If there's one thing Greg and Raquel Massa hate, it's weeds—all varieties, but especially the azolla—an insidious, fernlike plant that grows on the surface of water. Each spring, azolla plants invade the couple's rice farm, snaking their way through the dense, muddy paddies that stretch for miles along the Sacramento River near Chico, California. They strangle young rice plants and force Greg into an endless and tedious battle.

The rivalry—Massa versus azolla—has spanned three generations. Greg's grandfather, Manuel Massa, planted the family's (and some of California's) first rice crops in 1916, on the same land that Greg and Raquel now manage. Back then, rice farming was a hard and uncertain life; Manuel was largely powerless against the azolla, which in some seasons claimed his entire crop.

By 1962, when Greg's father, Manuel Jr., took over, American ingenuity and modern science had completely changed the nature of the fight. Heavy doses of chemical herbicides enabled him to obliterate the weed. And specially bred higher-yield rice varieties developed during the Green Revolution (see Chapter 20), along with modern farming equipment and a heavy dose of chemical *fertilizers* (nutrients that boost plant growth), made the family farm both efficient and profitable.

Of course, that modern approach, known as **industrial agriculture**, had its own problems. For one thing, it relied on cheap fossil fuel energy and lots and lots of water, both of which are in much shorter supply these days. For another, it impaired ecosystem services, often gravely, because it involved clearing huge swaths of land to increase production, and focusing all resources on a single crop. On top of that, chemical fertilizers and *pesticides* (such as insecticides that kill insects or herbicides that kill plants) were expensive and not especially good for the land.

WHERE IS CHICO, CALIFORNIA?

Greg and Raquel wanted to find a better, more sustainable way. **Sustainable agriculture** is farming that meets the needs of the farmer and society as a whole without compromising the environment or future productivity. The techniques used will maintain or even enhance the environment. They often do this by mimicking the traits of a sustainable ecosystem—they rely on renewable energy and local matter resources for inputs and depend on biodiversity to trap energy, deal with waste, and control populations. [INFOGRAPHIC 22.1]

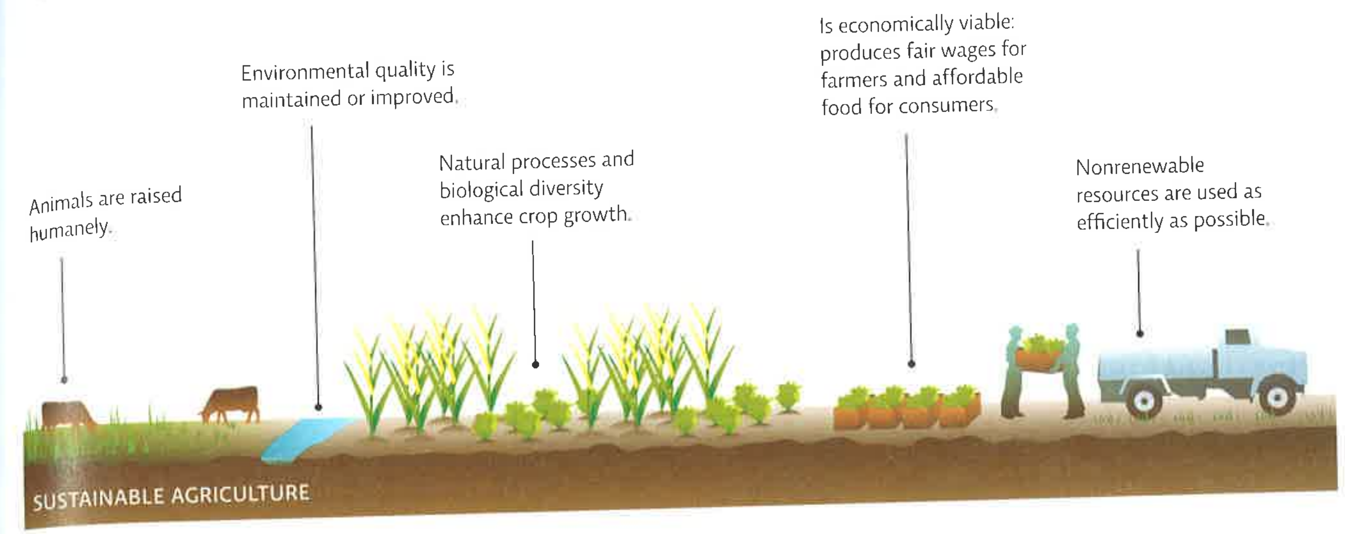
So when Greg and Raquel took over in 1997, they converted a portion of their farm to a sustainable farming method known as **organic agriculture**. Instead of synthetic fertilizers and pesticides, organic agriculture employs more natural, or "organic," techniques in the growing of crops—such as using manure as fertilizer and luring in natural predators to control pests. This type of farming uses fewer or no chemicals and in some cases may even produce food that is more nutritious. For example, research by Washington State University soil scientist John Reganold showed that organically grown strawberries had a longer shelf life and a higher level of antioxidants than conventionally grown berries. But organic farming forced Greg and Raquel to battle weeds much as the first Manuel had: with great difficulty.

The trick was to lower water levels enough to kill water-loving weeds, but not so much that the rice crop also died. Each day, Greg would wade into the paddies to see how the rice plants were faring against the azolla. Some weeks, he worried the entire crop would die. After a few seasons, the Massas started to despair: How could they make their farm environmentally friendly without losing their livelihood to an army of mangy weeds?

industrial agriculture Farming methods that rely on technology, synthetic chemical inputs, and economies of scale to increase productivity and profits.
sustainable agriculture Farming methods that can be used indefinitely because they do not deplete resources, such as soil and water, faster than they are replaced.
organic agriculture Farming that does not use synthetic fertilizer, pesticides, or other chemical additives like hormones (for animal rearing).
monoculture Farming method in which a single variety of one crop is planted, typically in rows over huge swaths of land, with large inputs of fertilizer, pesticides, and water.

Infographic 22.1 | **SUSTAINABLE AGRICULTURE**

According to the U.S. Department of Agriculture, sustainable agriculture is farming that uses only limited amounts of nonrenewable resources (like fossil fuels) and does not degrade the environment or the well-being of people or society as a whole.



The Massa's story is the story of modern farming; it's the story of how we feed ourselves. And on a planet where population is exploding, climate is shifting, and energy and water resources are running low, it's also a story of constant change.

Modern industrial farming techniques are productive but come with some significant trade-offs.

The changes that helped Greg's father thrive also ushered in a whole new way of growing crops, known as **monoculture** farming. Instead of growing a mix of plants, or growing different crops each season, farmers began growing the same, single crop year after year. Before long, farms that had been populated by a variety of crops morphed into industrial operations, focused on just one crop. Thus, biodiversity was replaced by specialization, and farm ecosystems that more closely resembled nature were replaced by operations completely dependent on technology. "In the 1920s, half of Iowa's farms produced 20 commodities each," says Fred Kirschenmann, a Distinguished Fellow at Iowa State University's Leopold Center for Sustainable Agriculture. "Today 80% of the state's cultivated land is exclusively corn or soybean. Farming systems that were once supported by complexity and diversity of species have now been replaced by reliance on inputs." Worldwide, 90% of our food comes from just 15 crop species and 8 species of livestock.

The advantages of this new approach were obvious—a single crop was much easier to manage and to mass produce, and with greater ease came not only greater efficiency and greater profits, but also drastically greater amounts of food for a planet that never seemed to have enough.

In recent years, however, the disadvantages of industrial agriculture have become equally apparent. In monoculture farming, the crop that is chosen is not necessarily locally adapted. Instead of choosing the crop best suited to the existing ecosystem, farmers focused on those crops with the highest market demand, and thus the highest dollar value. Because these crops were not locally adapted, and because the volume of plants grown increased exponentially, the average farm became heavily dependent on external inputs—water, pesticides, and fertilizer—added to the farm from outside its own ecosystem.

Worldwide, 90% of our food comes from just 15 crop species and 8 species of livestock.

Fertilizers boost growth because they provide nutrients needed by plants, such as nitrogen and phosphorus (see Chapter 7 for more on nutrient cycles). And while heavy doses of fertilizer can indeed boost crop production, the excess nutrients (whatever is not used by the plants) can soak into the ground and contaminate the groundwater or be easily washed from fields by rain and modern irrigation practices. The excess, or *runoff*, enters waterways, and ultimately creates hypoxic, or oxygen-poor, regions that threaten aquatic life. This process, known as **cultural eutrophication**, has been a significant problem in the United States, where nutrient runoff from farms in Iowa and other "Corn Belt" states has created a summertime dead zone in the Gulf of Mexico (see Chapter 18). [INFOGRAPHIC 22.2]

Monoculture crops are also more vulnerable to pests or disease—a single infestation can wipe out the entire crop because what kills one plant will likely kill them all. To deal with this, farmers have turned to pesticides, but this also has proven problematic. To be sure, pesticides kill weed and insect pests and thus dramatically reduce the number of crops lost each year to infestation. But because they are toxic, pesticides also pose a threat to human and ecosystem health. And as scientists quickly discovered, pest populations can develop **pesticide resistance**, an unintentional example of artificial selection (see Chapter 12). Herbicide-resistant weeds and insecticide-resistant insects are cropping up all around the world. This forces us to employ more drastic measures, in the form of higher doses or more toxic chemicals—but as resistance to that next pesticide develops, the cycle repeats itself. It's like an arms race between humans and pests, with the deck stacked in favor of the pests. [INFOGRAPHIC 22.3]

Infographic **22.2** | **THE USE OF FERTILIZER COMES WITH TRADE-OFFS**

ADVANTAGES

INCREASE PRODUCTIVITY

↑ Fertilizer can greatly increase productivity of the soil and is required for many of the high-yield varieties now under industrial cultivation. Vital soil nutrients like nitrogen and phosphorus are often in limited supply (see Chapter 7 for more on nutrient cycles) and plant growth slows if one nutrient starts to run out. The addition of extra nutrients overcomes this deficiency and can boost growth.

GROW CROPS IN MARGINAL SOILS

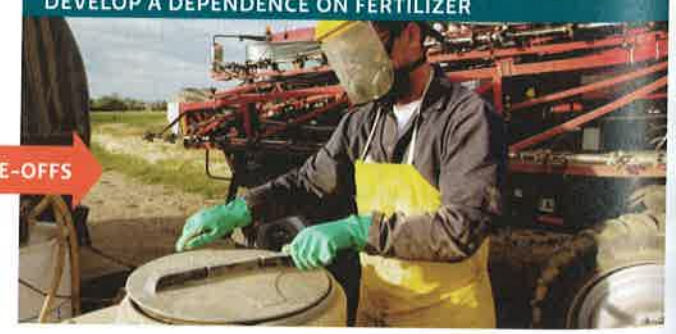
↑ Fertilizers help crops grow in areas that may not otherwise be able to support agriculture. This may be the only way to farm in many areas of the world and would help increase local food supplies.

DISADVANTAGES

CULTURAL EUTROPHICATION

↑ Runoff pollution that contains fertilizer can also boost the growth of algae, causing algal blooms that block sunlight and prevent underwater photosynthesis, reducing the addition of oxygen to the water. As organisms die and organic material builds up, decomposing bacteria increase in number, seriously depleting the oxygen content of the water and leading to the death of many more aquatic organisms such as fish.

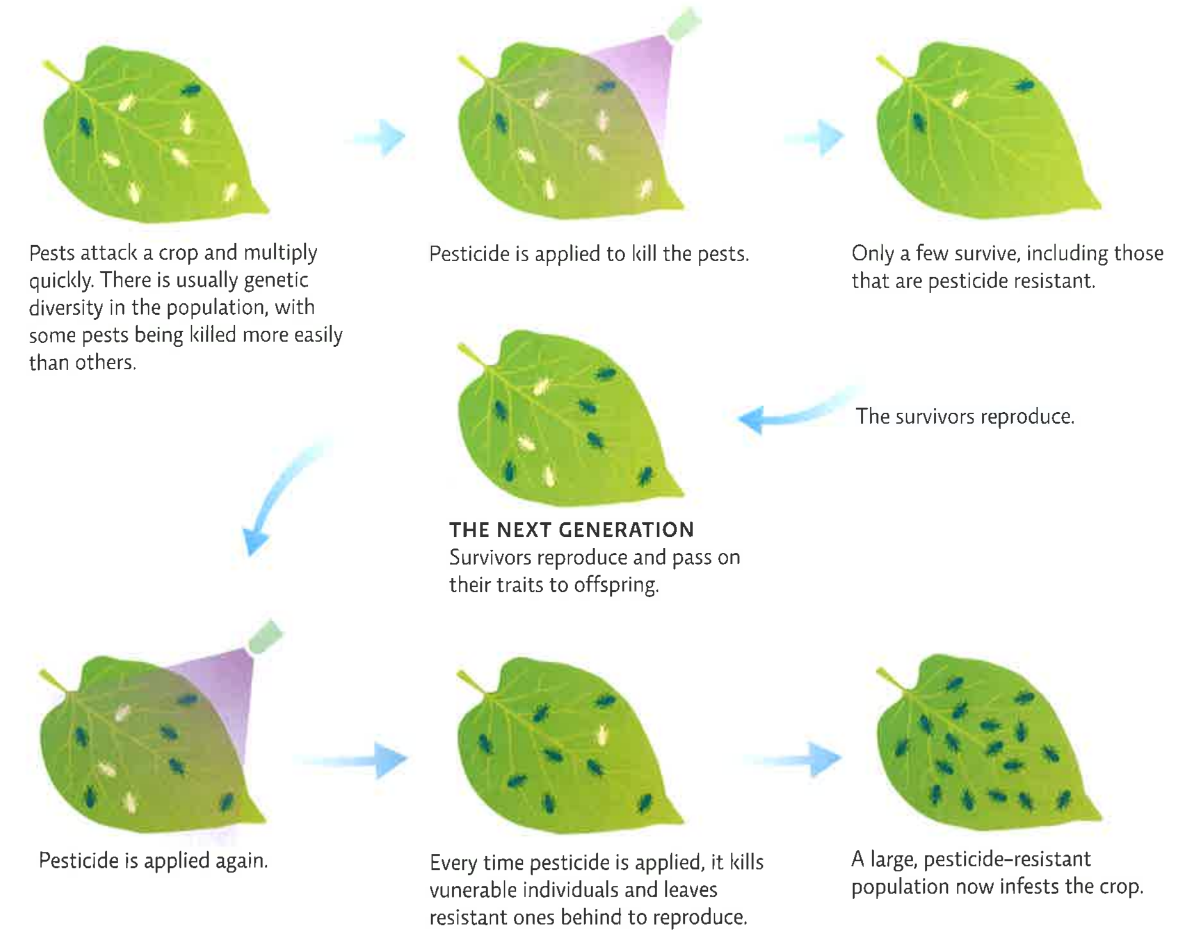
DEVELOP A DEPENDENCE ON FERTILIZER



↑ The extra plant growth that fertilizers support can pull other nutrients out of the soil, depleting soils further and requiring even more fertilizer in the future. In addition, some crops may be less nutritious when grown in nutrient-depleted soil, even with the addition of fertilizers (which will not be able to fully restore soil fertility).

Infographic **22.3** | **EMERGENCE OF PESTICIDE-RESISTANT PESTS**

↓ Exposure to a pesticide will not make an individual pest resistant; it will likely kill it. However, if a few pests survive because they happen to be naturally resistant, they will breed and their offspring (most of which are also pesticide resistant) will make up the next generation. Over time, the original pesticide will no longer be effective and will have to be applied at a higher dose or a different pesticide will have to be used. Application of a pesticide might even increase the size of the pest population by killing the predators that eat the pests.



Even water inputs have created problems: It turns out that the use of irrigation can result in soil salinization; as water evaporates from the soil, salts are left behind and eventually become so concentrated that they impede crop growth. And if all that weren't enough, the colossal machines used to plow endless fields of corn and soybean have compacted the soil, making it harder for plants to take root and grow.

On top of that, the quality of the food itself can also suffer. Several recent studies have shown a decline in the nutrient content of food grown on soils subjected to years of industrial farming. In one of the first such studies, University of Texas researcher Donald Davis compared the nutritional content of 43 fruits and vegetables grown in 1950 to those grown in 1999, noting a decline in 6 nutrients (protein, calcium, phosphorus, iron, and vitamins B2 and C). Davis suspects this is due to the impoverished soil in which the crops are grown.

As modern farmers face these enormous challenges, (and global warming and energy and water shortages along with them), the story of how we feed ourselves is changing yet again. This time, we may have to consider not just high-tech solutions but look back to the natural world for answers. In searching for a new weapon against the azolla, Raquel found a Japanese rice farmer who was doing just that.

cultural eutrophication Nutrient enrichment of an aquatic ecosystem that stimulates excess plant growth and disrupts normal energy uptake and matter cycles.

pesticide resistance The ability of a pest to withstand exposure to a given pesticide, the result of natural selection favoring the survivors of an original population that was exposed to the pesticide.

↑ Greg Massa, right, with rice plants in hand.

Mimicking natural ecosystems can make farms more productive and help address some environmental problems.

Takao Furuno was, by most standards, a very successful industrial rice farmer, with annual yields among the highest in southern Japan. But it was a tough grind. Each year he was forced to put all his earnings back into the next year's crop—insecticides, herbicides, irrigation, and fertilizer—so that despite his success, he and his family were left with very little for themselves at the end of each season.

In searching for a better way, he turned, as he often did, to his forebears to see what he could learn from their knowledge. He was surprised to discover that they used to keep ducks in their rice paddies. Like most rice farmers, Furuno considered ducks a pest, albeit a slightly cuter one than the azolla. Adult ducks eat rice seeds before they have a chance to grow, and as they forage, trample young seedlings into the mud. This disturbance creates open patches of water, which in turn, invites only more ducks. "If you're not careful, you end up with a big problem pretty quickly," says Raquel.

But ducklings, Furuno soon realized, were too small to do such damage; for one thing, their bills were not big or strong enough to extract seeds from mud. Instead, they ate bugs and weeds. Azolla was one of their favorites.

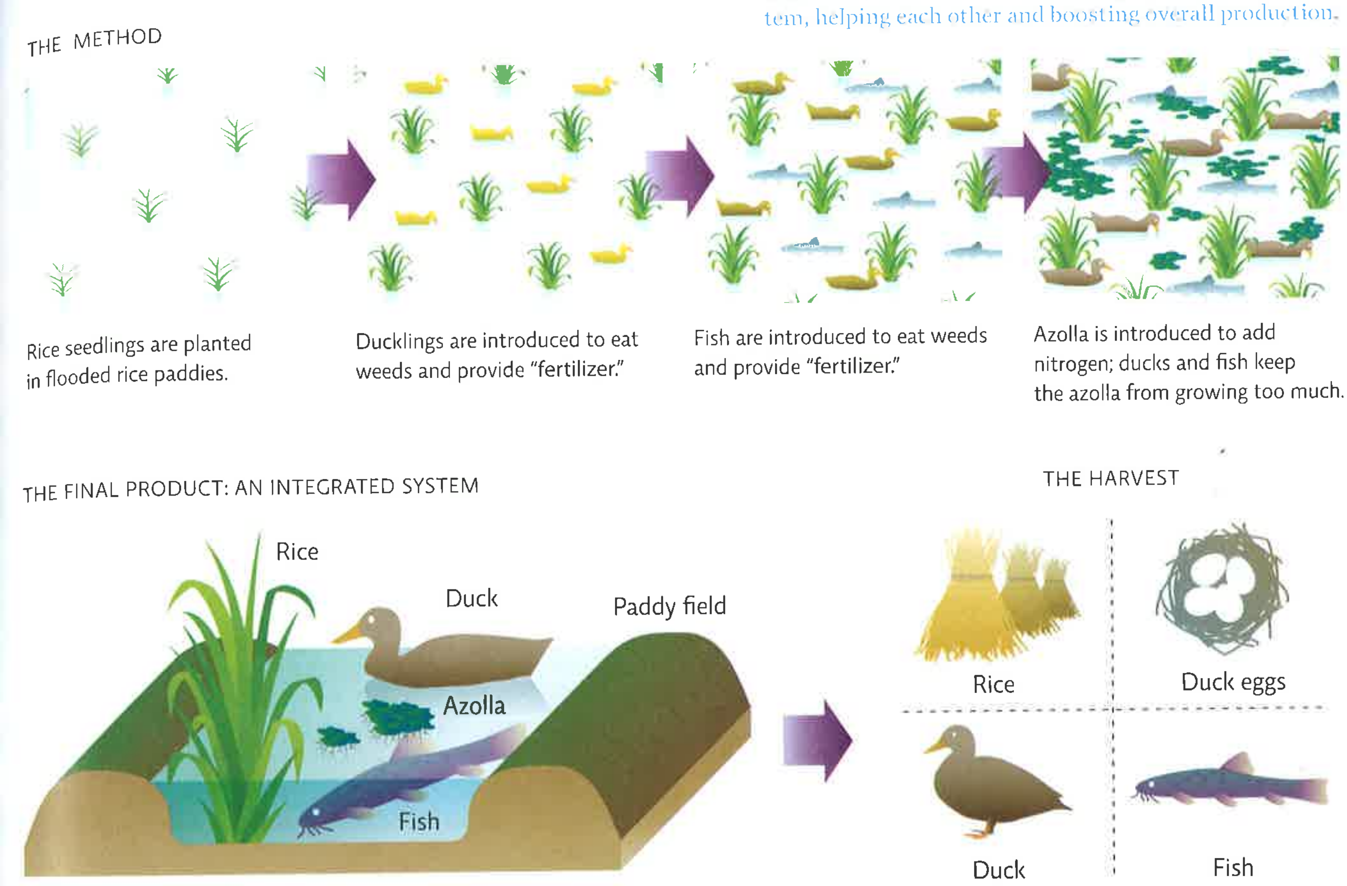
Furuno's forbears also grew loaches—a type of fish—in their paddies. The loaches would also eat azolla and could be harvested and sold as food.

Together the ducklings and loaches would keep the weed from strangling the rice crop; but they would not completely eliminate the azolla the way a heavy dose of pesticides would. Furuno quickly discovered that, when kept at this benign concentration, the azolla (which contains symbiotic bacteria that produce nitrogen) actually fertilized the rice. In fact, between the nitrogen from the azolla, and the duck and fish droppings, he soon found that he no longer needed to spend money on synthetic fertilizer.

When raising ducks, fish, and rice crops together, Furuno discovered the root crowns (where the root meets the stem) of rice plants increased to about twice the size that they had been in his old industrial system. A larger root crown meant more rice. "We're not exactly sure why the crowns grew," Furuno told an audience of American farmers at a recent convention in Iowa. "But the ducks seem to actually change the way the rice grows. It's got something to do with the synergy of the whole system." Furuno's operation is an elegant example of biomimicry—a farm operating like a natural ecosystem. This type of farming, known as **agroecology**, considers both ecological concepts (modeling a farm after an ecosystem) and the value of traditional farming knowledge

Infographic 22.4 | **AGROECOLOGY: THE DUCK/RICE FARM**

↓ Takao Furuno's farm is a self-regulating, multiple-species system that naturally meets the needs of the farm ecosystem. All of the species play a role in the system, helping each other and boosting overall production.



as a rich resource for sustainable and effective farming methods. [INFOGRAPHIC 22.4]

There were other financial gains, too. Duck eggs, duck meat, and fish all fetched a good price in the market. And because he was no longer using pesticides, he could also grow fruit on the edges of his rice field. (He opted for fig trees, as he could harvest the figs annually without having to replant.)

Furuno's farm is an example of **polyculture**—intentionally raising more than one species on a given plot of land. In the decade and a half since Furuno began duck/rice farming, his rice yields have increased by 20–50%, making his among the most productive farms in the world, nearly twice as productive as conventional farms. This kind of success is especially important for farmers in many developing countries, who struggle to produce enough food for current populations. Increasing production with lesser dependence on expensive inputs, and using methods that enhance rather than diminish environmental quality, can help communities become more self-sufficient and help them achieve food security.

The Bangladesh Rice Research Institute, which has evaluated Furuno's method and independently verified his success, recommends the technique to Bangladeshi farmers. And by now, some 10,000 Japanese farmers have followed Furuno's lead; his method is also catching on in China, the Philippines...and California.

Furuno's method of duck/rice farming turned out to be a good fit for the Massas. Not only would the rice plants rely on natural fertilizers and natural pest control, but the duck eggs and meat produced would be more humanely grown than those produced by factory farms. The ducks

agroecology Scientific field that considers the area's ecology and indigenous knowledge, and favors methods that protect the environment and meet the needs of local people.

polyculture Farming method in which a mix of different species are grown together in one area.

would grow up in ponds, not crammed together on slats in a barn without access to swimming water. They would get to splash around, and express their "duckiness," as Raquel puts it.

When the ducks first arrived on the Massa farm, they were just 24 hours old, cotton-ball-sized tufts of yellow feathers. The Massa children cared for them in wooden crates in their barn. But as Raquel soon learned, small ducklings grow mighty quickly. In just 2 weeks, they were large enough to turn loose. Furuno had advised stocking about 100 ducks per acre, but Greg and Raquel did not want to sacrifice that much land for this first attempt, so they fenced off just a quarter acre instead. This amount of space provided plenty of room for their 120 ducks to swim and forage in, but as it turned out, not enough food to support them. "They quickly ate all the weeds in the field," says Greg. They also trampled some of the rice plants in their pond because their section of the field was too small. But even as they ran out of weeds to eat, the baby ducks stayed away from the rice plants, just as Furuno had insisted they would.

Integrated pest management is another feature of sustainable agriculture.

Both of Greg and Raquel's azolla-control methods—reducing water levels and employing duck predators—are examples of **integrated pest management (IPM)**, or the use of a variety of methods to help reduce a pest population. The goal of IPM is to successfully control pests while minimizing or eliminating the use of chemical toxins. First, the farmer must examine the lifecycle of the pest and the pest's interactions with the environment to identify the best way to deal with the pest. In general, IPM techniques fall into four different categories: cultural control, biological control, mechanical control, and chemical control.

In sustainable agriculture, farmers use a combination of cultural, mechanical, and biological controls to deal with pest problems, and only resort to chemicals if these methods don't adequately deter the pests. If a pesticide is going to be used, the preference is for natural, biodegradable chemicals that are toxic only to a limited group of organisms. For example, pyrethrum, a compound naturally produced by a flower in the chrysanthemum family, is directly toxic to insects but not to mammals; it is certified for organic agriculture since it breaks down quickly and does not linger in the environment. However, while it does kill pest insects, it is also toxic to *good* insects like honeybees, so its use is avoided during times of pollination. Synthetic pesticides, like those commonly used in industrial agriculture, are not acceptable for use on certified organic crops but may be part of an IPM plan for conventionally raised crops. [INFOGRAPHIC 22.5]

Sustainable agriculture techniques can protect soil and keep farm productivity high.

Greg and Raquel were well versed in the problems of modern agriculture. Before settling in California to take over the family farm, they had worked as tropical ecologists in Costa Rica, where they learned about traditional, nonindustrial farming methods that help protect the soil and keep productivity high without the use of synthetic fertilizers or pesticides.

Soil is vital to life on Earth—it supports the growth of plants and the animals who feed on those plants. Its formation is very slow (it can take more than 1,000 years to form 2.5 centimeters [1 inch] of topsoil) and depends on myriad soil organisms (see Chapter 14). Modern farming can contribute to a decline in soil fertility and to the direct loss of soil though erosion. However, some traditional (preindustrial) methods can actually help restore or protect soil. For example, methods such as **terracing** and **contour farming** can decrease soil erosion from sloped land. Other techniques that protect the soil include **reduced-tillage** methods, as well as planting a **cover crop** in the off-season to prevent exposed soil from washing away. This last approach has the added advantage of helping to restore fertility. Soil fertility can also be enhanced and pests controlled using **crop rotation** and **strip cropping**. In addition, systems like Furuno's that combine animal and plant rearing return animal waste—a natural fertilizer—to the soil. [INFOGRAPHIC 22.6]

In rice farming, the Massas saw a chance to implement all the concepts and theories they had learned as ecology students, and refined and discussed as scientists, on their

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integrated pest management (IPM) The use of a variety of methods to control a pest population, with the goal of minimizing or eliminating the use of chemical toxins.

terracing On steep slopes, land is leveled into steps; reduces soil erosion and runoff down the hillside.

contour farming Farming on hilly land in rows that are planted along the slope, following the lay of the land, rather than oriented downhill.

reduced-tillage Planting crops in soil that is minimally disturbed and that retains some plant residue from the previous planting.

cover crop A crop planted in the off-season to help prevent soil erosion and to return nutrients to the soil.

crop rotation Planting different crops on a given plot of land every few years to maintain soil fertility and reduce pest outbreaks.

strip cropping Alternating different crops in adjacent strips, several rows wide; helps keep pest populations low.

Infographic 22.5 | **INTEGRATED PEST MANAGEMENT (IPM)**

Controlling pests is important for our agricultural yields as well as for our health and for the health of our pets. Rather than using harsh methods in an attempt to completely eliminate the pest (which rarely works anyway), a combination of less hazardous methods can often reduce pest numbers to manageable levels.

INTEGRATED PEST MANAGEMENT HAS SEVERAL STEPS

1. IDENTIFY TRUE PESTS
Not all "bugs" and "weeds" are pests—some plants and animals are innocuous or actually beneficial. By working to control actual pests only, we save time and money, and we help the environment by maintaining diversity and preventing toxic pollution.

2. SET AN ACTION THRESHOLD AND MONITOR PESTS
The pest population size that is unacceptable must be identified. We may have zero tolerance for some pests (e.g., fleas and ticks in our homes) but be able to tolerate small populations of crop pests; we will only act if the action threshold is reached.

3. DEVELOP AN ACTION PLAN
This may include a variety of methods, each of which aids in pest control by excluding, discouraging, or killing pests. The goal is to control the pest while avoiding or minimizing the use of chemical control agents which may be toxic and have unwanted health and environmental effects.

PREVENTION AND CONTROL METHODS

CULTURAL Usually the first method chosen as part of the action plan; involves cultivation techniques that minimize the habitat or food source for the pest so that other control methods can then be used to adequately control the pests.

Strip cropping minimizes potential food for pests that don't disperse over great distances, lessening the chance of an outbreak of pests.

MECHANICAL Relies on methods that physically exclude, trap, or repel pests, such as physical barriers or traps, or removing pests or weeds by hand or with machinery; can be labor intensive but often inexpensive and may be particularly useful in developing countries with plentiful labor but little cash.

Netting can keep out birds and rabbits that would eat the crops. Reducing water levels in rice paddies to kill azolla is an example of mechanical control.

BIOLOGICAL Introducing predators, sterile males, or plants that repel the pest; technique works best if it follows cultural and mechanical steps.

Ladybugs, predatory beetles that eat pests such as this aphid, can actually be purchased and released, or steps can be taken to attract them naturally to the area. The ideal control agent is a specialist whose preferred food is the pest in question, and who does not attack nontarget species.

CHEMICAL Applying chemicals that kill or repel pests; a last resort that is used only if the other three methods cannot control the pests.

To minimize health and environmental concerns, the preferred chemical is the one that can do the job while being the least toxic and the most degradable.

Infographic 22.6 | **SUSTAINABLE SOIL MANAGEMENT PRACTICES**

↓ Many traditional methods are useful for sustainable agriculture because they focus on protecting the soil, the heart of successful farming.

CONTOUR FARMING When farming on hilly land, rows are planted along the slope, following the lay of the land, rather than oriented downhill to reduce the loss of water and soil after a rainfall.

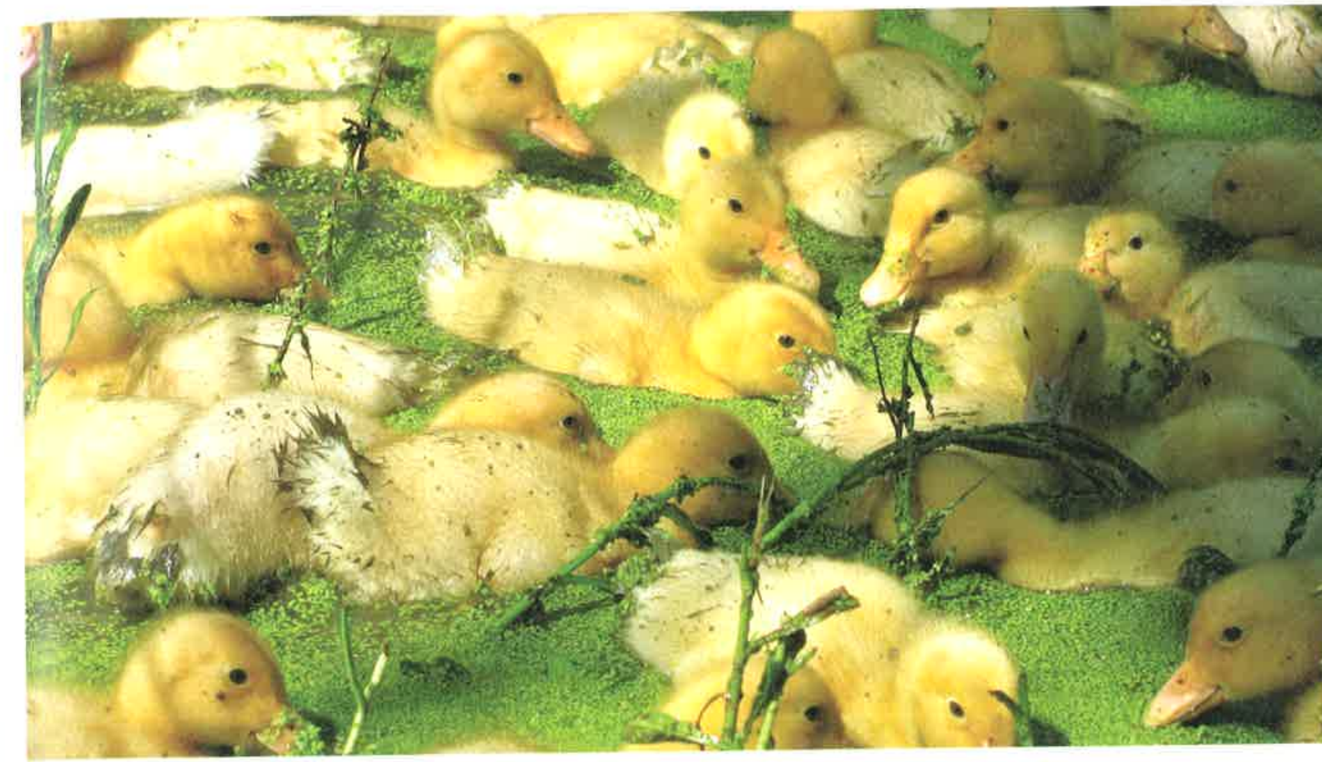
REDUCED TILLAGE Planting crops into soil that is minimally tilled reduces soil erosion and water needs (it reduces water evaporation). It also requires less fuel because of less tractor use.

TERRACE FARMING On steep slopes, the land can be leveled into steps. This reduces soil erosion and allows a crop like rice to stay flooded when needed.

CROP ROTATION Planting different crops on a given plot of land every few years helps maintain soil fertility and reduces pest outbreaks since pests (or their offspring) from the year before will not find a suitable food when they emerge in the new season.

STRIP CROPPING Alternating different crops in strips that are several rows wide keeps pest populations low; it is less likely the pests will travel beyond the edge of a strip and they may not find another row of this crop.

COVER CROPS During the off-season, rather than letting a field stand bare, a crop can be planted that will hold the soil in place. Nitrogen-fixing crops like alfalfa that improve the soil are often chosen.



↑ Ducklings in the Massa Organics rice fields

own land. "We wanted a farm where success was measured not just in crop yield, but in the overall health of the land," Greg says. "A place where we would count profits, but we would also count the number of sandhill cranes and California quail we saw populating the area."

They also wanted to create a farm that was at least partly local (they planned to sell a portion of their rice at local outlets like farmers' markets and food co-ops). More and more consumers are buying food from local farmers; local agriculture supports local economies and provides fresher and thus healthier food to consumers. Because transportation depends on fossil fuels, the more **food miles** a product travels before reaching the consumer, the greater the **carbon footprint** of that food. And much of our food has traveled quite far—about 2,400 kilometers (1,500 miles), on average.

However, transportation is not the main use of fossil fuels when crops are raised industrially. Research by Christopher Weber and Scott Matthews of Carnegie Mellon University determined that about 90% of the carbon footprint for food grown using conventional industrial methods is from the production of the crop (fuel for equipment, raw materials for pesticides and fertilizer production), not its transport. Therefore, buying organically grown produce—even from far away—may reduce the carbon footprint more so than buying locally grown industrial crops. Of course, the best option is to choose organic foods that are locally grown. Likewise, because beef raised in industrial Concentrated Animal Feeding Operations has one of the highest carbon footprints of all agricultural products (see Chapter 21), one of the best things you can do is to replace at least some of the beef you eat with chicken, pork, fish, or meatless dishes.

Consumers are becoming more aware that things like food miles, and the way food is raised matter for the environment, their communities, and their own health. Organic foods and ethically raised animal products are claiming a bigger share of consumer dollars annually. But this has opened the door to **greenwashing**—making claims about the environmental benefits of sustainably raised or organic foods that are misleading (organic cookies are probably not really healthier than those made with conventional ingredients; "cage free" eggs may still be from chickens living in overcrowded conditions). Consumers need to be diligent about evaluating claims and make informed decisions about what to purchase. [INFOGRAPHIC 22.7]

food miles The distance a food travels from its site of production to the consumer.

carbon footprint The amount of carbon released to the atmosphere by a person, company, nation, or activity.

greenwashing Claiming environmental benefits about a product when the benefits are actually minor or nonexistent.

Infographic 22.7 | **CONSUMER CHOICES MATTER**

↓ Because the growing and transport of our food impacts the environment and our own health so much, choosing foods produced in a way that has a lower impact makes a difference. This also supports sustainable agriculture as an economic endeavor, helping the farmers and communities pursuing these methods.

CONSIDER HOW YOUR FOOD IS RAISED...

Industrially grown food is usually cheaper, but has a higher environmental impact and a high carbon footprint (more fossil fuels are used to produce it) than sustainably grown food. The best way to reduce the carbon footprint of the food you buy is to opt for organically grown food when possible (no fossil fuel–derived fertilizers or pesticides).

...AND HOW FAR IT IS SHIPPED

Even though more fossil fuels go into the *production* of industrially grown foods than in shipping it to market, buying food produced closer to home decreases the transportation part of the carbon footprint. For example, in Iowa, the average grocery store apple has traveled 2,779 kilometers (1,726 miles), and the average head of broccoli, 2,971 kilometers (1,846 miles), while locally grown produce has traveled 56 miles on average. So while transportation does not represent the main way fossil fuels are used in agriculture, it still has a significant impact.

PERSONAL FOOD CHOICES

↓ Buying organic food not only reduces the carbon footprint of the food, it is also healthier for you. But it can get expensive, so if your buying dollars are limited, consider focusing your purchases, when you are able, on the "dirty dozen"—the 12 fruits and vegetables most likely to be contaminated with pesticide residue. The "clean 15" are the products least likely to have pesticide residue, so if you can't afford to buy all organic produce, buy these from the regular produce shelf—but always wash all produce well before eating or cooking!

THE CLEAN 15
The fresh fruit and vegetables with the lowest pesticide residue.

1 Onions	9 Eggplant
2 Sweet corn	10 Kiwi
3 Pineapples	11 Cantaloupe (domestic)
4 Avocados	12 Sweet potatoes
5 Cabbage	13 Grapefruit
6 Sweet peas	14 Watermelon
7 Asparagus	15 Mushrooms
8 Mangoes	

THE DIRTY DOZEN
(in order of pesticide exposure when eaten) Buy organic if possible.

1 Apples	9 Lettuce
2 Celery	10 Cucumbers
3 Sweet bell peppers	11 Blueberries
4 Peaches	12 Potatoes
5 Strawberries	
6 Nectarines (imported)	
7 Grapes	
8 Spinach	

Infographic 22.8 | **THE ADVANTAGES AND DISADVANTAGES OF SUSTAINABLE AGRICULTURE**

	CONSUMER	FARMER & ENVIRONMENT	SOCIETY
ADVANTAGES	• Fresher, tastier, and healthier food (better nutrient profile, no pesticide residue if organic, etc.) • Satisfaction in making a more ethical and environmentally sound choice	• Using fewer inputs of water and fossil fuels saves money and causes less environmental damage. • Soil is not degraded and may be enhanced. • Less use of toxic chemicals benefits the environment and local communities. • More genetic diversity and species diversity makes it less likely that a pest outbreak or other problem will decimate the entire crop.	• Many sustainable methods are less expensive so are suitable for developing nations • Methods are available that minimize water need—useful in arid areas • Local production of food can increase food security (see Chapter 20).
DISADVANTAGES	• Sustainably grown crops may be more expensive. • Greenwashing can mislead consumers. • Organic produce may have more blemishes. • Shelf life of sustainable produce is shorter (not waxed, not picked before ripe)	• May be more labor intensive • Only crops native to the area or suitable for the climate grow well, so a farmer may not be able to grow all crops in all areas. • Crops grown sustainably may not be as productive per acre as industrially farmed crops (in the short term). • Fewer government subsidies are available for sustainable agriculture compared to those for industrially grown crops. • The certification process for getting crops to be labeled as organic takes time and is costly to farmers.	• Productivity per acre is lower for some sustainably produced food (but higher for others). • Research is needed to identify best methods and crops for a given area. • Farmers need training to implement these systems (though if indigenous methods are used, it may be the locals who educate the researchers).

It shouldn't be surprising that sustainable and organic agriculture have their own set of trade-offs: While they might be more environmentally friendly than high-input industrial methods, they may also be more expensive and in some cases produce less food per acre of land. But Greg and Raquel were determined to at least try. [INFOGRAPHIC 22.8]

To achieve their goals, the Massas began by installing a recirculation system to reclaim and reuse irrigation water. They planted native oak trees along field borders to serve as a natural windbreak (windbreaks prevent soil from being carried away by wind erosion), and installed nest boxes for wood ducks, barn owls, and bats so that those wild animals would keep area pests in check. "The idea was to restore as much of the natural biodiversity as possible," says Greg, "so that we would not need artificial inputs to run the system." They also took their sustainable ideals to the next level and built a straw house to live in—made of 2 foot thick walls of rice bale, coated on both sides with plastic or stucco—that can withstand the unforgiving heat of a Chico summer and maintain a steady temperature almost entirely by itself. The house is fireproof, rodent proof, and as Greg likes to joke, bulletproof, too.

A sustainable food future will depend on a variety of methods.

Furuno and the Massas are not the only ones experimenting with polyculture. Indeed, many farmers and scientists across the country are turning to agroecology—working to develop mixed agriculture systems, where instead of planting a single crop, they grow a mix of different species that better replicates the normal ecological community makeup of a given region. Evidence is mounting that such systems can increase a farm's productivity.

Historically, Native Americans planted the "three sisters"—corn, beans, and squash—together in the same plot. Recent studies by plant scientist Mitsuru Tsubo and others confirm a higher productivity per acre in such plots. Though perhaps not a good model for large-scale agriculture, this type of polyculture is recommended for smaller farmers, especially in water-poor areas because it leads to a more efficient use of water by the plants (the more densely planted plots have lower soil temperatures and less water evaporation from soil).

A 2010 report by the International Livestock Research Institute concluded that mixed polyculture farms—ones that, like Furuno's and the Massas', grow both plants and livestock—hold the most promise for intensifying food production worldwide. "It is not big efficient farms on high potential lands but rather one billion small, mixed, family farmers tending rice paddies or cultivating maize and beans while raising a few chickens and pigs, a herd of goats or a cow or two...[who are] likely to play the biggest role in global food security over the next several decades," the institute's executive director, Knut Hove, wrote in the report. "These 'mixed extensive' farms make up the biggest...and most environmentally sustainable agricultural system in the world."

Polyculture operations based on agroecological principles of complex, synergistic systems may do more to free the farmer from expensive corporate inputs than other methods—even large-scale organic farms are industrial operations that have just traded chemical inputs for organic and biological ones. Agroecologist Miguel Altieri argues that all types of monoculture farming, even organic ones, require external inputs and are not a viable option for small farmers or those in developing nations.

Meanwhile, at the Land Institute in Kansas, Wes Jackson is working on a more ambitious plan that he says would correct a mistake made well before the Green Revolution or the rise of factory farms: He wants to replace virtually all of our existing grain crops—which are **annual crops**—with **perennial crop** varieties. Early farmers domesticated annual plants—which grow, produce seeds, and die in a year—because they could manipulate them to produce higher yields from one year to the next (by selecting the best producers and junking the rest, or by crossbreeding plants with good traits). But annuals have to be replanted every season, which requires labor and fossil fuel energy and necessitates tearing up the ground and disrupting the delicate balance of soil ecosystems.

Perennials, on the other hand, can be harvested year after year without disturbing the soil to replant—that means heavy equipment is used less often to manage perennial crops. And the deep roots perennials develop not only hold soil in place, but they tap much farther down into underground aquifers than their annual counterparts, thus dramatically reducing the amount of irrigation needed. Less herbicide is needed for perennial plots as well—weeds do not readily sprout and grow among the established plants. This makes perennials especially attractive for regions with marginal land or an arid climate.

"We hope to advance and enlarge upon the idea that the ecosystem is the necessary conceptual tool for truly sustainable grain agriculture," Jackson told the *Atlantic* in a recent interview. "We believe we can have an agriculture where management by human intervention is greatly reduced."

Saving seeds is a critical step in a sustainable food future.

One unintended consequence of modern monoculture farming is that fewer and fewer varieties of crops are planted. In the past, each region used locally adapted crop varieties developed over hundreds, even thousands, of years by area farmers—crops that were adapted to the local climate, soil conditions, pests, etc. These different varieties were all genetically distinct and represented the genetic diversity of the crop as a whole. But as independent farmers joined the industrialized food production system, their tendency was to plant the single variety of corn or wheat or rice that was currently the highest producer. This has led to an erosion of genetic diversity (the variation among individuals within a species). The problem with this loss is that such genetic raw material allows crops to respond to changes such as the arrival of a new fungal pest, a drier climate, etc. This perhaps has never been as important as it is now, with so many mouths to feed on a rapidly changing planet.

For example, the need to grow rice in arid climates challenges plant breeders to select for plants that can tolerate drier conditions. By going to the myriad wild varieties that exist (known as *wild-type* varieties), breeders can start selecting the individual plants that best tolerate drier conditions, and hopefully produce a variety of rice that can grow under these new conditions. Without a wealth of rice varieties to choose from, plant breeders would have a harder time developing new strains to meet specific needs.

The fear is that, if not planted, many plant varieties could be lost forever. **Seed banks**, such as one located in the high Arctic in Svalbard, Norway, are one solution to this dilemma. There the seeds are kept in cold storage, housed in a tunnel carved out of a mountain; even if the power goes out, these seeds will stay frozen. Managed by Norway and the international Global Crop Diversity Trust, the Svalbard bank holds more than 700,000 varieties of crops from all over the world. The trust also helps developing nations find crop varieties and produce seeds for the seed bank. Local, community seed banks may be of even more immediate use to local farmers, and many are springing up in India and Africa. Most of these programs are run by women's groups, such as those supported by the Indian nonprofit organization, GREEN Foundation (GREEN stands for genetic resource, ecology, energy, and nutrition).

annual crops Crops that grow, produce seeds, and die in a year and must be replanted each season.
perennial crops Crops that do not die at the end of the growing season but live for several years, allowing them to be harvested annually without replanting.
seed banks Places where seeds are stored in order to protect the genetic diversity of the world's crops.

Can sustainable farming methods feed the world?

In the meantime, for the Massas, ducks have proven to be the best possible solution to the challenges of modern rice farming. They ended up with duck meat to sell, and though they didn't take any precise measurements of yields during their first trial run, their rice crops did not appear to suffer at all. "We learned a couple of things," Raquel says. "The ducks trampled some of the rice in their pond, which would not have been a problem if we had used a larger section of the field. I also think we used the wrong breed of duck. They were a little too large to move effectively between the dense plants, and they were not active enough in their foraging activities. These ducks were bred to sit around all day and eat and gain weight quickly for industrial meat production. We are currently researching which breeds to try next."

Still, in the end, the Massas harvested both rice and duck meat. The key to successful duck/rice farming is to remove the ducks before they get big enough to trample rice plants or strong enough to pluck rice seeds from deep within the mud. The hard part isn't knowing when to do this, but having the resolve for what comes next: killing and eating the ducks. The Massa family struggled, but ultimately felt good about the outcome. "I know the conditions in which they were raised were more humane than 99% of the meat ducks in this country," says Raquel. "They had it good and you can taste that in the finished product."◉

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BRING IT HOME

PERSONAL CHOICES THAT HELP

While a typical supermarket may seem to present a dizzying array of food choices to the consumer, a look at the ingredient labels betrays our increasing reliance on growing monocultures of common strains of corn, soy, and wheat. These choices will only change if you, the consumer, demand it.

Individual Steps

→ Carefully examine the labels on the food you buy—as your food budget allows, opt for food products that are organically grown and, if available, locally produced.

Group Action

→ Organize a community garden that specializes in heirloom varieties of vegetables that might not be found in the local grocery stores. Start by requesting a seed catalog from www.rareseeds.org.

→ Research specific farming practices that more closely mimic those found in natural ecosystems, such as Joel Salatin's Polyface Farm (http://www.polyfacefarms.com).

→ Subscribe to a community supported agriculture (CSA) farm and receive a weekly supply of sustainably grown produce. A list of CSAs in your area can be found at www.localharvest.org/csa.

Policy Change

→ Identify bodies of water in your area that may be impacted by cultural eutrophication from fertilizer runoff. Meet with local officials and propose ordinances limiting fertilizer use by homeowners, golf courses, or other possible sources of the pollution.