Beets *(Beta vulgaris)*

CHAPTER ONE

A Perspective On Our Food Supply

IN THE BEGINNING

All food for people and other land-based[1] creatures originates in a uniform way. A continuous wave of light leaves the surface of the sun, races across 150 million kilometers (93 million miles) of swirling empty space in less than 9 minutes, and touches down on the green leaf of a living plant. A fraction of a second later, the chlorophyll in the leaf has used that energy to combine carbon, hydrogen, and oxygen from earth's abundant air and water into glucose, the sweet fuel of life. There are several intermediate steps and there are numerous variations on the theme, but basically it is this process, called photosynthesis, that begins all of our land-based food chains.

Glucose is a simple sugar that can then be converted into more complex sugars, starches, and fibers. It can also combine with nitrogen and minerals from the soil to make thousands of different protein, fat, vitamin, and other molecules that make up foods.

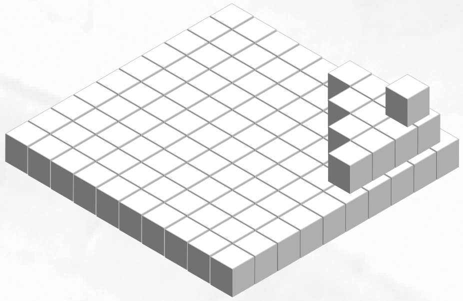
To function well as solar energy collectors, leaves usually take the form of a thin sheet or lamina that is light enough and strong enough to expose a large surface to the sunlight. Storing the food molecules formed during photosynthesis in the leaf itself would make it too thick and heavy for efficient sunlight harvesting. Because of this, plants generally translocate the foods that are formed in the leaf to be stored in their stems, roots, seeds, and fruits.

Moving food out of the leaves and into the roots and seeds requires energy (shipping and handling costs), which is drawn from the carbohydrates formed by photosynthesis. Because of this additional energy cost, the maximum potential food energy is always in the leaves. This is a relatively simple concept, although it runs counter to our usual preconceptions about food. To grasp the basics of nutrition, it is important to understand how food systems actually work. It might help to think of a grain of wheat as a place where wheat leaves have stored the food they made from sunlight. Similarly a potato tuber is a place where potato leaves do their banking. An apple is a stash of food that the leaves of the apple tree made by harvesting sunlight.

THE TROPHIC PYRAMID SCHEME

The word trophic comes from the Greek word for food. Trophic levels are the feeding positions in a food chain. Green plants are the producers and form the first trophic level. Herbivores are consumers of green plants and form the second trophic level. Carnivores as secondary and tertiary consumers form the third and sometimes even the fourth trophic levels. All of the levels end in decay and recycling back to the primary producers as compost.

1 Aquatic food chains usually begin with algae. These are leafless, usually floating plants that are able to perform photosynthesis using chlorophyll.



100 kg Plants; 10 kg Herbivores; 1 kg Carnivore

The energy that is lost moving from one trophic level to the next is much greater than the translocation losses that result from moving food out of leaves where it is originally formed to the plants' storage organs. In fact, the energy lost moving from one trophic level to the next is generally around 90%. The 90% that is lost is mostly expended as heat and movement: staying warm and moving around. So 1,000 kg of grass becomes 100 kg of grasshoppers, which becomes 10 kg of frogs, which becomes 1 kg of hawk. Or to make it more relevant to the human condition, 1000 kg of corn becomes 100 kg of pig, and 100 kg of pig becomes 10 kg of human. The much simplified trophic pyramid demonstrates why there is always more grass than hamburgers and why animal products, such as meat, milk, and eggs, usually cost more than vegetable products.

As a general rule, moving toward the base of the pyramid increases the quantity of food available; while moving toward the top of the pyramid increases the quality of the food, while decreasing the quantity available. This is because food is normally upgraded by being eaten. A cow eats grass and converts the grass into meat, milk, and manure. Its digestive process sorts out and reorganizes the molecules in the grass into patterns that are more useful to cows, and eliminates those that are useless to them. Because people are more similar to cows than grass, the new cow-processed molecules tend to be more useful to us than the original grass molecules. Another way of saying this is that the cow has pre-digested or at least begun the digestion process for us. Because of this pre-digestion several nutrients that are critical to human health—notably protein, iron, and vitamin A—are more readily utilized when they come from animal-based foods.

So not only are animal-based foods less prevalent in nature due to the trophic pyramid, they are generally more valuable nutritionally due to pre-digestion. Taken together, these two basic ecological realities account for the almost universally high social status accorded the eating of animal products. This can be seen clearly in the tendency to increase meat consumption when family income goes up. On a larger scale we can see that whole societies, such as China and Brazil, typically produce and consume more meat as their economy strengthens.

MAKING BOTH ENDS MEAT

Two fundamental strategies are employed in an effort to improve the human food supply. We try to increase the quantity of high-quality animal-based foods at the top of the trophic pyramid, and we try to improve the quality of the plentiful plant-based food available near the wide base of the pyramid. Feeding rough plant food to meat animals is an attempt to do both these things simultaneously.

Hunters in early cultures were rewarded for bringing nutritionally valuable meat to their clan. They could increase the supply of meat somewhat by becoming better hunters, and there was high value placed on making the best spears and bows. The limitation that they encountered was that of the game animal population. If they became too skilled at hunting they could decimate the population of deer or whatever the game of choice was. This is essentially the situation with modern fishing. There is little point in developing more sophisticated fishing techniques as the limiting factor is increasingly the lack of fish, not the fisherman's skill.

The domestication of animals turned hunters into herdsmen and ranchers, and allowed for more control over the production of meat. Competing carnivorous animals such as wolves and coyotes were killed and competition for the best grazing land became intense. Cattle, pigs, goats, sheep, chickens, turkeys, and other animals were selectively bred for their efficiency in converting plant foods to meat, milk, and eggs.

By the mid-twentieth century ingenious humans had proven themselves remarkably adept at increasing the previously limited amount of animal foods available. After the Second World War the mechanization of agriculture accelerated rapidly with the lion's share of the effort going to streamlining animal husbandry and increasing the yield of feed crops, especially corn (maize) and soybeans. Improved farm machinery, soluble fertilizers, insecticides, herbicides, and high-yielding hybrid seeds combined to push corn yields up six-fold over prewar levels. The vast bulk of the corn and soybeans grown, along with a considerable percentage of the wheat, barley, oats, sorghum, and cassava are fed to animals rather than being eaten directly by humans.

The industrialized economies of the United States, along with much of Europe, Japan, and Australia were productive enough to satisfy their citizens' deep longing for animal products. As expected, malnutrition became a rarity where the diet was now so rich in easily absorbed nutrients. Wasting, stunting, anemia, and infectious diseases were increasingly viewed as the difficulties of people too poor to eat meat regularly.

Feeding plants to meat and milk animals is one of the basic ways in which we upgrade the value of plants as food. There are at least three other strategies that we employ to improve the quality of food from plants. They are often combined.

Choosing

In most hunter and gatherer societies women did most of the gathering, and the gathering accounted for more food than the hunting. Gathering is not like harvesting row crops. The most successful gatherers were not only hard-working but highly skilled at recognizing which parts of which plants to pick. This was no mean feat. In some tropical areas there might be 100,000 plant species to choose among. Some looked very similar and some were poisonous. Gatherers had to possess a keen working knowledge of where the most nutritious plants were growing and when they were at their nutritional peak.

Processing

Gatherers also upgraded the plant-based food they brought home by processing it. The most basic processing was likely stripping leaves from stems. Stems invariably have more crude fiber and fewer nutrients than leaves, so the more carefully the stems are removed, the higher the quality of the leaves.

Over time more sophisticated food processes were developed. Drying food, boiling hard seeds, making soups and stews to soften leaves and roots, and grinding and sifting flour, were all techniques that upgraded the quality of plant foods. Pressing oil, fermenting greens into sauerkraut, making pasta, and making tofu, or soybean curd, were more sophisticated processes that came a bit later in our history. Most processes were efforts to soften or remove the fibrous cell walls of the plants in order to decrease the energy required to digest the plant foods and thereby increase their net food value. Most anthropologists believe that this increase in net food value allowed early humans to allocate fewer resources to our digestive system and more to our energy-demanding brains.

Many early food processes focused on removing water to extend the food's useful life and to reduce its weight and volume for easier storage and transport. Sun drying was likely the first food preservation technique employed.

Modern food processing deconstructs inexpensive plant foods from near the trophic pyramid's base and turns them into ingredients for manufactured foods. Pure white flour, crystal clear corn syrup and soy oil can be mixed together with a bit of flavoring and coloring, to make a thousand different foods. Because the fibrous cell walls have been largely removed by processing, these foods are very easily digested. In a very real sense the processing is akin to a mechanical cow, predigesting the plants and making the energy in them more accessible to the human digestive tract.

Breeding

Almost all plant foods have been modified to make them better human foods by a gradual process called selective breeding. Most people would have difficulty enjoying a salad made from the wild predecessors of lettuce or carrots. Compared to today's version of these vegetables, the wild ones were small, harsh flavored and tough textured. With the start of the Neolithic Revolution, some 10,000 years ago, people began to understand that saving and planting seed from the biggest and best tasting specimens year after year improved their food plants.

Over many generations of preferential seed planting, these plants changed to more closely reflect our will and our tastes. Since selective breeding requires a great deal of effort and patience, annual plants that produced a good supply of seeds in a relatively short time were often favored for these early genetic modification efforts.

Over the past hundred years the domestication of plants has become much more systematic as the principles of genetic heredity became clearer. Moving beyond simple selection of the most promising plants for reproduction, we began cross-breeding two varieties to bring traits from one to the other. In this way we were able to cross-breed a variety of spinach that had a desirable color with a variety that had poor color but higher yield. Then by back-crossing the new hybrid spinach variety with the well-colored variety the undesirable trait of poor color could be gradually eliminated.

Despite this dramatic development of humans being able to change the nature of plants, what we are looking for in leaf crops has remained pretty much the same for millennia. Like our Paleolithic ancestors we are still looking for leaves that are easily harvested with mild flavor, tender texture, vigorous growth, resistance to disease, and a favorable ratio of edible leaf to fibrous stem.

Commercial agriculture has added a couple of traits that help make leaf crops profitable. A predictable and uniform harvest time is very important to the biggest growers because harvest is by far the most expensive labor component of production. The idea is to bring in the crews of pickers and pass once through the field harvesting everything in one fell swoop.

They have little use for cut-and-come-again crops that provide a steady flow of edible greens over a long period.

Other important traits for profitable production of leaf crops are the ability to withstand long-distance shipping and a long shelf life. Crops that ship and store well can be grown on a large scale where the conditions are optimal in terms of climate, land prices and labor costs.

While most everyone was happier eating the new tender mild flavored lettuce breeds, there were some problems. The old lettuce was a tough scrappy plant, able to hold its own and to reproduce in the wild. The new lettuce needed to be pampered: watered and protected from insects. Modern iceberg lettuce requires far more water and more pesticide per unit of nutrition produced than hardier vegetables, such as cress or mustard greens, that have undergone less intensive breeding.

The impact of plant breeding efforts can hardly be overstated. The Green Revolution of the 1970s began with the breeding of much higher-yielding varieties of wheat and rice. These new grain seeds turned much of Asia from food deficient countries into grain exporters, and supported a rapidly growing world population. The new varieties had shorter stems than the traditional strains. This enabled them to produce more grain when the level of soluble nitrogen fertilizer was increased to spur growth. The older, long-stemmed varieties would get so tall they fell over or “lodged” when given additional fertilizer.

With the start of the twenty-first century the rules of the game of plant domestication were rewritten by the advent of commercial genetic engineering. Crop scientists are now able to directly manipulate the genes of plants to create varieties with the traits we desire most. This means that undesirable genes can be almost instantly replaced with more desirable ones. It also enables, for the first time, the possibility of using genes from one species to alter the plants from another species, fast-forwarding the evolution of the plant. The possibilities are nearly endless, limited largely by the financial motivations of the companies and institutions capable of doing this work.

To say that genetic engineering is controversial would be an understatement. Proponents claim it can safely provide larger yields of more nutritious food with less environmental damage. Opponents fear it may be a biological Faustian bargain. Some of the objections have to do with the manifest possibility of modified genes escaping and commingling with non-GM (genetically modified) plants. Some people have ethical and even spiritual concerns that bio-tech companies are being allowed to patent and claim exclusive ownership over life forms. Much of the concern stems from how quickly the technology is being deployed and how little oversight or public input is involved in decisions that could have very significant long term consequences. It is not a huge conceptual jump from genetically manipulating rice to have more beta-carotene, to genetically manipulating people so that they absorb beta-carotene more efficiently, or to make them smarter, more athletic or more attractive.

PROGRESS

In the middle of the twentieth century the biggest question facing the world was who could most quickly bring about something called "progress." In the realm of food, progress was called for to close the "Protein Gap." This was the gap between the protein people in developing societies were getting and the protein they needed in order to reach their full physical and mental potential. The question of how to best close this gap was essentially reduced to "How can the poor, unsuccessful, plant-eating societies be transformed into rich, successful, meat-eating societies, or at least moderately prosperous societies eating upgraded refined plant foods?"

Before the end of the century, before most people had gotten even a whiff of broiling sirloin, two small cracks appeared in this progress-oriented view of food. The first fissure in the monolithic view was largely nutritional in nature and the second one agricultural. Wealthier people were experiencing historically high rates of a cluster of illnesses: heart disease, high blood pressure, stroke, cancers, and diabetes. Antibiotics had infectious diseases under control, and heart disease and cancer became the new leading causes of death.

At first, public health officials were baffled. However, it gradually became evident that something good was removed when plant foods were upgraded by refining them to remove fiber. Without the fiber from the cell walls slowing things down, refined sugars and starches are often digested too quickly for the body to process properly. The rapid absorption of refined carbohydrates causes large fluctuations in the blood sugar level. This can lead to insulin resistance, which can trigger the onset of diabetes in people with a genetic predisposition to that disease. A great many of the people eating these foods were taking in more calories than their increasingly sedentary lifestyles required, and they were storing the excess as body fat. A grotesque mirror image of the wasting and stunting caused by too little food was emerging. An epidemic of obesity had begun within the industrialized nations.

Fiber removal was not the only problem. The push for longer shelf life was also contributing to the new health crisis. In order to make standardized products with a long enough shelf life to be marketed all over the globe, manufacturers needed to remove all the volatile or perishable components in the food. So along with the fiber, the nutritious germ was removed from grains, the complex of minerals from sugar and corn syrup, and essential fatty acids from purified oils.

Some investigators began to wonder if the increased consumption of meat, milk, and eggs might also be involved. There had long been a somewhat marginal movement of vegetarians in the United States and Europe who campaigned against meat-eating largely on moral grounds involving just treatment of animals. Researchers found unexpected support for the vegetarian diet when looking into careful records kept by the Dutch people during the Nazi blockade. The health of the people actually seemed to improve when the war reduced their access to meat, milk, and eggs.

While animal-based foods in the diet did indeed provide protection against stunting, iron deficiency anemia, and vitamin A deficiency; it was becoming clear that too much of these foods could clog our arteries and predispose us to several diet-related chronic degenerative diseases. Several indicators were beginning to point toward fat from animals being a culprit in the new health problems, particularly the cholesterol in that fat. This was bad news to the meat packers and to the dairy lobby, who responded by lobbying and advertising vigorously to blunt the financial impact of this information.

In 1972 the World Health Organization declared the Protein Gap over by cutting the daily recommendation for protein by half. This new position, based on considerable research, maintained that if people were getting enough calories they were probably getting enough protein. While this premise has proven true in most instances, it doesn't take into account low-protein foods like cassava. Neither does it address the rapid increase in 'empty calorie' foods like soda that supply plenty of calories, but no protein or other nutrients.[2]

THE FRENCH PARADOX

A fascinating exception to the pattern of animal-based foods leading to heart disease and cancer was found in France. Although the French diet was rich in meat, eggs, and cheese, and thus high in animal fats and cholesterol, they had much less heart disease and cancer than the Americans. This "French paradox" was thought to be linked to compounds called antioxidants[3]

2 The human body has developed an evolutionary defense against short-term food scarcity. We are able to store extra calories from periods with plentiful food as insurance against temporary shortfalls. The extra calories are stored as fat, because it holds much more energy per kilo than sugars or starches. The weight of the average American adult has increased 10.4 kg (23 lbs) from 1980 to 2007. This represents about 82,000 calories worth of extra stored energy. If we had stored the excess as carbohydrates rather than fat we would have increased in weight by 23.6 kg (52 lbs) rather than 10.4 kg (23 lbs).

3 Antioxidants are compounds, commonly found in fruits and vegetables, which protect our

in the vegetables, garlic, and red wine so popular in France.

Initially scientists tried to isolate the active antioxidant ingredients that were responsible for reducing the risk of cancers. They focused on beta-carotene, the pigment that gives carrots their orange color. They were surprised when three studies showed that beta-carotene alone did not reduce cancer risk. Gradually, they came to believe the benefit was coming from a wide variety of compounds working together in whole fruits and vegetables.

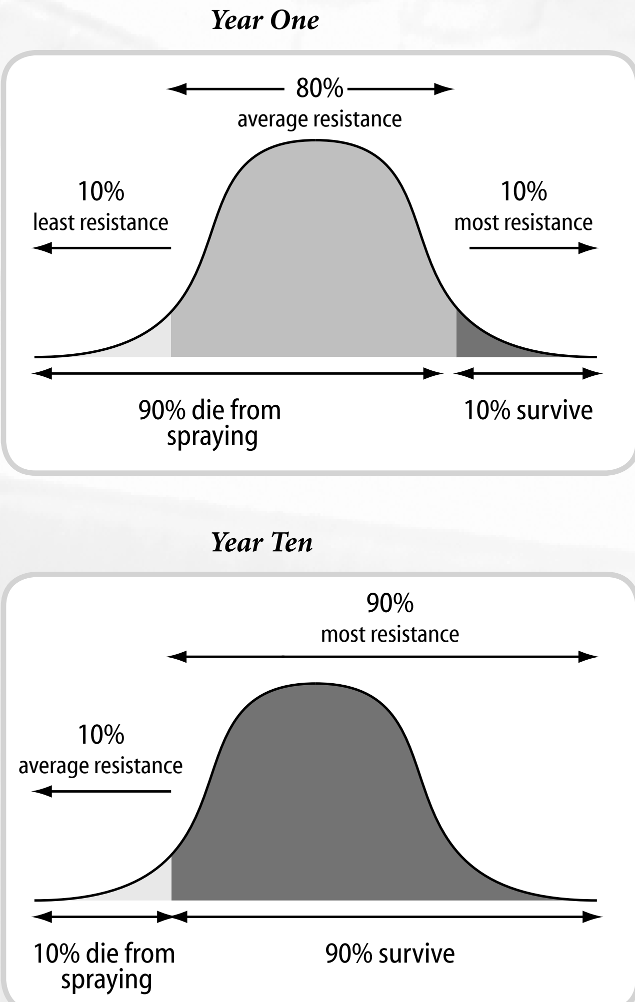
This was a powerful blow to the dominant view of both nutritional and medical science. The prevailing approach in these fields had been reductionist. First a protective mechanism in the human body would be studied, and the key active ingredient isolated. Finally the results would be reduced to a powder that could be distributed as a dietary supplement. It was a strategy that had proven effective (and profitable) with vitamin and mineral supplements as well as a slew of pharmaceuticals.

The findings from research into antioxidants simply suggested that we should eat a greater amount of different kinds of fruits and vegetables. This was not a message that could be easily reduced to a product and was obviously not a message that enhanced

Hyacinth Bean *(Lablab purpureus)*

bodies' cells from destructive oxygen reactions. Although we would die quickly without oxygen, four types of destructive oxygen reactions have been linked to over fifty human diseases.

Mexican Bean Beetle Natural Selection for Pesticide Resistance



the mystique of modern science or its spokesperson, the guy in a white lab coat.

COLLATERAL DAMAGE

The second fault line in the progress-oriented approach to food supply issues appeared in 1955 with the publication of *Silent Spring*. Rachel Carson, a well-known American biologist, wrote this popular book describing her investigation into agricultural pesticides. The gist of the book was that pesticides, in particular the insecticide DDT, were ending up in unintended places, setting off chains of unforeseen consequences and killing non-target beings, especially birds and amphibians.

The rationale for using pesticides is straightforward. Insects, say Mexican bean beetles, are ruining $500 worth of my bean crop. I can buy $100 worth of insecticide to kill the beetles, and save $400. There is a lot of competition for our food crops. Insects, nematodes, bacterial wilts and viruses are all looking for lunch in our crop fields. The agro-chemical industry has approached the problem with a simplistic military approach: identify the enemy's weakness and kill it as cheaply as possible.

Carson and the many other biologists that helped sound the alarm were not calling for surrender to the crop pests as much as diplomacy. In addition to killing innocent bystanders such as birds and frogs, insecticides were often creating secondary or rebound infestations. Continuing the above illustration, while Mexican bean beetles are eating my bean plants, to a much lesser extent so are aphids. The aphid population is being kept at a modest level by ladybugs. I spray for the bean beetles, killing them and the ladybugs. After a surprisingly short interval I am looking for something to spray on the aphids, whose population and resulting damage have increased rapidly in the absence of the ladybugs' predation.

An even more disturbing phenomenon was the development of genetic resistance. Any trait in any naturally occurring population can be plotted along a bell-shaped curve. In this example the trait is resistance to a pesticide and the population is the Mexican bean beetles in a bean field. The ones falling on the left-hand side of the curve are the least resistant; they all die in the first spraying.

The vast majority, in the hump of the bell, have intermediate or average resistance. The poison is very potent and kills all the beetles with average resistance as well. At the extreme right of the curve are the beetles with the greatest genetic resistance to the pesticide. Only 90% of the most resistant beetles are killed. Assuming there were a total of 100,000 bean beetles in the field before the pesticide was sprayed, the pesticide killed 99,900 or 99.9% of them. While in the short term I have protected my beans, in the long term I have made sure that only those beetles with the highest level of genetic resistance to the pesticide will be able to reproduce and pass on their genes.

Pesticides have been widely used since about 1950. During that time humans have had about three generations to begin adapting to their presence in our environment. However, an insect pest might have 180 generations in the same time frame as our three, during which they can genetically adapt to the pesticide. This combination of many generations, with lots of offspring (some insects have 30,000 offspring) and extreme environmental pressure from the fatal spray creates a Darwinian incubator. Within 60 years of use at least 500 species of insects have developed significant if not complete genetic resistance to a pesticide that had previously been effective against them. A parallel occurrence has been increasing genetic resistance to herbicide showing up in weed populations. An even more accelerated version of this sort of natural selection at work has occurred with genetic resistance to antibiotics in bacteria. For instance, it is now assumed that most staphylococcus bacteria in the United States have synthesized penicillinase, an enzyme that neutralizes penicillin, rendering that antibiotic nearly useless against staphylococcus infections.

A BRAND NEW DAY

The importance of *Silent Spring* went far beyond rousing public concern about indiscriminate pesticide use and getting DDT banned. It was about biology trying to tell chemistry something important. That something was that life takes place within very complex, dynamic, and interconnected systems. The science of ecology was beginning to take root.

There are a lot of possible definitions of ecology, but it is basically the study of how living beings interact with their environments. Viewing life in terms of networks, nested systems, feedback loops, flows, resource recycling and dynamic balance doesn't seem like it would be threatening. However, the ecological viewpoint stands in sharp contrast to the reductionist decision-making process of business and the military. A culture focused on simplistic, linear cause and effect wants results and wants them quickly. The ecological perspective is inherently more conservative, always taking into account longer-term effects and possible unintended consequences of actions.

Ecology has struggled to gain legitimacy in the world of academia, repeatedly having to distance itself from emotional environmentalist movements. But ultimately the power of ecology comes from the essential realization that despite our remarkable achievements, human beings are just one thread in a great web of life: a web that we did not weave. This is a more profound change of perspective than that brought about by Copernicus and Galileo, when they demonstrated that the sun, not the Earth, was the center of the solar system.

Applied Ecology is the field of using ecological principles and observations to make management decisions. Chief among applied ecology management guidelines is the precautionary principle. This is simply the common sense warning to avoid taking actions that may have negative consequences out of proportion to the benefit of the action. In other words, if there is a slight chance that an artificial colorant might cause allergic shock or long-term liver damage in some people and the benefit is a minor cosmetic improvement in the appearance of a product, the precautionary principle would suggest leaving the colorant out.

With food systems the precautionary principle encourages us to hedge our bets. For instance, we might choose to maintain the genetic capability of older food plants even if they have been replaced by more economical varieties, because something unforeseen might attack and destroy the new varieties. We would probably never need the old seed stock, but because the consequences of not having either the new or the old varieties could be catastrophic, we maintain the seeds. Or as Aldo Leopold put it, "To keep every cog and wheel is the first precaution of intelligent tinkering."