. Photo by Matt Kolan.

purchased at Elmore Roots, where they have cultivars that have proven successful in northern Vermont. Plant elderberries in gaps where they will get the maximum sun exposure.

Berries ripen in August/September (Dana 2001). Estimates of yield vary: Dana (2001) suggests a potential yield of 3-4 qts annually, while Way (1981) claims that a good plant can produce more than 15 lbs per year. Plants in the forest garden will receive only partial sun, potentially limiting their production levels to the lower end of the spectrum.

Sources:

Dana, M.N. 2001. Fruits and nuts for edible landscaping. Landscape Horticulture HO-190-W. Purdue University Cooperative Extension Service, West Lafayett, IN.

Jacke, D. and E. Toensmeier. 2005. *Edible Forest Gardens, Vol. 2: Design and Practice.* White River Junction, VT: Chelsea Green Press.

Way, R.D. 1981. Elderberry culture in New York State. *New York's Food and Life Sciences Bulletin* no. 91. New York State Agricultural Experiment Station, Geneva, NY. http://www.nysaes.cornell.edu/pubs/fls/OCRPDF/91.pdf; last accessed 4/06.

Ramps (*Allium tricoccum*)

Ramps, also known as wild leeks, are native to Vermont and prized as a tasty wild edible. Traditionally, wild leeks were the first greens of the season, "considered a tonic because they provided necessary vitamins and minerals following long winter months without any fresh vegetables" (Greenfield 2001). As a result of their nutritional importance, ramps became culturally important as well, and ramps festivals are still held to celebrate their arrival in many areas. Unfortunately, despite their historic importance, little specific information is available on the nutritional composition of wild leeks

A spring ephemeral, wild leeks send up their smooth, broad leaves early in the spring. They thrive under deciduous tree cover, as the leaves emerge well before tree leaf out occurs. The plant flowers during the summer, by which time its leaves have died back. Ramps form dense mats that successfully shade out competitors, so it is likely that little maintenance will be required once ramps are established in the forest garden.

Ramps on the forest garden site.

The forest garden site is likely to be a very successful location for cultivation of ramps, which naturally grow in rich, moist soils beneath a canopy of beech, birch, and sugar maple. Ramps should be planted in dense patches, as they naturally form mats.

Planting can be done through direct seeding or through transplanting of bulbs. For direct seeding, seeds should be collected and planted as soon as they are mature (late summer, early fall), as they require a warm, moist period to break root dormancy before the winter. If planted too late in the season they should still survive, but germination will be delayed by a year. As such, it takes between 6 and 18 months for ramps seeds to germinate (Greenfield 2001). To plant, rake back leaves from the forest floor, clear away competing plants and roots, loosen and rake the soil, and "sow the seeds thinly on top of the ground pressing them gently into the soil" (Greenfield 2001). Cover with several inches of leaves. Ramps thrive with high organic matter content, so add more leaves if necessary. It may take as many as 5 to 7 years for ramps to be ready to harvest.

Transplanting bulbs can accelerate the time to harvest to between 2 and 3 years. Transplanting is best done in March. They should be dug very carefully to avoid damaging the roots or bulbs. Prepare the planting bed the same way as for direct seeding, but transplant the bulbs about 3 inches deep and 4-6 inches apart, burying all the roots but keeping the very tip of the bulb above the soil surface (Greenfield 2001). Mulch with 2-3 inches of leaf litter.

Harvesting recommendations from Greenfield (2001):
Do not harvest plants until they have filled the site, have large bulbs, and have flowered. If whole plots are harvested at one time, it is recommended to have enough plots to allow for a 5 to 7 year rotation. That is, to have continuous harvest year after year, harvest only one-fifth or one-seventh of your production area each year. When harvesting a portion of a plot, no more than 15% of the ramps should be removed. If the thinning method is used, great care should be taken not to damage plants that are not harvested. Based on research done on wild populations; harvests should be limited to 5 to 10% of the plants in each plot.

Ramps should be dug carefully to avoid damaging the bulbs. Ramps do not keep well, so they should be stored in a cool place and used not long after harvest. Both roots and leaves can be eaten.

Source:

Greenfield, J. 2001. Cultivation of ramps. North Carolina Cooperative Extension Service, Horticulture Information Leaflets. http://www.ces.ncsu.edu/depts/hort/hil/hil-133.html; last accessed 4/06.

Ostrich Fern (*Matteuccia struthiopteris*)

Ostrich fern, one of the largest ferns in the Vermont flora, typically grows in river floodplains and on the forested banks of streams. It thrives in moist soils under shade and spreads aggressively by rhizomes once it is established on suitable sites. This species is a prized spring delicacy in Vermont, as its tightly coiled fiddleheads are a delicious vegetable.

Ostrich fern already occurs on the forest garden site in small numbers. This site is probably only marginally suitable for ostrich fern, since this species spreads aggressively and takes over the herbaceous layer on sites where it thrives. With some assistance, it may become more successfully established on this site.

Ostrich fern fiddleheads ready to be cooked.

Ostrich fern requires some shade, so caution should be taken in removing any trees or limbs to avoid exposing these plants to full sun. Ferns can be encouraged on this site by dividing the rhizomes of existing plants. Division should take place in early spring or in the fall after the leaves have died back. Remove competing plants from the planting site before digging up rhizomes for division, then plant divided rhizomes immediately.

Harvest fiddleheads in May after they emerge but before they unfurl. Use a sharp knife to cut the stalk just under the fiddlehead. Cut 2-3 fiddleheads per plant. Remove brown, papery coverings and cook fiddleheads for at least 10 minutes in boiling water (or steam for at least 20 minutes) as some sources report risk of illness if fiddleheads aren't adequately cooked. Fiddleheads can also be pickled.

American Ginseng (*Panax quinquefolia*)

American ginseng is a highly sought after medicinal plant. Though its benefits are generally not recognized by practitioners of western medicine, its root commands high prices in Asia, especially China, where it is believed to promote and enhance health and well-being. Native to Vermont, ginseng tends to grow in moist, rich woods.
Ginseng is one of the more commonly cultivated woodland herbs, so there are quite a few publications devoted to its propagation and growth. Ginseng can be cultivated in a number of ways: field cultivated ginseng is the most intensive method, requiring raised beds and artificial shade; woods cultivated ginseng is grown in tilled beds under the natural shade of a forested environment; and wild simulated ginseng is grown in untilled soils under natural forest shade (Beyfuss 1999b). Field cultivation yields a crop in a period of 3-4 years, while woods cultivation takes 6-9 years and wild simulation takes between 9 and 12 years to yield a crop. However, the value of the roots is highest for wild simulated ginseng and lowest for field cultivated, as wild simulated most closely resembles the appearance of true "wild" ginseng, which is believed to be more potent than cultivated roots (Beyfuss 1999b). True "wild ginseng" is gathered from naturally occurring populations; this is generally prohibited or strictly regulated, as American ginseng is an internationally protected species. Wild simulation is the least expensive

means of cultivation and produces the most valuable roots, though the duration of the growing time subjects the grower to both delay in realizing profits and to increased risk associated with the potential of herbivory, disturbance, or theft.

For LivingFuture’s forest garden, wild simulation of ginseng is recommended. With relatively few inputs, ginseng could be added to the suite of species cultivated in the garden. The diversified nature of the garden can serve as protection from risk: if the ginseng crop fails, the garden will still be producing other crops. If the crop succeeds, it could add greatly to the economic value of the garden’s products.

The only sure sign that an area is suitable for ginseng cultivation is the existence of a successful natural population on the site. However, other indicators can be used. The forest garden features several indicators of good suitability for ginseng cultivation. These include sugar maples in the canopy, a gentle north-facing slope, and blue cohosh and foamflower in the herbaceous layer. Drawbacks to the site include its rocky soil and its distance from the residence (theft has been a serious problem in areas where ginseng is commonly cultivated).

Since there is some uncertainty about how well ginseng will grow on the site, I recommend starting with test plots as outlined by Beyfuss (unknown year). Several test plots should be established along the northern edge and northeastern corner of the garden. These areas are suggested because they are toward the back of the garden and therefore are less likely to be disturbed by foot traffic. In addition, the northeast corner will remain shady after the removal of beech because of a higher density of sugar maple in this corner. As a result, this area will not be planted with other shrubs and herbs that would require maintenance (and therefore bring potential for trampling of ginseng plants). Test sites should be distributed among a range of microsite conditions, including pits and mounds and differing amounts of shade. Test plots should be 3’ by 3’ and should be well-marked with survey flags. In each plot, rake back leaves, scratch soil surface, remove rocks and roots that might prevent seeds from contacting soil, and then scatter 50 seeds evenly over the plot. Walk on the seeds to ensure good contact with the soil, then rake leaves back over the plot. Beyfuss (unknown date) recommends planting in late September through mid-October.

The following spring, inspect plots as soon as the snow melts. Beyfuss recommends surveying slug populations by setting slug traps (beer-filled saucers set on the ground); if >1 slug is trapped per plot, he suggests use of a pesticide (organic pesticides are available for slugs).

Beyfuss (unknown date) offers the following recommendations for monitoring of test sites:
Count number of emerged seedlings in May, (the number you count times 2 will be your approximate germination percentage) and continue to count them every week or so until fall (this number times 2 will be your seedling survivability percentage). Record all data in the permanent notebook. A record keeping sheet should have columns with the following headings.

Test plot number, date planted, today's date, # of emerged seedlings, # of slugs trapped, soil conditions (i.e. dry, moist soggy etc), other observations. This information will be extremely important for any serious grower to provide complete documentation of the endeavor as well as to allow future information for Pest Management thresholds etc.

Determine which of the plots performed best and expand the plots in that immediate area to 10 foot wide by 10 feet long. Abandon areas that have poor germination and or survivability. Within a few years you will have located the very best locations for serious expansion.

Thin successful test plots after three years of growth to a density of one plant per square foot.
Once successful sites have been located and expanded, areas planted with ginseng should be delineated to minimize trampling, and no other crops should be planted in those areas. Access to sugar maples should not be a problem, since sugaring occurs during winter when plants have died back. However, if snowpack is minimal and the ground is not well-frozen, care should be taken to minimize soil compaction on and around the ginseng roots.

After unsuitable microsites have been abandoned for ginseng cultivation, they can be planted with another crop or groundcover. At that point, some crops in the garden should be producing already; planting decisions should be based on which crops have done well on similar microsites, and which products are in highest demand.

One report suggests that a half acre plot can produce 80 lb of dried ginseng roots after 9 years (Beyfuss 1999b). The area of the forest garden devoted to ginseng will be much smaller than that, so yield is likely to be in the vicinity of 20 lb or less. As of 1999, a pound of dried roots was valued at $300. It is impossible to say what the market value of ginseng root will be by the time of harvest from the forest garden; however, Beyfuss (1999b) predicts increasing demand.

Sources:
Beyfuss, R.L. 2004. American Ginseng Production. <http://counties.cce.cornell.edu/greene/ginseng.html>; last modified 2/04; last accessed 4/06.
Beyfuss, R.L. 1999a. American ginseng production in woodlots. *Agroforestry Notes* (AF Note – 14, Forest Farming-3. Produced by the National Agroforestry Center in Lincoln, Nebraska, a partnership of the USDA Forest Service and the USDA Natural Resources Conservation Service.
Beyfuss, R.L. 1999b. Economics and Marketing of Ginseng. *Agroforestry Notes* (AF Note – 15, Forest Farming-4. Produced by the National Agroforestry Center in Lincoln, Nebraska, a partnership of the USDA Forest Service and the USDA Natural Resources Conservation Service.

Beyfuss, R.L. unknown date. Ginseng site evaluation protocol. http://www.dnr.cornell.edu/ext/agroforestry/sare/Ginsengsiteevalprotocol.htm; last accessed: 4/06.
Das, S., L. Shillington, and T. Hammett. 2001. Ginseng. Non-timber forest products, Fact sheet no. 7. Virginia Tech Special Forest Products Program. http://www.sfp.forprod.vt.edu/factsheets/ginseng.pdf; last accessed 4/06.

Goldenseal (*Hydrastis canadensis*)

Goldenseal resembles ginseng both in its preferred growth conditions and its long history of use as a medicinal plant. This herb is also native to Vermont and grows well in rich, moist woodland soils. Unlike ginseng, its medicinal properties are well-documented and it is widely used in the United States to treat a wide range of disorders and symptoms (Beyfuss unknown date).

Unlike ginseng, the conditions under which goldenseal is cultivated do not strongly affect the value of its roots; ginseng roots that are old and gnarled command much higher prices than younger, field-grown roots, but the appearance of goldenseal roots is not important. As a result, goldenseal roots should be harvested after 5 to 6 years, when the root has achieved its maximum size.

Goldenseal grows best in soils with high organic matter content. As a result, amendment of soil with compost is recommended at time of planting. This species can be propagated from rhizome pieces, root cuttings, one year old seedlings, or seed (Davis 2000). Seeds should be planted in the fall. Davis (2000) recommends planting 10-12 seeds per foot in rows three inches apart. Seeds should be planted ½ inch deep and covered lightly with mulch. If planting rhizome pieces or seedlings (which accelerates harvest by a year or two), dig a narrow trench 2-3 inches deep. Planting stock should be spaced about 6 inches apart, placed with bud facing up, and buried with soil (Davis 2000).

In LivingFuture's forest garden, goldenseal should be planted in the same areas as ginseng (the north edge and northeast corner) and well-marked to prevent trampling. I have not found any evidence to suggest that ginseng and goldenseal can *not* be grown in polyculture, so I recommend experimenting with the possibility using test plots. Some test plots should include only ginseng, some only goldenseal, and some both. Individual plants of the two species should not be planted too close to one another, as goldenseal roots will be harvested several years before ginseng and care should be taken to avoid disturbing the soil around the ginseng roots prior to their harvest.

The market for goldenseal roots is much less predictable than that of ginseng; it fluctuates a great deal depending on supply and demand (Beyfuss unknown date). As a result, it is impossible to estimate the profits from the forest garden's yield of goldenseal.

Sources:

Beyfuss, R.L. unknown date. Growing ginseng and goldenseal in your forest. New York State Department of Environmenal Conservation. http://www.dec.state.ny.us/website/dlf/privland/forprot/ginseng/growing.html; last accessed 4/06.
Das, S., L. Shillington, and T. Hammett. 2001. Goldenseal. Non-timber forest products, Fact sheet no. 8. Virginia Tech Special Forest Products Program. http://www.sfp.forprod.vt.edu/factsheets/goldenseal.pdf; last accessed 4/06.

Davis, J.M. 2000. Commercial goldenseal cultivation. North Carolina State University, Horticulture Information Leaflets. http://www.ces.ncsu.edu/depts/hort/hil/hil-131.html; last accessed 4/06.

Secondary species

American Plum (*Prunus americana*)

A multi-stemmed, shrubby tree species, the American plum is native to the United States but its natural range does not extend into Vermont. However, cultivated varieties thrive in Vermont. This species reproduces both sexually and vegetatively, often root suckering and forming dense thickets. In fact, plums do best when planted in clusters. There must be at least two for cross-pollination (Jacke and Toensmeier 2005). This potentially limits the suitability of this species for the forest garden; there may not be any gaps large enough to provide ample sun to a cluster of plums. Thus, this species should not be included in the first round of plantings, but considered if a large enough gap is opened.

Plums can be purchased from Elmore Roots.

Source:

Jacke, D. and E. Toensmeier. 2005. *Edible Forest Gardens, Vol. 2: Design and Practice.* White River Junction, VT: Chelsea Green Press.

Pear (*Pyrus* spp.) *non-native

*invasion risk: none (this small tree requires full sun and so is unlikely to invade our forested ecosystems)
This sun-loving tree species grows to a height of 25-30 feet, although its cultivars take forms ranging from dwarf to full size. Cultivars of both the Asian pear (*P. bretschneideris*) and the European pear (*P. communis*) are suitable for this region, though the European species is more cold-hardy (Jacke and Toensmeier 2005). This fruit is less susceptible to pest and disease than is the apple. At least two of each variety must be planted for pollination.

This species may not be suitable for the forest garden for two reasons: first, the species requires full sun and, since at least two need to be planted for pollination purposes, there is unlikely to be a sufficiently large gap open; and second, the species is non-native and all plants on the "primary species" list are natives, which allows the site to be a demonstration of the productivity of native species.

Source:

Jacke, D. and E. Toensmeier. 2005. *Edible Forest Gardens, Vol. 2: Design and Practice.* White River Junction, VT: Chelsea Green Press.

Red Raspberry (*Rubus idaeus*)

The forest garden site is not ideal for raspberries, but they are so delicious that it may be worth a try! Raspberries grow best in full sun in well-drained, sandy loam soils with high organic matter content (Lord and Handley 1995). The edge of the road on the southern side of the forest garden is the best potential location for raspberries; the roadcut provides a reasonable gap, and some *Rubus* are already growing in this area. However, the ditch beside the road is too wet for raspberries, so they need to be placed on higher ground or slightly further into the garden. This plant should not be planted during the first year; it is better to wait, observe site conditions for a full season, and proceed with planting if an area is identified as being sufficiently sunny and dry. Raspberries require a fair amount of maintenance, so there should be a good chance of reasonable yields before they are planted.

Sources:

Lord, W.G. and D. Handley. 1995. Growing Raspberries. University of New Hampshire Cooperative Extension. http://extension.unh.edu/Pubs/AgPubs/Apft1400.pdf; last accessed, 4/06.

Jostaberry (*Ribes nidigrolaria*) *non-native

*invasion risk: unknown (this cultivar is very cold hardy and tolerates shade, so it may be able to spread in the forest)

This cultivated hybrid is a cross between the gooseberry (*R. uva-crispa*) and black current (*R. nigrum*). Jostaberry is a multi-stemmed shrub that grows to a height of 8 feet (Jacke 2005). While many *Ribes* species are hosts for the white pine blister rust, jostaberry is resistant, which is one of the main reasons to consider it for the site. *Ribes* species that do serve as hosts for white pine blister rust should be avoided, as there are white pines adjacent to the forest garden.

This cultivar is extremely cold hardy and heat intolerant, so thrives in cool microclimate. It can tolerate shade but produces more in the sun. Rooting depth of 8-16 inches; prefers loamy soils with good drainage, pH 6.2 to 6.5, 1% organic matter (Rieger 2005). It has been reported to produce delicious berries, but John Patrick Hayden (pers. comm.)

reported that he has heard that this cultivar does not produce well. Further research is needed before this (or other *Ribes* species) can be included in the garden.

Wood Nettle (*Laportaea canadensis*)

This edible herb thrives in part to full shade and may be a dynamic accumulator (Jacke and Toensmeier 2005). However, it will spread vegetatively, so use of rhizome barriers is recommended (Jacke and Toensmeier 2005).

Source:

Jacke, D. and E. Toensmeier. 2005. *Edible Forest Gardens, Vol. 2: Design and Practice*. White River Junction, VT: Chelsea Green Press.

Other Species for Consideration

Foamflower (*Tiarella cordifolia*)
Ground cover in rich woods
Canada violet (*Viola canadensis*)
Edible leaves and flowers, good groundcover. Tolerates partial shade.
Highbush Blueberry (*Vaccinium corymbosum*)
Lowbush Blueberry (*Vaccinium angustifolium*)
Groundnut (*Apios americana*)
Asparagus (*Asparagus officinalis*)
Sweet Cicely (*Myrrhis odorata*)
Edible greens and seeds; nectary plant
Highbush cranberry (*Viburnum trilobum)*
Produces berries that are unpalatable fresh but can be made into jams. A favorite for wildlife.