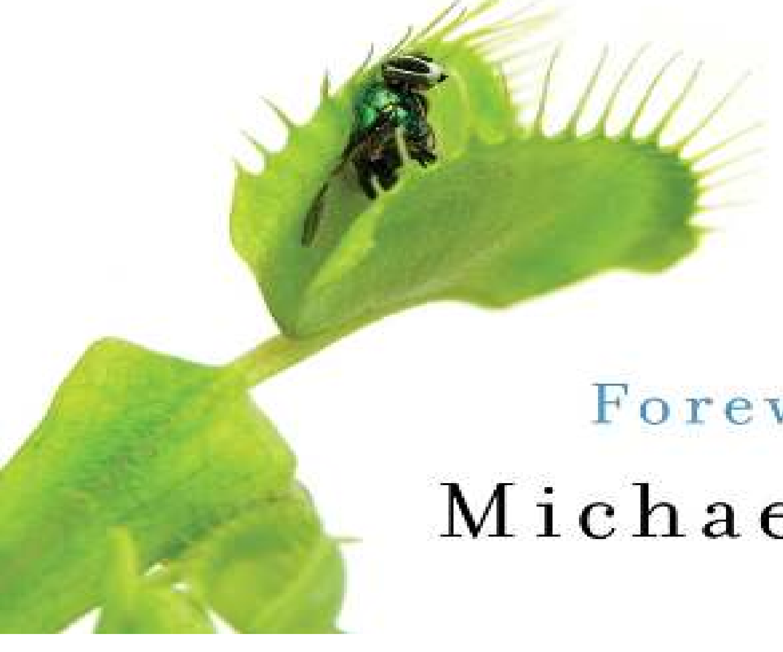
Brilliant Green

The Surprising History and Science of Plant Intelligence

Stefano Mancuso
Alessandra Viola



Foreword by
Michael Pollan

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Foreword

BY MICHAEL POLLAN

Most people who bother to think about plants at all tend to regard them as the mute, immobi furniture of our world—useful enough, and generally attractive, but obviously second-class citizens the republic of life on Earth. It takes a leap of imagination over the high fence of our self-regard recognize not only our utter dependence on plants, but also the fact that they are considerably le passive than they appear, and in fact are wily protagonists in the drama of their own lives—and ours.

Brilliant Green will give you a bracing boost over that fence, and put you down in a place whe everything—ourselves included—suddenly looks completely different. Chances are, you will con away convinced that it is only human arrogance, and the fact that the lives of plants unfold in wh amounts to a much slower dimension of time, that keeps us from appreciating their intelligence—ye intelligence—and consequent success in the game of life, which has been extraordinary, and dwar our own. Plants dominate every terrestrial environment, composing ninety-nine percent of the bioma on Earth. By comparison, humans and all the other animals are, in the words of this intellectual exhilarating book, only a trace.

In Stefano Mancuso, the plants have found their most eloquent or impassioned human advoca since Charles Darwin, who famously wrote that, “It has always pleased me to exalt plants in the sca of organized beings.” Stefano Mancuso is a leading researcher—he is a plant physiologist—in th relatively young, and still somewhat controversial, field of “plant intelligence.” That term strik many plant scientists as tendentious, or just over the top, but as soon as you define intelligence a very simply, the ability to solve the problems that life presents, it becomes impossible to deny such capability to plants. We jealously guard terms like *intelligence*—and *learning* and *memory* an *communication*—as the monopolies of animals, but *Brilliant Green* makes a persuasive case that the are all qualities we now must share.

I first met Stefano Mancuso in 2013 at his lab, provocatively titled the International Laboratory Plant Neurobiology at the University of Florence, when I was researching an article for the *Ne Yorker* on plant intelligence. He shared with me that his conviction that humans fail to perceive th reality of plant life had its origins in a science fiction story he remembers reading as a teenager. race of aliens living in a radically sped-up dimension of time arrive on Earth and, unable to detect an movement in humans, come to the logical conclusion that we are “inert material” with which the may do so as they please. The aliens proceed ruthlessly to exploit us. (Mancuso subsequently recalle that the story was actually a somewhat mangled recollection of an early *Star Trek* episode calle “Wink of an Eye,” easy to find online and well worth seeing.)

That formative leap of imagination—opening him up to a plant’s-eye view of us, speedy, heedles and arrogant—has inspired Mancuso’s scientific research and now, with science writer Alessandr Viola, this marvelous collaboration. But while *Brilliant Green* is most assuredly *not* a work of scien fiction—there is good science to back up its every claim—it is, like the best science, the product of powerful imagination, one with the ability to see the world from a completely fresh an unencumbered point of view—and to communicate that perspective to the rest of us. So, put aside f a couple of hours your accustomed anthropocentrism, and step into this other, richer, and mor wonderful world. You won't regret it, and you won't emerge from it ever quite the same again.

Introduction

Are plants intelligent? Do they solve problems and communicate with their surroundings—with oth plants, insects, and higher animals? Or are they passive, unfeeling organisms without a trace individual or social behavior?

Differing answers to such questions date back to ancient Greece, when philosophers of opposi schools of thought argued for and against the proposition that plants have a “soul.” What drove the reasoning? And above all, after centuries of scientific discovery, why is there still disagreement abo whether plants are intelligent? Surprisingly, many of the points raised today are the same ones raise centuries ago, and hinge not on science but on sentiment and cultural preconceptions that have existe for thousands of years.

Although casual observation may suggest that the plant world’s level of complexity is pretty lo over the centuries the idea that plants are sentient organisms which can communicate, have a soci life, and solve problems by using elegant strategies—that they are, in a word, *intelligent*—h occasionally raised its head. Philosophers and scientists in different times and cultural contexts (fro Democritus to Plato, from Linnaeus to Darwin, from Fechner to Bose, to mention only some of t best known) have embraced the belief that plants have much more complicated abilities than a commonly observable.

Until the mid-twentieth century there were only brilliant intuitions. But discoveries over the pa fifty years have finally shed light on this subject, compelling us to see the plant world with new eye In the first chapter we’ll explain this, and we’ll see that even today, arguments for denying plant intelligence rely less on scientific data than on cultural prejudices and influences that have persiste for millennia.

The time seems ripe for a change in our thinking. On the basis of decades of experiments, plants a starting to be regarded as beings capable of calculation and choice, learning and memory. A few yea ago, Switzerland, amid much less rational polemics, became the first country in the world to affir the rights of plants with a special declaration.

But what are plants, really, and how did they come to be the way that they are? We humans hav lived with them from the time we appeared on Earth, yet we can’t say we know them at all. This isn just a scientific or cultural problem; it goes much deeper. The relationship between humans and plan is so difficult because our evolutionary paths have been so different.

Like all animals, humans are endowed with unique organs, and thus every human being is indivisible organism. But plants are sessile—they can’t move from one place to another—and they’ve evolved in a different way, constructing a modular body without individual organs. The reas for such a “solution” is obvious: if an herbivorous predator removed an organ whose function couldn be performed by another part of the plant, that *ipso facto* would cause the plant’s death.

Until now, this basic difference from the animal world has been one of the main obstacles to o understanding and recognizing plants as intelligent beings. In the second chapter, we’ll try to expla how this difference occurred. We’ll see how every plant has the ability to survive massive predatio and that what ultimately distinguishes a plant from an animal is its divisibility: its being equipp with numerous “command centers” and a network structure not unlike the Internet’s. Understandin ~~plants is becoming more and more important. They enabled our coming into existence~~ on Ear (through photosynthesis, creating the oxygen that made animal life possible), and today we st depend on them for our survival (they are at the base of the food chain). They’re also the origin energy sources (fossil fuels) that have sustained our civilization for thousands of years. Thus they a precious “raw materials,” essential for our food, medicine, energy, and equipment. And we’re growin increasingly dependent on them for our scientific and technological development.

In the third chapter we’ll see that plants have all five senses that humans do: sight, hearing, touc taste, and smell—each developed in a “plant” way, of course, but no less real. So from this point o view could we say they resemble us? Not at all: they’re much more sensitive, and besides our fiv senses, they have at least fifteen others. For example, they sense and calculate gravit electromagnetic fields, and humidity, and they can analyze numerous chemical gradients.

Though the idea doesn’t jibe with our general impression of plants, they may be more like us in th social sphere. In the fourth chapter we’ll see how plants use their senses to orient themselves in th world, interacting with other plant organisms, insects, and animals, communicating with each other b means of chemical molecules and exchanging information. Plants talk to each other, recognize the kin, and exhibit various character traits. As in the animal kingdom, in the plant world some a opportunists, some are generous, some are honest, and some are manipulators, rewarding those th help them and punishing those that would do them harm.

Then how can we deny that they are intelligent? The question comes down to terminology, and depends on how we choose to define *intelligence*. In the fifth chapter we’ll see that intelligence can b construed as “problem-solving ability,” and that by this definition plants are not just intelligent b brilliant at solving the problems related to their existence. To start with, they don’t have a brain lik ours, yet they are able to respond adaptively to external stresses and, though using this word about plant may seem strange, to be “aware” of what they are, and of their surroundings.

It was Charles Darwin who, on the basis of solid, quantifiable scientific data, first suggested th plants were much more advanced organisms than they were thought to be. Today, almost a century an a half later, a compelling body of research shows that higher-order plants really are “intelligent”: ab to receive signals from their environment, process the information, and devise solutions adaptive their own survival. What’s more, they manifest a kind of “swarm intelligence” that enables them behave not as an individual but as a multitude—the same behavior seen in an ant colony, a shoal o fish, or a flock of birds.

Plants could live very well without us, in general. But without them we would die out very quickl And yet in many languages (including our own), expressions such as “to vegetate” or “to be vegetable” are used to indicate a condition of life reduced to the minimum.

“Vegetable, to whom?” . . . If plants could speak, maybe that would be one of their first questions t us.

CHAPTER 1

The Root of the Problem

In the beginning, there was green: a chaos of plant cells. Then God created the animals, ending wi the noblest of them all: man. In the Bible, as in many other cosmogonies, man is the supreme fruit the divine work, the chosen one. He appears near the end of Creation, when everything awaits hir ready to be subjugated and ruled by the “master of Creation.”

In the Biblical account, the divine work is completed in a time frame of seven days. Plants a created on the third day, while the most presumptuous of all living creatures comes into the world— last—on the sixth. This sequence approximates present-day scientific findings, according to whic living cells capable of performing photosynthesis first appeared on the planet more than three and half billion years ago, while the first Homo sapiens, so-called modern man, only appeared 200,0(years ago (a few seconds ago, in the evolutionary time frame). But arriving last hasn’t kept huma beings from feeling privileged, even though current knowledge on the subject of evolution h drastically reduced our role of “master of the universe,” downgrading our status to that “newcomer”—a relative position that brings no *a priori* guarantee of supremacy over other specie despite what our cultural conditioning would have us believe.

The idea that plants possess a “brain” or a “soul,” and that even the simplest plant organisms ca feel and react to external stresses, has been proposed over the centuries by numerous philosophers ar scientists. From Democritus to Plato, from Fechner to Darwin (to cite only a few examples), some the most brilliant minds of all time have been exponents of the intelligence of plants, some attributir to them the capacity to feel, others imagining them as humans with their heads in the groun sensitive living beings, intelligent and endowed with all human faculties, except those precluded b their . . . odd position.

Dozens of great thinkers have theorized and documented the intelligence of plants. Yet the belie that plants are less intelligent and evolved beings than invertebrates, and that on an “evolutiona scale” (a concept without basis in fact but still fixed in our mentality) they’re barely above inanima objects, persists in human cultures everywhere and manifests itself in our everyday behavior. N matter how many voices are raised in support of recognizing plant intelligence on the basis experiments and scientific discoveries, infinitely more oppose this hypothesis. It’s as if by tac agreement religions, literature, philosophy, and even modern science promulgate in Western cultur the idea that plants are beings endowed with a level of life (not to speak of “intelligence,” for th moment) lower than that of other species.

Plants and the Great Monotheistic Religions

“And of every living thing of all flesh, two of every sort shalt thou bring into the ark, to keep the alive with thee; they shall be male and female. Of fowls after their kind, and of cattle after their kin of every creeping thing of the earth after his kind; two of every sort shall come unto thee, to kee them alive.” With these words, according to the Old Testament, God told Noah what to save from th universal Flood so that life would continue on our planet. Obeying God’s instructions, before th ~~Flood Noah loaded onto the ark birds, animals, and every creature that moved: “clean” and “unclear~~ creatures, in pairs, to assure the reproduction of every species.

And plants? Not a word about them. In Holy Scripture the plant world not only isn’t considere equal to the animal world, it isn’t considered at all. It is left to its fate, probably to either be destroye by the Flood or to survive it along with other inanimate things. Plants were so unimportant that the was no reason to care about them.

And yet the contradictions this passage contains are soon evident. The first becomes obvious as th narrative continues. After the ark’s slow coming aground, when the rain has stopped for several day Noah sends a dove to bring back news of the world. Is there dry land anywhere? Are there plac above water nearby? Are they inhabitable? The dove returns with an olive branch in its beak: a sig that some lands have reemerged and that on them life is possible again. Noah therefore knows (even he doesn’t say it) that without plants there can be no life on Earth.

The dove’s news is soon confirmed, and in a short while the ark has come to rest on Mount Arara The great patriarch debarks, lets the animals off, and then gives thanks to God. His duties are fulfille And what does Noah do next? He plants a vineyard. But where does the original vine come from, if isn’t mentioned elsewhere in the story? Noah brought it with him before the Flood, aware of i usefulness, though not that it was a living being.

In this way, almost without the reader’s realizing it, the idea that plants are not living creatur comes through the story in Holy Scripture. In Genesis, two plants, the olive and the grape vine, a associated with the value of rebirth and of life, though the vital quality of the plant world in gener goes unrecognized.

All three of the Abrahamic religions have implicitly failed to recognize that plants are livir beings, in effect grouping them with inanimate objects. Islamic art, for example, respecting th prohibition against representing Allah or any other living creature, is passionately devoted to th representation of plants and flowers, so much so that the floral style is emblematic. Without stating outright, this shows the belief that plants are not living beings—otherwise representing them would b forbidden! In the Koran, there is actually no explicit ban on representing animals; the prohibition transmitted through the *hadith*, the sayings of the prophet Mohammad that form the basis for th interpretation of Islamic law, by virtue of the fact that in Islam there is no God but Allah ar everything comes from him, and everything is him—which evidently doesn’t mean plants.

The relationship between humans and plants is totally ambivalent. For example, the same Judais which is based on the Old Testament forbids the gratuitous destruction of trees and celebrates the ne year of trees (Tu Bishvat). The ambivalence comes from the fact that on the one hand we humans a intimately aware that we can’t exist without plants, and on the other hand we’re unwilling to recogni the role they play on the planet.

It’s true that not all religions have the same relationship to the plant world. Native Americans ar other indigenous peoples recognize its undeniable sacredness. If some religions have sacralized plan (or rather, parts of them), others have gone so far as to hate or even demonize them. For exampl during the Inquisition, plants believed to be used in potions by women accused of witchcraft—garli parsley, and fennel—were put on trial along with the witches! Even today, plants with psychotrop effects receive special treatment: some are banned altogether (How do you ban a plant? Could you ba an animal?), others are regulated, still others are considered sacred and used by shamans in trib ceremonies.

The Plant World According to Writers and Philosophers

Hated, loved, ignored, or sacralized, plants are part of our lives and so of our art, folklore, ar literature. In the works they create, the imagination of artists and writers helps construct a vision the world. What does art tell us about the relationship between human beings and the plant worl Though there certainly are important exceptions, in general, writers depict the plant world as a stati inorganic part of the countryside, passive as a hill or a mountain chain. Consider, for exampl *Robinson Crusoe* (1719) by Daniel Defoe, where plants are depicted as part of the landscape but nev as living organisms. For the first hundred pages, the whole plot of the novel is based on Robinson search for other living organisms on the island . . . while he is literally surrounded by them in the for of plants. More recently, in *Suddenly in the Depths of the Forest* (2005) by Amos Oz, a small villag is under a curse that prevents any form of life except humans . . . while the village is complete encircled by the plants of the forest.

In philosophy, as we have noted, inquiries into plants' nature have animated the discussions of gre minds for centuries. Whether plants had life (or a “soul,” as they called it then) was an endless debated question centuries before Christ. In Greece, birthplace of Western philosophy, opposin positions on this matter long coexisted: on one side Aristotle of Stagira (384/383–322 BCE) thoug that the plant world was closer to the inorganic world than to the world of living things; on the othe Democritus of Abdera (460–360 BCE) and his followers showed a high estimation of plants, eve comparing them to human beings.

In classifying living things, Aristotle divided them according to the presence or absence of soul, concept which for him had nothing to do with spirituality. To understand it, we need to consider th root of the word *animate*, which even today means “having the ability to move.” In one of his work he wrote: “Two characteristic marks have above all others been recognized as distinguishing th which has soul in it from that which has not—movement and sensation” *(On the Soul)*. On the basis this definition, and with the support of such observations as were possible in those times, Aristot initially considered plants to be “inanimate.” But then he had to reconsider. After all, plants coul reproduce! How could one argue that they were inanimate? The philosopher then opted for a differe solution and gave them a low-level soul, a plant soul created expressly for them, which in practic terms only permitted them reproduction. If plants couldn't be thought of as equal to inanimate thing because they could reproduce, still—Aristotle decided—they shouldn't be considered all that differe from them, either.

Aristotelian thinking influenced Western culture for many centuries, especially in certai disciplines such as botany, where it held sway almost until the beginning of the Enlightenment. So it little wonder that philosophers long considered plants to be “immobile” and not worth furth consideration.

However, from antiquity to the present day, some philosophers have paid the highest honors to th plant world. For example, almost a century before Aristotle, Democritus described plants in completely different way. His philosophy was based on atomistic mechanics: every object, even if appeared to be immobile, was composed of atoms in continuous motion, separated in a vacuum According to this vision of reality, everything moved, and thus at an atomic level even plants we mobile. Democritus even compared trees to upside-down humans, with their head set in the groun and their feet in the air—an image that would often recur through the centuries.

The Aristotelian and Democritean conceptions in ancient Greece thus often gave rise to a kind o unconscious ambivalence, which held that plants were simultaneously inanimate beings an intelligent organisms.

The Fathers of Botany: Linnaeus and Darwin

Carl Nilsson Linnaeus (1707–1778), usually known as Carl Linnaeus, was a physician, explorer, an naturalist whose many interests included the classification of all plants. For this reason, he is ofte known as “the great classifier,” which only partly does him justice, since in addition to his work o classification he conducted intensive research throughout his lifetime.

Linnaeus’s ideas concerning the plant world were idiosyncratic almost from the start. First, h identified “reproductive organs” in plants, and he made the “sexual system” the principal taxonom criterion upon which he based his work of classification. In a bizarre contradiction, this decisio earned him both the first university chair and also condemnation for “immorality.” (It was known th plants had a sex. But studying this in order to classify plants? . . . how scandalous.) Then the scienti proposed another innovative theory, which only by accident drew less criticism than the firs Linnaeus maintained, with surprising determination and simplicity, that plants . . . sleep.

Even the title of *Somnus Plantarum (The Sleep of Plants)*, his treatise of 1755, didn’t observe th caution used by scientists in those days to protect their theories from possible attacks. In fact, base on scientific knowledge of that time and on his own observations of the different positions assumed b the leaves and branches during the night, it was relatively easy for Linnaeus to assert that plants slee But it would be several centuries before sleep was recognized as a fundamental biological functio related to the brain’s most evolved activities, and so his idea was not even contested.

Today the same theory has plenty of opponents, and even Linnaeus, if he had known the man functions of sleep, would probably interpret his own observations differently and would deny th existence of an activity in plants that could be compared to an activity of animals. In fact, he did den it in another instance: that of insectivorous plants. Linnaeus was quite familiar with plants that a insects, such as Dionaea muscipula (the Venus flytrap), for example. And he certainly had th experience of observing one as it enclosed, trapped, and digested an insect. Yet that reality (a plan eating an animal) was so incompatible with the rigid pyramidal organization of nature, in which plan were relegated to the lowest level of life, that Linnaeus, like his contemporaries, sought a myriad other possible explanations rather than acknowledge plain evidence. Without any regard to scientif confirmation of his assertions, from time to time he therefore hypothesized that the insects didn’t d at all, and that they chose to remain inside the plant of their own volition and for their ow convenience, or that they landed on the plant by chance and not because they were attracted to it. O even that the plant trap closed by chance, and so couldn’t possibly lure an animal. Ambivalenc toward the plant world still had its hold on the mind of the great Swedish botanist!

Not until Charles Darwin published his treatise on insectivorous plants in 1875 did a scienti finally assert the existence of plant organisms that feed on animals. But even Darwin, with h characteristic caution, didn’t go so far as to call them “carnivores” (as we do today), though he w perfectly aware of plants that prey on rats and other small mammals, such as several supercarnivor belonging to the genus Nepenthes. Some “insectivores!”

We shouldn’t be dismayed by Darwin’s caution, any more than we are by Galileo’s, or the cautio of other scientists in centuries past. It’s because of their “diplomacy,” in fact, that certai revolutionary ideas could slowly filter through the collective consciousness—and into a scientif community that was very conservative. But let’s return to Linnaeus for a moment, and ask ourselve how was it possible for him to assert so boldly that plants sleep, without being shunned or persecute

by his peers? This isn’t hard to answer: for a long time it was thought that his theory had no basis
fact, ~~so it wasn’t even worth refuting. And furthermore, who cared whether plants slept, when~~ slee
wasn’t believed to have any particular function?

Today, we know how many important vital and cerebral functions are linked to this physiologic process. But until the turn of this century, even modern science maintained that only the most evolve animals sleep. In 2000, this was disproved by the Italian neuroscientist Giulio Tononi, who showe that even the fruit fly, one of the “simplest” insects in existence, takes its well-deserved rest. The why shouldn’t plants? Maybe the only possible explanation is that this idea doesn’t fit with how w think about the vegetal world.

Humans Are the Most Evolved Beings on the Planet. Or Are They?

With few or no exceptions, unfortunately, the idea of the plant world and the so-called Pyramid o Living Things that we’ve taken with us down through the centuries is the one contained in the *Liber d sapiente* (Book of Wisdom), published in 1509 by Charles de Bovelles (c. 1479–1567). An illuminate illustration from the book is worth more than a thousand words: it shows the living and nonlivin species in ascending order. It starts with rocks (which are given the following lapidary comment: *Es* meaning they exist and that’s all; they have no further attributes), continues to plants (*Est et vivi* thus a plant exists and is alive, but nothing more) and animals (*Sentit:* an animal is endowed wi senses), and finally comes to man (*Intelligit:* only man has the faculty of understanding).

The Renaissance idea that among living creatures, some species are more or less evolved an endowed with greater or lesser vital capacities, is still in vogue. It is part of our cultural humus, an nearly impossible for us to give up, despite the passage of more than 150 years since the publication 1859 of *The Origin of Species*, the foundational work given us by Charles Darwin to understand life o our planet—a book so important that the great biologist Theodosius Dobzhansky wrote: “Nothing biology makes sense except in the light of evolution.” The theories of the great British scientist, wh was a biologist, botanist, geologist, and zoologist, are now part of humanity’s scientific inheritanc Yet the idea that plants are passive beings, without sensation or any capacity for communicatio behavior, or computation—which comes from a completely erroneous view of evolution—is sti strongly rooted even in the scientific community.

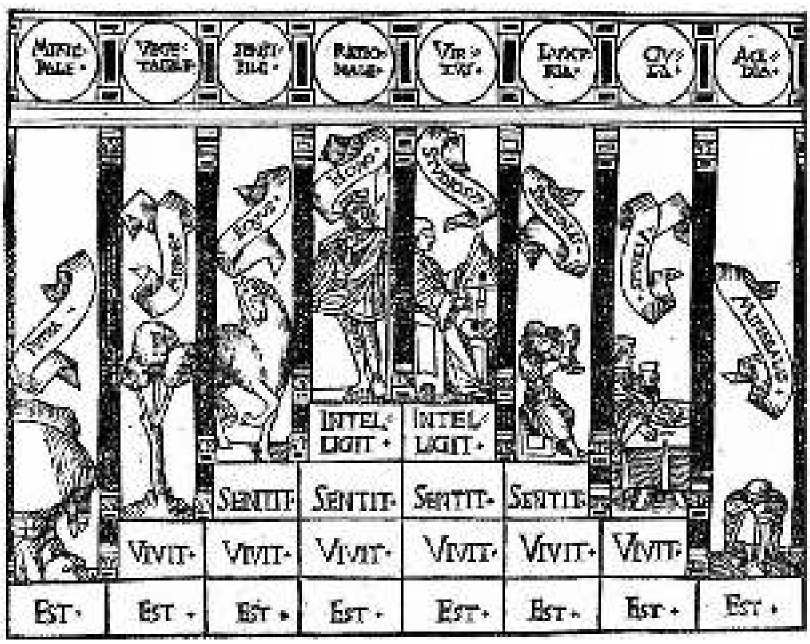

Figure 1-1. Charles de Bovelles's "Pyramid of the Living," from *The Book of Wisdom* (1509). Our way of looking at the natural world hasn't changed much.

It was Darwin who proved beyond any reasonable doubt that the question should not be put in tho terms, because there are not more- and less-evolved organisms; from the Darwinian point of view, a living beings now populating the earth are at the end of their evolutionary branch—otherwise, the would be extinct. This is a very important assumption since, for Darwin, being at the end of one evolutionary chain means to have shown, over the course of evolution, extraordinary capacities f adaptation. Of course, the genius naturalist knew well that plants are extremely sophisticated ar complex creatures, with many capacities beyond those that are commonly recognized. He devoted great part of his life and work to botanical studies (some six volumes and about seventy essays illustrating through them the theory of evolution that brought him imperishable fame. Yet the va amount of research on the plant world carried out by Darwin has always been treated as secondar further demonstration—if any were needed—of the scant consideration plants have always received science.

In his book *One Hundred and One Botanists*, published in 1994, Duane Isely stated: "More has bee written about Darwin than any other biologist who ever lived. . . . Curiously, in light of this flood, h is rarely presented as a botanist. True, the fact that he wrote several books about his research on plan is mentioned in much Darwinia, but it is casual, somewhat in the light of 'Well, the great man need to play now and then.'" Darwin wrote and affirmed several times that he considered plants to be th most extraordinary living things he had ever encountered ("It has always pleased me to exalt plants the scale of organised beings," he confessed in his autobiography), a theme that he took up again an amplified in his fundamental *The Power of Movement in Plants*, published in 1880. Darwin was scientist of the old school: he observed nature and deduced its laws. Though not a dogge experimenter, in this book he explains the results of hundreds and hundreds of experiments he carrie out with his son Francis, describing and interpreting the innumerable movements of plants: a gre many different movements, which involved in most cases not the aerial part but the root, in which h was able to identify a sort of "command center."

For the English naturalist, the last paragraph of his works is always the most important. It is whe he presents his final considerations on the subject under discussion, in a way that makes them simp and accessible to everyone. Here is a marvelous example from the famous epilogue to the *Origin Species*:

> There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning, endless forms most beautiful and most wonderful have been, and are being, evolved.

In the final, expressive paragraph on the movement of plants, the scientist clearly states h conviction that in the roots there is something similar to the brain of a lower animal (an importa assertion, to which we will return in chapter 5). In fact, a plant has thousands of root tips, eac endowed with its own "computing center," a phrase we use to make plain to even the most spitef critics that from Darwin on, no one has ever thought or said that in the root there's an actual brain- walnut-shaped and resembling a human's—which somehow escaped notice for millennia. Instead, th hypothesis is that at a plant's root tip there is a kind of plant analog, endowed with many of the sam functions as an animal brain. What's so shocking about that?

~~Though Darwin's assertions were potentially of great consequence, he was careful not to elabora~~ on them in his books. Already old when he wrote *The Power of Movement in Plants*, Darwin w certain that plants should be considered intelligent organisms, but he also knew that saying so wou stir up a hornet's nest of controversy about his studies. Remember, he'd already had problem defending his theory that humans descended from apes! And so he left the task of developing h thesis to others, especially to his son Francis.

Profoundly influenced by his father's ideas and research, Francis Darwin (1848–1925) carried c Charles's work, becoming one of the first professors of plant physiology in the world and writing th first treatise in English on this new field of study. At the end of the nineteenth century, it still seeme paradoxical to associate the two ideas (plants and physiology). But Francis, who had studied plan and their behavior at his father's side for many years, had become convinced of their intelligenc Now a world-famous scientist in his own right, on September 2, 1908, at the opening of the annu congress of the British Association for the Advancement of Science, he threw caution to the wind ar declared that plants are intelligent beings. This provoked the expected storm of protest, but h repeated the assertion, even publishing a thirty-page article in *Science* the same year.

The impact was extraordinary. The debate was reported in newspapers all over the world ar divided scientists into two opposing camps. One side—persuaded by the evidence Francis Darw offered to support his assertions—quickly affirmed the existence of plant intelligence; the other sic adamantly rejected the possibility. Just like in ancient Greece!

Figure 1-2. *New York Times* page reporting Francis Darwin's announcement at the 1908 annual meeting of the British Association f the Advancement of Science: Plants have a primitive form of intelligence.

Years before this debate, Charles Darwin had had a most fruitful correspondence with an Italia botanist in Liguria who is now forgotten—unjustly, since he was one of the most important naturalis of his time and can even be credited with creating the field of plant biology. Federico Delpino (1833 1905), director of the Botanical Garden of Naples, was an outstanding scientist. Through h correspondence with Darwin, he had become convinced of plants' intelligence, and he devoted himse to field experiments studying their faculties, concentrating over a long period of time on so-calle myrmecophilia, the symbiosis some plants establish with ants (the term comes from the Gree *murmex*, “ant,” and *philos*, “friend”). Charles Darwin was well aware that many plants produce nect ~~even apart from the flower (though obviously, most of it is produced in the flower in order to~~ attra insects and utilize them as pollen vectors during pollination), and he had also observed that necta being very sweet, attracts ants. But he had never studied the phenomenon closely, being convince that “extrafloral” nectar production (so called because it occurs outside the flower) was essential due to the elimination of waste substances by the plant. On this point, however, Delpino complete disagreed with the great man. Nectar is a very energy-rich substance that plants produce at great co to themselves. So, he wondered, why would they get rid of it? There had to be another explanation.

Starting from his observations of ants, Delpino reached the conclusion that myrmecophilic plan secrete nectar in parts of themselves other than their flowers expressly to attract ants and mak advantageous use of them as a defensive strategy: the ants, satisfied with their meal, in return for th food, defend the plants from herbivores, like real warriors. Have you ever leaned against a plant or tree and jumped away from the bites of these feisty little hymenopterans? Ants come to the defense o their host plant instantly, lining up, surrounding the potential predator, and forcing it to retreat! would be hard to argue that this behavior isn’t extremely convenient for both species.

According to entomologists, in fact, ants carry out very intelligent behavior, defending their sourc of food. For botanists, however, the story has always been (and still is) very different. Not many a willing to say that the plant’s behavior also is intelligent (and purposeful) and that the secretion o nectar is a deliberate strategy for acquiring that unusual army of bodyguards.

Plants: Always Second Fiddle

By now, it should come as no surprise that many extraordinary scientific discoveries resulting fro experimentation with plants have taken decades to be “confirmed” by research conducted on animal Discoveries about fundamental mechanisms of life, essentially ignored or greatly undervalued as lon as they pertained to the plant world, suddenly become famous when they concern the animal world.

Consider the experiments conducted on peas by Gregor Johann Mendel (1822–1884): they actual marked the beginning of genetics, but for forty years his conclusions were almost completely ignore until the first genetics boom began, with experiments on animals. Or look at the experience, which ha a happy ending for a change, of Barbara McClintock (1902–1992), who won the Nobel Prize in 198 for her discovery of genome lability. Before McClintock proved otherwise, it was thought th genomes (that is, the entire genetic makeup) were fixed and could not vary over the lifetime of living being. The “stability of the genome” was untouchable scientific dogma. During the 1940s, wi a series of experiments on corn, McClintock discovered that this principle wasn’t unassailable at all.

It was a fundamental discovery—so why was it awarded the Nobel Prize forty years later? Th reason is simple: her research was carried out on plants, and since McClintock’s observations ra counter to academic orthodoxy, she was marginalized by the scientific community for a long time. B in the early 1980s, analogous research carried out on animals confirmed the existence of genom lability in other species, and this “rediscovery,” not only her own research, won McClintock the Nob Prize and recognition of her own contribution.

Of course, genome lability is far from the only example of such discoveries. There’s a pretty lon list, from the discovery of the cell (which was first made in plants) to RNA interference, which wo Andrew Fire and Craig C. Mello the 2006 Nobel Prize. That was essentially a “rediscovery” on worm *(Caenorhabditis elegans)* of findings made by Richard Jorgensen on petunias twenty yea earlier. And the upshot? Nobody knows about the research on petunias, while the research on a ver lowly worm (but an animal) merited a Nobel Prize for Physiology and Medicine.

~~There are many more examples, but the basic story is the same: the plant world always gets secon~~ ranking, even in academia. Yet plants are often used in research because of the similarity betwee their physiology and that of animals, not to mention that experimentation on these organisms rais fewer ethical problems. But are we really sure that the ethical implications are inconsequential? W hope that reading this book will help plant some doubts on that score.

When the absurd subjection of the plant world to the animal world finally comes to a halt, it will b possible to study plants—much more usefully—for their differences from animals, rather than the similarities to them. New and fascinating frontiers for research will open up. But we might b forgiven for asking: What brilliant researcher would devote herself to plants instead of animal knowing that she will be excluded from the majority of scientific awards?

As we have seen, this state of affairs is a natural outcome of our culture. In life as in science, th common scale of values relegates plants to last place among living things. An entire realm, the pla world, is underappreciated, despite the fact that our survival on the planet and our future depend on it

CHAPTER 2

The Plant: A Stranger

Human beings have lived with plants since our appearance on the earth about 200,000 years ago. Tw hundred thousand years would seem to be enough time to get to know someone. But it hasn't bee enough time for us to get to know plants. We know very little about the plant world, and we probabl see plants in much the same way as the first *Homo sapiens* did.

This assertion, though patently indemonstrable, may be clarified with a simple example. Let consider an animal—say, a cat—and try to describe its characteristics. What can we say about the ca It's smart, clever, affectionate, sociable, opportunistic, agile, quick, and who knows how many othe things. Now let's consider a plant—say, an oak tree—and describe its characteristics, too. What there to say about an oak tree? It's tall, shady, knotty, fragrant . . . what else? At most, we could ad some aesthetic qualities and appreciations of its usefulness. We certainly wouldn't include attribute referring to its "social dimension," whereas in the case of the cat we've said that it is sociable (thou "individualistic" would also describe a cat's way of relating to its environment). We wouldn attribute any sort of intelligence to a plant—whereas in the cat we recognize it easily—nor would occur to us to call an oak affectionate!

And yet something's off about this. How is it possible that living beings that are unintellige without social aptitudes, and incapable of relating to their environment, have survived and evolved the planet? If plants really functioned so poorly, natural selection would have swept them away lo ago!

But we don't need to look to the past as evidence; in the last several decades, science has be showing that plants are endowed with feeling, weave complex social relations, and can communica with themselves and with animals, all of which we will explore in the following chapters. So why human beings still see the plant world only as raw material, or a food source, or decor? What preve us from going beyond this initial, superficial valuation of the life forms that populate it?

Euglena versus Paramecium: An Even Match?

Besides the cultural factors we saw in the first chapter, two others influence our perception of t plant world: an evolutionary factor and a temporal one.

Let's start with the evolutionary factor and attempt an analysis, first by asking what we mean by t word *evolution*. Evolution refers to the slow, continuous process of adaptation to the environment, the course of which a living organism develops the characteristics most suited to its survival. Duri this process, each species acquires or loses characteristics and capacities in relation to the kind habitat in which it lives. Of course, all of this happens over very long periods of time, but it can le to macroscopic changes between the original and the eventual organism. Evolution has played fundamental role in differentiating animals from plants, and today it's part of the problem that kee us from deeply knowing the plant kingdom.

To see this more clearly, let's take a step back.

We know that the first single-celled organisms that appeared on the planet were algae—that is, th ~~plant kind of living things. Through photosynthesis, they created the oxygen that enabled life to~~ sprea over the earth. This included the emergence of eukaryotes, or animal cells.

In those days, as today, plant and animal cells were not as different as one might think. To be sur plant cells are more complex, because compared to animal cells they have an additional organelle- the chloroplast—in which photosynthesis takes place; and a cell wall that surrounds the entire ce making it far more robust than an animal cell. But these two differences aside, plant and animal cel are really very similar.

So how to explain the fact that when a single-celled plant organism is compared to a single-celle "animal" (so to speak), the latter is always considered more complex, more evolved—in a wor superior?

Let's compare two unicellular beings, one animal and one plant: the paramecium and the euglen We're taking some license in calling the paramecium an animal since, along with other protozoa, it now in a separate classification, the protists. But until a few years ago, for all intents and purposes, was considered an animal: as the name *protozoa* implies (from the Greek *protos*, "first," and *zoo* "animal"), it's a proto-animal.

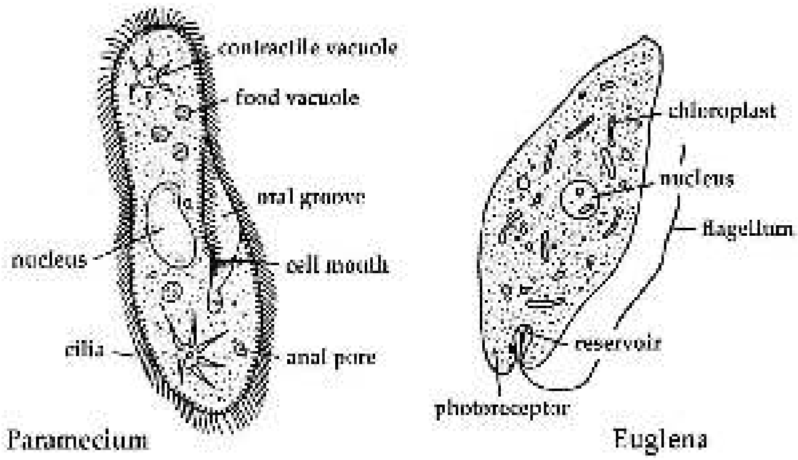

Figure 2-1. Structural comparison of the paramecium and the euglena. The two organisms are very similar, but the second has a primitive eye (a photoreceptor) with which it perceives light.

The paramecium is a minuscule unicellular organism whose body is covered with cilia that act lil oars, allowing it to swim and move around in the water. If you look at it under a microscope, you can help being fascinated by its elegant evolution, and by movements that seem to imply elegant behavic It's a true champion among living beings: a single cell, but capable of astonishing activity. Writin about another little amoeba-like unicellular animal, Herbert Spencer Jennings (1868–1947) in h book *Behavior of the Lower Organisms*, published in 1906, wondered whether we would be more a to grant intelligence to the predatory amoeba if it were the size of a whale, and a potential threat humans.

And in the other corner, we have another marvel of creation, a minuscule single-celled green alg the euglena. It, too, can be classified with the protists, but without a doubt it has a plant nature.

Looking at such simple living organisms and discovering their extraordinary abilities can help u see what underlies our prejudiced view of the plant world. What do these unicellular organisms hav in common, and how are they different from each other? Do the animals really have a minimal for of intelligence, but not the plants?

To get a general idea, let's start with the paramecium. For such a small organism, it has surprisin abilities: for example, it can locate food and move to reach it.

~~Naturally, in order to live, the euglena needs energy, too. Normally, it supplies its energy~~ need through photosynthesis, like all plants, but if light is scarce, it doesn't give up: it transforms itself in a predator and behaves like an animal. It can locate food and move to reach it—yes, it's a plant, but moves! This microscopic alga, in fact, swims with the aid of very thin flagella.

Obviously, both the paramecium and the euglena can reproduce. If you watch them moving in th water, there don't seem to be many differences between them. But wait: there are electrical signa traversing the body of the paramecium, transmitting information across a single cell. For this reaso it's been called a "swimming neuron," which seems like a pretty good definition of a paramecium. B there are the same kind of electrical impulses going across the single-celled body of the euglena. S they're even again.

Can the paramecium and the euglena do the same things? Does the match between plants ar animals end in a draw? No way—but the outcome isn't what we would expect. The one with the ace u its sleeve isn't the paramecium but the euglena, which has another capacity that beats the competitio hands-down: it can carry out photosynthesis. To improve this capacity, it has developed a rudimentar sense of sight, which allows it to intercept light frequencies and then to find the best position f receiving light.

But if the euglena can do everything a paramecium can do, and in addition, can see and produ energy by transforming light from the sun, why has no one ever called it a "swimming neuron" some other epithet that expresses its exceptional abilities? Hard to say. There's no rational way t explain the general disregard for solid scientific evidence that plant cells have greater capacities tha those of animal cells.

Five Hundred Million Years Ago

Returning to the evolutionary obstacle we mentioned at the beginning of the chapter, let's go bac about 500 million years, when the differentiation between plants and animals began. The fir organisms chose two divergent paths, which can be summed up thus: plants opted for a stationa lifestyle, animals for a nomadic one. It's interesting to note in passing that the same choice in favor a stationary life gave birth to the first great civilizations.

Plants faced the necessity of obtaining from the earth, the air, and the sun everything they needed order to live; animals, on the other hand, needed to feed on other animals or on plants, and for th purpose developed manifold movement capacities (running, flying, swimming, and so on). On th account plants are defined as "autotrophic" (from the Greek *autos*, "by itself," and *trophe*, "food" that is, self-sufficient, not dependent on other living things for their survival; and animals "heterotrophic" (from the Greek *eteros*, "other," and *trophe*, "food"), because they're not sel sufficient.

From generation to generation, this initial choice led to other fundamental differences between th animal and plant worlds, to the point that now they can be considered the yin and yang, the black ar white, of ecosystems. Plants are stationary and animals are mobile; animals are aggressive, plan passive; animals are swift, plants slow. We could come up with dozens of such antithetical pairing but they would amount to the same thing: life has evolved very differently in the plant world and th animal world over the past 500 million years.

The primitive choice to evolve as beings that are stationary or in motion led, over time, to a extraordinary differentiation in bodies and ways of life: animals have chosen to defend and fe themselves, and to reproduce, through motion (or flight), while plants have chosen to remain fixed one ~~place, which has imposed on them the necessity of finding solutions that are completely~~ origina at least from our point of view (which, let’s not forget, is an animal one).

A Plant Is a Colony

To start with, being stationary and therefore subject to being preyed on by animals, plants developed kind of “passive resistance” to external attack. Their bodies are constructed on a modular design, which each part is important but none is truly indispensable. This structure represents a fundament advantage vis-à-vis the animal kingdom, especially considering the number of herbivores on th planet and the impossibility of escaping their voracious appetites. The first advantage of having modular organization, to give just one example, is that, for a plant, being eaten isn’t that big a dea Could any animal say that?

The physiology of plants, as we will see, is based on different principles from that of animal While animals have evolved to concentrate almost all their most important vital functions in a fe organs such as the brain, lungs, stomach, and so on, plants have taken into account the reality of bein easy prey, and avoided concentrating their faculties in a few neurological areas. It’s a bit like n keeping all your money in one place, but instead dividing it up and hiding it in several places minimize the loss in case of theft, or diversifying your investments to distribute risk. In short, a ve wise move!

A plant’s functions are not related to organs—which means plants breathe without having lung nourish themselves without having a mouth or stomach, stand erect without having a skeleton, and we will soon see, make decisions without having a brain.

It’s because of this very special physiology that large portions of a plant can be removed witho putting its survival at risk: some plants can have up to 90 or 95 percent of themselves eaten, but the grow back normally from the small surviving nub. A meadow grazed on by an entire herd can gro back in a few days. You don’t have to be an herbivore to experience this phenomenon; if you’ve eve tried to cut back an ivy or a windweed, or even to clip your lawn, you know what we’re talking abou So as an evolutionary strategy, plants, being stationary (or more properly speaking, sessil organisms, have chosen to be composed of divisible parts in order to better withstand predato Animals, on the other hand, which based their defensive strategies on movement from the outs never developed regenerative capacities, or did so only in a few cases. Yes, a lizard can grow back i tail, but a foot, an arm, or its head, once cut off, doesn’t grow back. But if part of a plant is removed, generally not only survives, but sometimes even benefits: consider the rejuvenating effects of prunin This characteristic is a direct result of its structure, which is very different from ours. A plant is mac up of repeating modules: the branches, stem, leaves, and roots are all combinations of very simp modules, which essentially add on to each other independently, a little like Lego blocks.

True, a geranium on a terrace doesn’t give that impression: it looks like a unique being. But if yo take off a piece and then replant it—if you take a cutting, in gardener’s parlance—the piece geranium will put out new roots and grow into a new plant, whereas neither our arm nor an elephant foot can regenerate a whole new organism or stay alive apart from the rest of the body.

It’s no accident that we continually refer to ourselves as *individuals*: the term comes from the Lat *in* (which here means “not”) and *dividuus* (“divisible”). Our body really is indivisible: if we’re cut half, the two halves can’t live separately; they die. But if we cut a plant in half, the two parts can st live independently, for the simple reason that a plant isn’t an individual. In fact, the right way to thin about a tree, a cactus, or a shrub is not to compare it to a human being or any other animal, but ~~picture it as a colony. A tree is much more like a colony of bees or ants than an individual animal~~.

Though plants are very ancient, from this standpoint they also turn out to be exceptionally moder One of the cardinal concepts underlying many of the technologies made possible by the advent of t Internet and based on the interconnection of groups (such as social networks) is that of so-call emergent properties, typical of superorganisms or swarm intelligences. These are properties th single entities develop only by virtue of the unitary functioning of the group; none of the individu components possesses them on their own—just as bees or ants, by forming colonies, develop collective intelligence much greater than that of their individual members. We'll discuss pla behavior at greater length in chapter 5, on plant intelligence.

A Problem of Tempos

Let's return to the reasons that prevent us from recognizing plants for what they are—soci organisms, sophisticated and highly evolved like us. There's another aspect to our inability to percei the complex reality, one that has to do with time.

We all know that the average lifespan of living creatures varies considerably from species species: a human being lives about 80 years; a bee less than two months; a giant tortoise more th 100 years. Beyond the variation in average life span, animals also have different vital rhythms: som hibernate; some move and reproduce much faster than we do, others much more slowly. It wouldn seem to be that hard to recognize the existence of time scales very different from our own. But th isn't the case. A flow of events that gives rise to a time scale so slow as to be imperceptible to o eyes doesn't compute. While these adjectives are obviously meaningless in absolute terms, anoth way of putting it is that we are "fast" and plants are "slow." Very slow.

The difference in speed between us and them is so great that our perception can't grasp it. It's a b like a *trompe l'oeil* or an optical illusion, but on a temporal scale. For example, we know very we that a plant moves to capture light, to distance itself from danger, and to seek support (in the case the climbing plants). For decades, modern techniques of photography and film have enabled us reconstruct plant movement, which Darwin had already discussed and validated. Today a quic Internet search will bring you to a video showing a flower opening or a shoot growing. Yet in o perception, plants remain "still."

The sight of these movies astounds us, it speaks to the existence of movements in plants, but doesn't budge our unshakable conviction, partly instinctive, that these creatures are closer to t mineral world than to animal life. Our senses don't perceive plants moving, so we act as if they a inanimate objects. It makes no difference that we know they grow and therefore move; to us they' motionless because their movements escape our sight, and thus our deep understanding.

But what's the significance of our denial? In the hypertechnological society we live in, there a many things of which we have no direct (sensory) knowledge, but whose properties we don't doub Few people know how a television works, or a phone or a computer, but we wouldn't think belittling their technical characteristics merely because we have no direct sensory experience of t ways they work. Our knowledge of the structure of the universe and the composition of matter mediated by extremely complicated instruments. But who would think of denying the complexity atomic structure, even though it's much more removed from our sense perception than the structure plants? Of course, education plays an important role in this regard.

So why doesn't something similar happen with respect to plants? It doesn't seem improbable th