



Brilliant Green

*The Surprising History
and Science of Plant
Intelligence*

Stefano Mancuso
Alessandra Viola



Foreword by
Michael Pollan

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OF PLANT INTELLIGENCE

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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, immobile furniture of our world—useful enough, and generally attractive, but obviously second-class citizens of the republic of life on Earth. It takes a leap of imagination over the high fence of our self-regard to recognize not only our utter dependence on plants, but also the fact that they are considerably less 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 where everything—ourselves included—suddenly looks completely different. Chances are, you will come away convinced that it is only human arrogance, and the fact that the lives of plants unfold in what amounts to a much slower dimension of time, that keeps us from appreciating their intelligence—yes, intelligence—and consequent success in the game of life, which has been extraordinary, and dwarfed by our own. Plants dominate every terrestrial environment, composing ninety-nine percent of the biomass on Earth. By comparison, humans and all the other animals are, in the words of this intellectual and exhilarating book, only a trace.

In Stefano Mancuso, the plants have found their most eloquent or impassioned human advocate since Charles Darwin, who famously wrote that, “It has always pleased me to exalt plants in the scale of organized beings.” Stefano Mancuso is a leading researcher—he is a plant physiologist—in the relatively young, and still somewhat controversial, field of “plant intelligence.” That term strikes many plant scientists as tendentious, or just over the top, but as soon as you define intelligence as 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* and *communication*—as the monopolies of animals, but *Brilliant Green* makes a persuasive case that they are all qualities we now must share.

I first met Stefano Mancuso in 2013 at his lab, provocatively titled the International Laboratory for Plant Neurobiology at the University of Florence, when I was researching an article for the *New Yorker* on plant intelligence. He shared with me that his conviction that humans fail to perceive the reality of plant life had its origins in a science fiction story he remembers reading as a teenager. A race of aliens living in a radically sped-up dimension of time arrive on Earth and, unable to detect any movement in humans, come to the logical conclusion that we are “inert material” with which they may do so as they please. The aliens proceed ruthlessly to exploit us. (Mancuso subsequently recalled that the story was actually a somewhat mangled recollection of an early *Star Trek* episode called “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, heedless, and arrogant—has inspired Mancuso’s scientific research and now, with science writer Alessandra Viola, this marvelous collaboration. But while *Brilliant Green* is most assuredly *not* a work of science fiction—there is good science to back up its every claim—it is, like the best science, the product of a powerful imagination, one with the ability to see the world from a completely fresh angle.

unencumbered point of view—and to communicate that perspective to the rest of us. So, put aside for a couple of hours your accustomed anthropocentrism, and step into this other, richer, and more 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 other plants, insects, and higher animals? Or are they passive, unfeeling organisms without a trace of individual or social behavior?

Differing answers to such questions date back to ancient Greece, when philosophers of opposing 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 about whether plants are intelligent? Surprisingly, many of the points raised today are the same ones raised centuries ago, and hinge not on science but on sentiment and cultural preconceptions that have existed for thousands of years.

Although casual observation may suggest that the plant world’s level of complexity is pretty low, over the centuries the idea that plants are sentient organisms which can communicate, have a social life, and solve problems by using elegant strategies—that they are, in a word, *intelligent*—has occasionally raised its head. Philosophers and scientists in different times and cultural contexts (from Democritus to Plato, from Linnaeus to Darwin, from Fechner to Bose, to mention only some of the best known) have embraced the belief that plants have much more complicated abilities than are commonly observable.

Until the mid-twentieth century there were only brilliant intuitions. But discoveries over the past fifty years have finally shed light on this subject, compelling us to see the plant world with new eyes. 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 persisted for millennia.

The time seems ripe for a change in our thinking. On the basis of decades of experiments, plants are starting to be regarded as beings capable of calculation and choice, learning and memory. A few years ago, Switzerland, amid much less rational polemics, became the first country in the world to affirm 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 have lived with them from the time we appeared on Earth, yet we can’t say we know them at all. This isn’t just a scientific or cultural problem; it goes much deeper. The relationship between humans and plants 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 an indivisible organism. But plants are sessile—they can’t move from one place to another—and so they’ve evolved in a different way, constructing a modular body without individual organs. The reason for such a “solution” is obvious: if an herbivorous predator removed an organ whose function couldn’t 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 our understanding and recognizing plants as intelligent beings. In the second chapter, we’ll try to explain how this difference occurred. We’ll see how every plant has the ability to survive massive predation, and that what ultimately distinguishes a plant from an animal is its divisibility: its being equipped

with numerous “command centers” and a network structure not unlike the Internet’s. Understanding plants is becoming more and more important. They enabled our coming into existence on Earth (through photosynthesis, creating the oxygen that made animal life possible), and today we still depend on them for our survival (they are at the base of the food chain). They’re also the original energy sources (fossil fuels) that have sustained our civilization for thousands of years. Thus they are precious “raw materials,” essential for our food, medicine, energy, and equipment. And we’re growing 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, touch, taste, and smell—each developed in a “plant” way, of course, but no less real. So from this point of view could we say they resemble us? Not at all: they’re much more sensitive, and besides our five senses, they have at least fifteen others. For example, they sense and calculate gravity, 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 the social sphere. In the fourth chapter we’ll see how plants use their senses to orient themselves in the world, interacting with other plant organisms, insects, and animals, communicating with each other by means of chemical molecules and exchanging information. Plants talk to each other, recognize their kin, and exhibit various character traits. As in the animal kingdom, in the plant world some are opportunists, some are generous, some are honest, and some are manipulators, rewarding those that 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 be construed as “problem-solving ability,” and that by this definition plants are not just intelligent but brilliant at solving the problems related to their existence. To start with, they don’t have a brain like ours, yet they are able to respond adaptively to external stresses and, though using this word about a 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 that plants were much more advanced organisms than they were thought to be. Today, almost a century and a half later, a compelling body of research shows that higher-order plants really are “intelligent”: able to receive signals from their environment, process the information, and devise solutions adaptive to their own survival. What’s more, they manifest a kind of “swarm intelligence” that enables them to behave not as an individual but as a multitude—the same behavior seen in an ant colony, a shoal of fish, or a flock of birds.

Plants could live very well without us, in general. But without them we would die out very quickly. 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 to us.

The Root of the Problem

In the beginning, there was green: a chaos of plant cells. Then God created the animals, ending with the noblest of them all: man. In the Bible, as in many other cosmogonies, man is the supreme fruit of the divine work, the chosen one. He appears near the end of Creation, when everything awaits him, 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 are 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 which living cells capable of performing photosynthesis first appeared on the planet more than three and a half billion years ago, while the first *Homo sapiens*, so-called modern man, only appeared 200,000 years ago (a few seconds ago, in the evolutionary time frame). But arriving last hasn't kept human beings from feeling privileged, even though current knowledge on the subject of evolution has drastically reduced our role of “master of the universe,” downgrading our status to that of a “newcomer”—a relative position that brings no *a priori* guarantee of supremacy over other species 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 can feel and react to external stresses, has been proposed over the centuries by numerous philosophers and scientists. From Democritus to Plato, from Fechner to Darwin (to cite only a few examples), some of the most brilliant minds of all time have been exponents of the intelligence of plants, some attributing to them the capacity to feel, others imagining them as humans with their heads in the ground. Sensitive living beings, intelligent and endowed with all human faculties, except those precluded by their . . . odd position.

Dozens of great thinkers have theorized and documented the intelligence of plants. Yet the belief that plants are less intelligent and evolved beings than invertebrates, and that on an “evolutionary scale” (a concept without basis in fact but still fixed in our mentality) they're barely above inanimate objects, persists in human cultures everywhere and manifests itself in our everyday behavior. No matter how many voices are raised in support of recognizing plant intelligence on the basis of experiments and scientific discoveries, infinitely more oppose this hypothesis. It's as if by tacit agreement religions, literature, philosophy, and even modern science promulgate in Western culture the idea that plants are beings endowed with a level of life (not to speak of “intelligence,” for the 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 thee alive with thee; they shall be male and female. Of fowls after their kind, and of cattle after their kind, and of every creeping thing of the earth after his kind; two of every sort shall come unto thee, to keep thee alive.” With these words, according to the Old Testament, God told Noah what to save from the

universal Flood so that life would continue on our planet. Obeying God's instructions, before the Flood Noah loaded onto the ark birds, animals, and every creature that moved: "clean" and "unclean" 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 considered equal to the animal world, it isn't considered at all. It is left to its fate, probably to either be destroyed by the Flood or to survive it along with other inanimate things. Plants were so unimportant that there was no reason to care about them.

And yet the contradictions this passage contains are soon evident. The first becomes obvious as the narrative continues. After the ark's slow coming aground, when the rain has stopped for several days, Noah sends a dove to bring back news of the world. Is there dry land anywhere? Are there places above water nearby? Are they inhabitable? The dove returns with an olive branch in its beak: a sign that some lands have reemerged and that on them life is possible again. Noah therefore knows (even if 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 Ararat. The great patriarch debarks, lets the animals off, and then gives thanks to God. His duties are fulfilled. And what does Noah do next? He plants a vineyard. But where does the original vine come from, if it isn't mentioned elsewhere in the story? Noah brought it with him before the Flood, aware of its 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 creatures comes through the story in Holy Scripture. In Genesis, two plants, the olive and the grape vine, are associated with the value of rebirth and of life, though the vital quality of the plant world in general goes unrecognized.

All three of the Abrahamic religions have implicitly failed to recognize that plants are living beings, in effect grouping them with inanimate objects. Islamic art, for example, respecting the prohibition against representing Allah or any other living creature, is passionately devoted to the 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 be forbidden! In the Koran, there is actually no explicit ban on representing animals; the prohibition is transmitted through the *hadith*, the sayings of the prophet Mohammad that form the basis for the interpretation of Islamic law, by virtue of the fact that in Islam there is no God but Allah and 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 Judaism which is based on the Old Testament forbids the gratuitous destruction of trees and celebrates the new year of trees (Tu Bishvat). The ambivalence comes from the fact that on the one hand we humans are intimately aware that we can't exist without plants, and on the other hand we're unwilling to recognize the role they play on the planet.

It's true that not all religions have the same relationship to the plant world. Native Americans and other indigenous peoples recognize its undeniable sacredness. If some religions have sacralized plants (or rather, parts of them), others have gone so far as to hate or even demonize them. For example, during the Inquisition, plants believed to be used in potions by women accused of witchcraft—garlic, parsley, and fennel—were put on trial along with the witches! Even today, plants with psychotropic effects receive special treatment: some are banned altogether (How do you ban a plant? Could you ban an animal?), others are regulated, still others are considered sacred and used by shamans in tribal 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, and literature. In the works they create, the imagination of artists and writers helps construct a vision of the world. What does art tell us about the relationship between human beings and the plant world? Though there certainly are important exceptions, in general, writers depict the plant world as a static, inorganic part of the countryside, passive as a hill or a mountain chain. Consider, for example *Robinson Crusoe* (1719) by Daniel Defoe, where plants are depicted as part of the landscape but never as living organisms. For the first hundred pages, the whole plot of the novel is based on Robinson's search for other living organisms on the island . . . while he is literally surrounded by them in the form of plants. More recently, in *Suddenly in the Depths of the Forest* (2005) by Amos Oz, a small village is under a curse that prevents any form of life except humans . . . while the village is completely encircled by the plants of the forest.

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

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

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

However, from antiquity to the present day, some philosophers have paid the highest honors to the plant world. For example, almost a century before Aristotle, Democritus described plants in a completely different way. His philosophy was based on atomistic mechanics: every object, even if it 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 were mobile. Democritus even compared trees to upside-down humans, with their head set in the ground 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 of unconscious ambivalence, which held that plants were simultaneously inanimate beings and

The Fathers of Botany: Linnaeus and Darwin

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

Linnaeus’s ideas concerning the plant world were idiosyncratic almost from the start. First, he identified “reproductive organs” in plants, and he made the “sexual system” the principal taxonomic criterion upon which he based his work of classification. In a bizarre contradiction, this decision earned him both the first university chair and also condemnation for “immorality.” (It was known that plants had a sex. But studying this in order to classify plants? . . . how scandalous.) Then the scientist proposed another innovative theory, which only by accident drew less criticism than the first. 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 the caution used by scientists in those days to protect their theories from possible attacks. In fact, based on scientific knowledge of that time and on his own observations of the different positions assumed by the leaves and branches during the night, it was relatively easy for Linnaeus to assert that plants sleep. But it would be several centuries before sleep was recognized as a fundamental biological function 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 many functions of sleep, would probably interpret his own observations differently and would deny the existence of an activity in plants that could be compared to an activity of animals. In fact, he did deny it in another instance: that of insectivorous plants. Linnaeus was quite familiar with plants that ate insects, such as *Dionaea muscipula* (the Venus flytrap), for example. And he certainly had the experience of observing one as it enclosed, trapped, and digested an insect. Yet that reality (a plant eating an animal) was so incompatible with the rigid pyramidal organization of nature, in which plants were relegated to the lowest level of life, that Linnaeus, like his contemporaries, sought a myriad of other possible explanations rather than acknowledge plain evidence. Without any regard to scientific confirmation of his assertions, from time to time he therefore hypothesized that the insects didn’t die at all, and that they chose to remain inside the plant of their own volition and for their own convenience, or that they landed on the plant by chance and not because they were attracted to it. Or even that the plant trap closed by chance, and so couldn’t possibly lure an animal. Ambivalence 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 scientist finally assert the existence of plant organisms that feed on animals. But even Darwin, with his characteristic caution, didn’t go so far as to call them “carnivores” (as we do today), though he was perfectly aware of plants that prey on rats and other small mammals, such as several supercarnivores 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 caution of other scientists in centuries past. It’s because of their “diplomacy,” in fact, that certain revolutionary ideas could slowly filter through the collective consciousness—and into a scientific community that was very conservative. But let’s return to Linnaeus for a moment, and ask ourselves how was it possible for him to assert so boldly that plants sleep, without being shunned or persecuted?

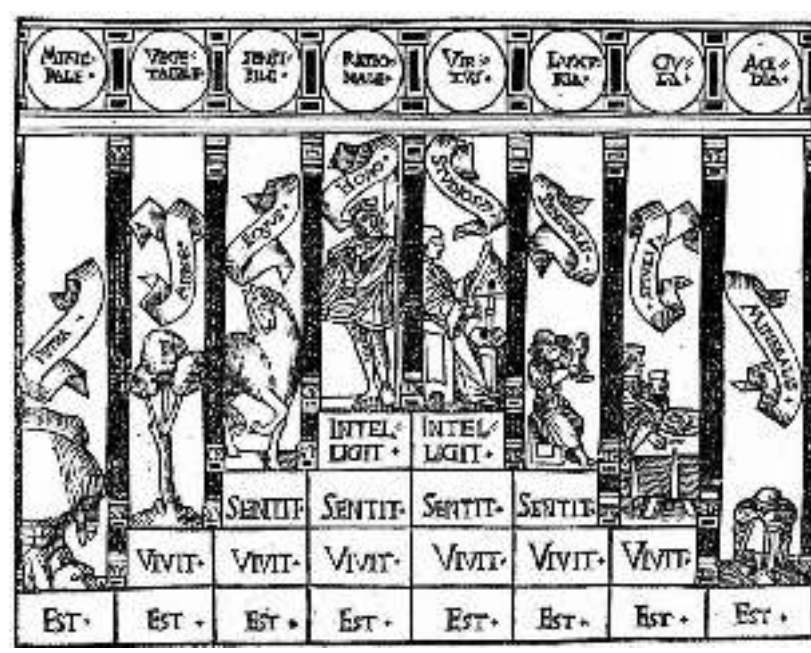
by his peers? This isn't hard to answer: for a long time it was thought that his theory had no basis in fact, so it wasn't even worth refuting. And furthermore, who cared whether plants slept, when sleep wasn't believed to have any particular function?

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 evolved animals sleep. In 2000, this was disproved by the Italian neuroscientist Giulio Tononi, who showed that even the fruit fly, one of the "simplest" insects in existence, takes its well-deserved rest. Then why shouldn't plants? Maybe the only possible explanation is that this idea doesn't fit with how we 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 of Living Things that we've taken with us down through the centuries is the one contained in the *Liber Sapientie* (Book of Wisdom), published in 1509 by Charles de Bovelles (c. 1479–1567). An illuminated illustration from the book is worth more than a thousand words: it shows the living and nonliving species in ascending order. It starts with rocks (which are given the following lapidary comment: *Est*, meaning they exist and that's all; they have no further attributes), continues to plants (*Est et vivit*, thus a plant exists and is alive, but nothing more) and animals (*Sentit*: an animal is endowed with 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 and endowed with greater or lesser vital capacities, is still in vogue. It is part of our cultural humus, and nearly impossible for us to give up, despite the passage of more than 150 years since the publication in 1859 of *The Origin of Species*, the foundational work given us by Charles Darwin to understand life on our planet—a book so important that the great biologist Theodosius Dobzhansky wrote: "Nothing in biology makes sense except in the light of evolution." The theories of the great British scientist, who was a biologist, botanist, geologist, and zoologist, are now part of humanity's scientific inheritance. Yet the idea that plants are passive beings, without sensation or any capacity for communication, behavior, or computation—which comes from a completely erroneous view of evolution—is still strongly rooted even in the scientific community.



It was Darwin who proved beyond any reasonable doubt that the question should not be put in those terms, because there are not more- and less-evolved organisms; from the Darwinian point of view, all living beings now populating the earth are at the end of their evolutionary branch—otherwise, they 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 for adaptation. Of course, the genius naturalist knew well that plants are extremely sophisticated and complex creatures, with many capacities beyond those that are commonly recognized. He devoted a 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 vast amount of research on the plant world carried out by Darwin has always been treated as secondary or further demonstration—if any were needed—of the scant consideration plants have always received in science.

In his book *One Hundred and One Botanists*, published in 1994, Duane Isely stated: “More has been written about Darwin than any other biologist who ever lived. . . . Curiously, in light of this flood, Darwin is rarely presented as a botanist. True, the fact that he wrote several books about his research on plants is mentioned in much Darwinia, but it is casual, somewhat in the light of ‘Well, the great man needs to play now and then.’” Darwin wrote and affirmed several times that he considered plants to be the most extraordinary living things he had ever encountered (“It has always pleased me to exalt plants on the scale of organised beings,” he confessed in his autobiography), a theme that he took up again and amplified in his fundamental *The Power of Movement in Plants*, published in 1880. Darwin was a scientist of the old school: he observed nature and deduced its laws. Though not a dogmatic experimenter, in this book he explains the results of hundreds and hundreds of experiments he carried out with his son Francis, describing and interpreting the innumerable movements of plants: a great many different movements, which involved in most cases not the aerial part but the root, in which Darwin 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 where he presents his final considerations on the subject under discussion, in a way that makes them simple and accessible to everyone. Here is a marvelous example from the famous epilogue to the *Origin of 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 his conviction that in the roots there is something similar to the brain of a lower animal (an important assertion, to which we will return in [chapter 5](#)). In fact, a plant has thousands of root tips, each endowed with its own “computing center,” a phrase we use to make plain to even the most spiteful 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, the hypothesis is that at a plant’s root tip there is a kind of plant analog, endowed with many of the same

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 elaborate on them in his books. Already old when he wrote *The Power of Movement in Plants*, Darwin was certain that plants should be considered intelligent organisms, but he also knew that saying so would stir up a hornet's nest of controversy about his studies. Remember, he'd already had problems defending his theory that humans descended from apes! And so he left the task of developing his thesis to others, especially to his son Francis.

Profoundly influenced by his father's ideas and research, Francis Darwin (1848–1925) carried on Charles's work, becoming one of the first professors of plant physiology in the world and writing the first treatise in English on this new field of study. At the end of the nineteenth century, it still seemed paradoxical to associate the two ideas (plants and physiology). But Francis, who had studied plants and their behavior at his father's side for many years, had become convinced of their intelligence. Now a world-famous scientist in his own right, on September 2, 1908, at the opening of the annual congress of the British Association for the Advancement of Science, he threw caution to the wind and declared that plants are intelligent beings. This provoked the expected storm of protest, but he 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 and divided scientists into two opposing camps. One side—persuaded by the evidence Francis Darwin offered to support his assertions—quickly affirmed the existence of plant intelligence; the other side 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 for 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 Italian botanist in Liguria who is now forgotten—unjustly, since he was one of the most important naturalists 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 his correspondence with Darwin, he had become convinced of plants' intelligence, and he devoted himself to field experiments studying their faculties, concentrating over a long period of time on so-called myrmecophilia, the symbiosis some plants establish with ants (the term comes from the Greek

murmex, “ant,” and *philos*, “friend”). Charles Darwin was well aware that many plants produce nectar even apart from the flower (though obviously, most of it is produced in the flower in order to attract insects and utilize them as pollen vectors during pollination), and he had also observed that nectar, being very sweet, attracts ants. But he had never studied the phenomenon closely, being convinced 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 completely disagreed with the great man. Nectar is a very energy-rich substance that plants produce at great cost 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 plants secrete nectar in parts of themselves other than their flowers expressly to attract ants and make advantageous use of them as a defensive strategy: the ants, satisfied with their meal, in return for their food, defend the plants from herbivores, like real warriors. Have you ever leaned against a plant on a tree and jumped away from the bites of these feisty little hymenopterans? Ants come to the defense of their host plant instantly, lining up, surrounding the potential predator, and forcing it to retreat! It 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 source of food. For botanists, however, the story has always been (and still is) very different. Not many are willing to say that the plant’s behavior also is intelligent (and purposeful) and that the secretion of 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 from experimentation with plants have taken decades to be “confirmed” by research conducted on animals. Discoveries about fundamental mechanisms of life, essentially ignored or greatly undervalued as long 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 actually marked the beginning of genetics, but for forty years his conclusions were almost completely ignored until the first genetics boom began, with experiments on animals. Or look at the experience, which had a happy ending for a change, of Barbara McClintock (1902–1992), who won the Nobel Prize in 1981 for her discovery of genome lability. Before McClintock proved otherwise, it was thought that genomes (that is, the entire genetic makeup) were fixed and could not vary over the lifetime of a living being. The “stability of the genome” was untouchable scientific dogma. During the 1940s, with 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? The reason is simple: her research was carried out on plants, and since McClintock’s observations ran counter to academic orthodoxy, she was marginalized by the scientific community for a long time. But in the early 1980s, analogous research carried out on animals confirmed the existence of genome lability in other species, and this “rediscovery,” not only her own research, won McClintock the Nobel Prize and recognition of her own contribution.

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

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 second ranking, even in academia. Yet plants are often used in research because of the similarity between their physiology and that of animals, not to mention that experimentation on these organisms raises fewer ethical problems. But are we really sure that the ethical implications are inconsequential? We 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 be 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 be forgiven for asking: What brilliant researcher would devote herself to plants instead of animals, 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, the common scale of values relegates plants to last place among living things. An entire realm, the plant world, is underappreciated, despite the fact that our survival on the planet and our future depend on it.

The Plant: A Stranger

Human beings have lived with plants since our appearance on the earth about 200,000 years ago. Two hundred thousand years would seem to be enough time to get to know someone. But it hasn't been enough time for us to get to know plants. We know very little about the plant world, and we probably 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's consider an animal—say, a cat—and try to describe its characteristics. What can we say about the cat? It's smart, clever, affectionate, sociable, opportunistic, agile, quick, and who knows how many other things. Now let's consider a plant—say, an oak tree—and describe its characteristics, too. What can we say there to say about an oak tree? It's tall, shady, knotty, fragrant . . . what else? At most, we could add some aesthetic qualities and appreciations of its usefulness. We certainly wouldn't include attributes referring to its “social dimension,” whereas in the case of the cat we've said that it is sociable (though “individualistic” would also describe a cat's way of relating to its environment). We wouldn't attribute any sort of intelligence to a plant—whereas in the case of the cat we recognize it easily—nor would it occur to us to call an oak affectionate!

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

But we don't need to look to the past as evidence; in the last several decades, science has been showing that plants are endowed with feeling, weave complex social relations, and can communicate with themselves and with animals, all of which we will explore in the following chapters. So why do human beings still see the plant world only as raw material, or a food source, or decor? What prevents 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 the 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 the 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. During this process, each species acquires or loses characteristics and capacities in relation to the kind of habitat in which it lives. Of course, all of this happens over very long periods of time, but it can lead to macroscopic changes between the original and the eventual organism. Evolution has played a fundamental role in differentiating animals from plants, and today it's part of the problem that keeps 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, the plant kind of living things. Through photosynthesis, they created the oxygen that enabled life to spread 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 sure, 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 cell, making it far more robust than an animal cell. But these two differences aside, plant and animal cells are really very similar.

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

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

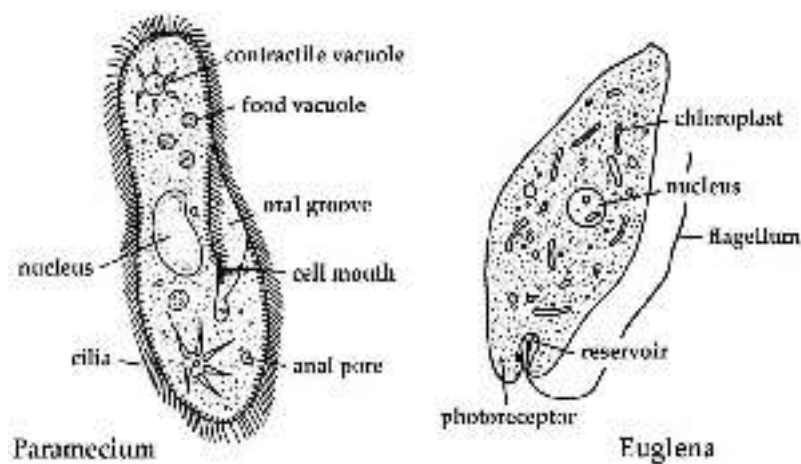


Figure 2-1. Structural comparison of the paramecium and the euglena. The two organisms are very similar, but the second has a primitive eye (a photoreceptor) with which it perceives light.

The paramecium is a minuscule unicellular organism whose body is covered with cilia that act like 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 behavior. It’s a true champion among living beings: a single cell, but capable of astonishing activity. Writing about another little amoeba-like unicellular animal, Herbert Spencer Jennings (1868–1947) in his book *Behavior of the Lower Organisms*, published in 1906, wondered whether we would be more apt to grant intelligence to the predatory amoeba if it were the size of a whale, and a potential threat to humans.

And in the other corner, we have another marvel of creation, a minuscule single-celled green alga—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 us see what underlies our prejudiced view of the plant world. What do these unicellular organisms have in common, and how are they different from each other? Do the animals really have a minimal form of intelligence, but not the plants?

To get a general idea, let’s start with the paramecium. For such a small organism, it has surprising

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 into a predator and behaves like an animal. It can locate food and move to reach it—yes, it's a plant, but it 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 the water, there don't seem to be many differences between them. But wait: there are electrical signals traversing the body of the paramecium, transmitting information across a single cell. For this reason, it's been called a "swimming neuron," which seems like a pretty good definition of a paramecium. But there are the same kind of electrical impulses going across the single-celled body of the euglena. So they're even again.

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

But if the euglena can do everything a paramecium can do, and in addition, can see and produce energy by transforming light from the sun, why has no one ever called it a "swimming neuron" or some other epithet that expresses its exceptional abilities? Hard to say. There's no rational way to explain the general disregard for solid scientific evidence that plant cells have greater capacities than 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 back about 500 million years, when the differentiation between plants and animals began. The first organisms chose two divergent paths, which can be summed up thus: plants opted for a stationary lifestyle, animals for a nomadic one. It's interesting to note in passing that the same choice in favor of 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 in order to live; animals, on the other hand, needed to feed on other animals or on plants, and for this purpose developed manifold movement capacities (running, flying, swimming, and so on). On this 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 are "heterotrophic" (from the Greek *eteros*, "other," and *trophe*, "food"), because they're not self-sufficient.

From generation to generation, this initial choice led to other fundamental differences between the animal and plant worlds, to the point that now they can be considered the yin and yang, the black and white, of ecosystems. Plants are stationary and animals are mobile; animals are aggressive, plants passive; animals are swift, plants slow. We could come up with dozens of such antithetical pairings but they would amount to the same thing: life has evolved very differently in the plant world and the 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 an extraordinary differentiation in bodies and ways of life: animals have chosen to defend and feed

themselves, and to reproduce, through motion (or flight), while plants have chosen to remain fixed in one place, which has imposed on them the necessity of finding solutions that are completely original—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 a kind of “passive resistance” to external attack. Their bodies are constructed on a modular design, in which each part is important but none is truly indispensable. This structure represents a fundamental advantage vis-à-vis the animal kingdom, especially considering the number of herbivores on the planet and the impossibility of escaping their voracious appetites. The first advantage of having a modular organization, to give just one example, is that, for a plant, being eaten isn't that big a deal. Could any animal say that?

The physiology of plants, as we will see, is based on different principles from that of animals. While animals have evolved to concentrate almost all their most important vital functions in a few organs such as the brain, lungs, stomach, and so on, plants have taken into account the reality of being easy prey, and avoided concentrating their faculties in a few neurological areas. It's a bit like not keeping all your money in one place, but instead dividing it up and hiding it in several places to minimize the loss in case of theft, or diversifying your investments to distribute risk. In short, a very wise move!

A plant's functions are not related to organs—which means plants breathe without having lungs, nourish themselves without having a mouth or stomach, stand erect without having a skeleton, and, as 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 without putting its survival at risk: some plants can have up to 90 or 95 percent of themselves eaten, but they grow back normally from the small surviving nub. A meadow grazed on by an entire herd can grow back in a few days. You don't have to be an herbivore to experience this phenomenon; if you've ever tried to cut back an ivy or a windweed, or even to clip your lawn, you know what we're talking about. So as an evolutionary strategy, plants, being stationary (or more properly speaking, sessile) organisms, have chosen to be composed of divisible parts in order to better withstand predators. Animals, on the other hand, which based their defensive strategies on movement from the outside, never developed regenerative capacities, or did so only in a few cases. Yes, a lizard can grow back its tail, but a foot, an arm, or its head, once cut off, doesn't grow back. But if part of a plant is removed, it generally not only survives, but sometimes even benefits: consider the rejuvenating effects of pruning. This characteristic is a direct result of its structure, which is very different from ours. A plant is made up of repeating modules: the branches, stem, leaves, and roots are all combinations of very simple 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 you take off a piece and then replant it—if you take a cutting, in gardener's parlance—the piece of geranium will put out new roots and grow into a new plant, whereas neither our arm nor an elephant's 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 Latin *in* (which here means “not”) and *dividuus* (“divisible”). Our body really is indivisible: if we're cut in half, the two halves can't live separately; they die. But if we cut a plant in half, the two parts can still live independently, for the simple reason that a plant isn't an individual. In fact, the right way to think

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 modern. One of the cardinal concepts underlying many of the technologies made possible by the advent of the Internet and based on the interconnection of groups (such as social networks) is that of so-called emergent properties, typical of superorganisms or swarm intelligences. These are properties that single entities develop only by virtue of the unitary functioning of the group; none of the individual components possesses them on their own—just as bees or ants, by forming colonies, develop a collective intelligence much greater than that of their individual members. We'll discuss plant 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—social organisms, sophisticated and highly evolved like us. There's another aspect to our inability to perceive the complex reality, one that has to do with time.

We all know that the average lifespan of living creatures varies considerably from species to species: a human being lives about 80 years; a bee less than two months; a giant tortoise more than 100 years. Beyond the variation in average life span, animals also have different vital rhythms: some hibernate; some move and reproduce much faster than we do, others much more slowly. It wouldn't seem to be that hard to recognize the existence of time scales very different from our own. But that isn't the case. A flow of events that gives rise to a time scale so slow as to be imperceptible to our eyes doesn't compute. While these adjectives are obviously meaningless in absolute terms, another 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 bit like a *trompe l'oeil* or an optical illusion, but on a temporal scale. For example, we know very well that a plant moves to capture light, to distance itself from danger, and to seek support (in the case of the climbing plants). For decades, modern techniques of photography and film have enabled us to reconstruct plant movement, which Darwin had already discussed and validated. Today a quick Internet search will bring you to a video showing a flower opening or a shoot growing. Yet in our perception, plants remain “still.”

The sight of these movies astounds us, it speaks to the existence of movements in plants, but it doesn't budge our unshakable conviction, partly instinctive, that these creatures are closer to the mineral world than to animal life. Our senses don't perceive plants moving, so we act as if they are inanimate objects. It makes no difference that we know they grow and therefore move; to us they're 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 are many things of which we have no direct (sensory) knowledge, but whose properties we don't doubt. Few people know how a television works, or a phone or a computer, but we wouldn't think of belittling their technical characteristics merely because we have no direct sensory experience of the ways they work. Our knowledge of the structure of the universe and the composition of matter is mediated by extremely complicated instruments. But who would think of denying the complexity of atomic structure, even though it's much more removed from our sense perception than the structure of 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 that

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