Plant Intelligence

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I: Plant Signalling and Behavior

Modern scientific research is now confirming what indigenous cultures have known for millennia or more: that plants are fully aware of their surroundings and are as responsive as animals to the world around them – in some cases even more so.

Before proceeding further, it is worth exploring what we mean by intelligence. There is no official accepted definition, just as there is not a single accepted definition for many basic concepts, one other prominent example being "life". Most definitions of intelligence revolve around the capacity of an organism to perceive and respond to its environment, to interpret and assess, and to adapt or modify its behavior based on that assessment. This is the lens through which we will examine plants and how they act in the world.

"**If intelligence is the capacity to acquire and apply knowledge, then, absolutely, plants are intelligent.**"[1] -Leslie Sieburth, biologist, University of Utah

Increasingly the intelligence of plants is being recognized in the scientific literature. At the same time, there are still many in the scientific community reluctant to use the *"I"* word, perhaps not wanting to engage in what they see as anthropomorphizing - or perhaps more afraid of being accused of such. And so in the literature *Plant Intelligence* is often referred to as *Plant Signaling and Behavior*. On its face this is no concern as it is only a label. On the other hand, it is worth asking at what point we stop holding onto anthropocentric biases and apply the same metric in an objective fashion not only to non-human animal species, but to species belonging to other Kingdoms which have clearly been evolving and adapting in as sophisticated way as ourselves. It is true that we should guard against interpreting the world through a human lens and assuming that plants that act in a way that is analogous to us are motivated by the same internal processes or intentions. However it is vital to point out that the opposite bias – what we might call *anthropocentrism* – is widely accepted within the scientific community, often without question or reflection. Indeed, it can be argued from an objective and scientific standpoint that humans and other animals are more alike than distinct – genetically and phylogenically, sharing a commonality of descent, and that the Cartesian bias of human behavior being unique is the more unscientific and unfounded starting point to explore these issues both philosophically and scientifically.

It is difficult for us to imagine that only a short time ago plants were not considered to be fully alive, or that the common belief was that spontaneous generation of plants in lieu of an understanding of flower and seed-based reproduction. Western society's ignorance of the complexity of plant physiology and behavior has been a self-fulfilling positive feedback cycle: our unfounded insistence that plants could simply not be intelligent made it unnecessary to look for any evidence to the contrary, and so the resulting continued ignorance was self-perpetuated.

Charles Darwin is a seminal figure in the modern history of Plant Intelligence science. It is no coincidence that the same man who focused his research on the *Commonality of Descent* also concluded that humans did not occupy a vaulted or special status in terms of cognitive faculties. Darwin's second-to-last published work, published in 1881, ended with the conclusion that earthworms clearly demonstrated intelligent behavior.[2] His second-to-last book, published in 1880, ended with a similar bombshell in the last paragraph – in this case that the roots of plants clearly exhibit a brain-like capacity.[3] To this day Darwin's The Power of Movement in Plants is considered to be one of the most comprehensive and important works on the subject, and is still often cited as a primary source in the scientific literature. Unfortunately until the last few years his conclusions on plant intelligence were ignored and it is only now that we are seeing a significant number of scientists delving into this fascinating world with an open mind.

One of the main challenges to the discipline of Plant Intelligence has been the Brain-bias: the belief (faith) that a brain is required for intelligence. Needless to say, human beings have an inherent conflict of interest in arriving at that particular conclusion. As it turns out, it is more and more recognized that this is certainly not the case. Some of the research in this area has focused on the Protists often referred to as "slime molds", in particular the species *Physarum polycephalum*, about which researchers concluded (emphasis added): "They do not accept whatever circumstances they find themselves in, but rather choose conditions most amenable to their survival. They remember, anticipate and decide. By doing so much with so little, slime molds represent **a successful and admirable alternative to convoluted brain-based intelligence**."[4, 5, 6]

More to the point, in recent research with pea plants (*Pisum sativum*), Maria Gagliano of the University of Western Australia demonstrated that pea plants can learn associatively through a Pavlovian-like response, modifying their behavior to the point of overriding their own phototropic instincts.[7] Gagliano is a scientist to follow for those interested in Plant Intelligence research, and is one of several editors of the book The Language of Plants, published in May 2017.[8]

One way to consider Plant Intelligence is through the lens of how plants sense the world around them, and respond to stimuli through movement, chemical production, or other responses. The author Daniel Chamovitz has done a thorough job of summarizing the analogues of plant senses in his book What a Plant Knows[9]. It should be noted however that (1) scientific research in this field is expanding rapidly to the extent that a fair amount of recent research has already rendered parts of his book outdated, and (2) Chamovitz's approach is fairly conservative in terms of his scope and conclusions, albeit this is a subjective opinion of my own.

Just as animals do, plants have *proprioception* – they can accurately place themselves in space and orient themselves to their surroundings. They do this through a combination of *gravitropism* (sensing the pull of gravity to know "up" and "down"), *phototropism* (sensing light and moving toward it, or in the case of shade-loving plants, possibly moving away from it).[10] Plants also engage in *photoperiodism*, meaning they can accurately measure the length of day and night, which when combined with a sensing of temperature gives plants an accurate indicator of time of year, to time hormonal changes stimulating flowering, senescence, waking from dormancy, etc. Plants also have circadian rhythms, as do humans and other animals, which can be disrupted just as in humans from exposure to artificial light.[11]

Another plant sense is *thigmotropism*, equivalent to our sense of touch. In fact some plants are much more sensitive to touch – up to 10x - than we are.[12] Whereas most plants appear "still" to our eyes only because they are moving slowly, the Venus fly-trap (*Dionaea muscipula)* is often studied for its ability to respond to touch with movement in a time-frame visible to human eyes. This plant has been shown in recently published research to have the capacity to accurately "count" in order to close up its leaves only when there is a high probability of prey (i.e. an insect) having touched it, rather than the wind or wind-borne debris.[13] In addition, the Venus fly-trap is now known to engage in electrical signaling that makes such rapid response possible; although plants clearly lack a nervous system in the same way as animals, it is now increasingly clear that plants do have an analogous "neuroid" network, perhaps making use of the phloem present in all vascular plants to insulate and make possible controlled electrical conductivity to and from distant parts of the individual plant. This is now being looked at as one physical aspect of, and mechanism for, plant consciousness.[14, 15]

Memory could perhaps be cited as an integral aspect of consciousness. Another plant known to move in a time frame observable by human eyes is the sensitive plant, or *Mimosa pudica*. In another study led by Monica Gagliano, this plant's reliable reaction to being touched – closing its leaves – can be manipulated to demonstrate that plants retain memories. In the experiment, potted plants would respond typically to the stressor of being dropped (in a controlled fashion that did not harm the plant) by closing up, but then eventually habituate to those stressors by ceasing to close, a memory they would retain for up to a month. As the authors write, "Astonishingly, Mimosa can display the learned response even when left undisturbed in a more favorable environment for a month. This relatively long-lasting learned behavioral change as a result of previous experience matches the persistence of habituation effects observed in many animals…"[16] Memory and associative learning have also been shown in other plants, including pea plants (*Pisum sativum*) in the study mentioned earlier, leading to more paradigm-shifting but difficult-to-avoid conclusions: **"… Our results now show that associative learning is also an essential component of plant behaviour. We propose that the ability to construct, remember and recall new relationships established via associative learning constitutes a universal adaptive mechanism shared by all organisms. The ubiquity of associative learning across taxa, including non-animal groups suggests that the role this learning process plays in nature is thus far underexplored and underappreciated."**[7] In a study published in 2016, the pea plant was also shown to engage in adaptive behavior and risk assessment. One of the authors, Alex Kacelnik of Oxford University, declared in the associated press release that "to our knowledge, this is the first demonstration of an adaptive response to risk in an organism without a nervous system."[17]

Other senses often thought to be the domain of animals, such as hearing and smell, have their analogues among plants. The dodder (*Cuscuta spp.*) is a small, vining parasitic plant that does not photosynthesize and thus relies entirely for its nutrition on its host plant by inserting its haustoria (aerial roots) directly into the host's tissue and even hijacking its defenses by inserting its RNA into the host's cells. We know from repeated experiments that dodder finds its prey by detecting airborne chemicals and moving in the direction of their source; it is quite discerning, engaging in preferential host plant selection (such as reliably preferring tomato plants over grasses), and behaving in a way remarkably similar to animals that are hunting or foraging.[18, 19]

Much less established is a plant analogue to the animal sense of hearing, but it is logical that the Plant Kingdom would have evolved able to detect and respond in some capacity to sound waves as an evolutionary benefit, and recent science is bearing this out. Certain angiosperms (flowering plants) are known to engage in buzz pollination, in which they detect the presence of their pollinators by the species-specific vibrational patterns of their wing beats (mainly bumble bees) to time their pollen production.[20] Other researchers have now shown that plants respond to the sound of insects chewing on leaves by increasing their chemical defenses.[21] Researchers such as Stefano Mancuso have hypothesized for several years now that plants may detect the *sound* of running water underground (i.e. not just detecting moisture itself in the soil) to assist them in locating water sources, and this has now been proven to be the case in a recently published study (April 2017).[22] This led the authors to urge more research into how noise pollution may be negatively impacting plant life.

Besides detecting sound, plant roots are now known to be able to detect light that is falling upon the above-ground parts of the plant. This is in addition to the previously known, widely established, and complex role that roots have in foraging for nutrients through the detection of moisture, temperature, gravity, and nutrient levels. Plant roots also play a crucial role in establishing and maintaining mutualistic relationships with soil fungi, which will be explored more below. All this adds up to a bounty of evidence supporting Charles Darwin's thesis from nearly 140 years ago that "that the tip of the radicle…having the power of directing the movements of the adjoining parts, acts like the brain of one of the lower animals."[3]

Research such as that cited above on how plants are aware of and respond to the world around them can seem astonishing to those who encounter it for the first time. This astonishment is a reflection of the deeply ingrained bias in Western culture that plants are less sophisticated than animals (and indeed, that all other animals are less sophisticated than humans). This hubris has resulted in effective self-censorship in the scientific community, leaving a tremendous void of basic research since Darwin's publication of The Power of Movement in Plants in 1880. **Our level of surprise mirrors our previously held level of prejudice.**

We are just now learning some of the most basic ways in which plants act and interact in the world. Or perhaps more accurately worded, we are just now establishing scientifically what many human beings have known for millennia and longer, that plants have a wisdom and intelligence that while distinct from ours is as complex and powerful. The most astonishing discoveries about plant intelligence, however, lie elsewhere: in the areas of communication and sharing.

II: Communicating and Sharing

It has been known for several decades that plants respond to perceived threats by increasing the production of defensive chemicals such as tannins to deter grazing, or other phytoconstituents with antiviral or antibacterial activity, depending on the nature of the perceived threat.[24] In other words, plants have the analogue of an animal immune system. In more recent years it has become established that plants signal to each other using airborne chemicals, thus stimulating neighboring plants to alter their chemistry prophylactically.[25] We now know that plants are not signaling each other exclusively through the air, but also through the Common Mycorrhizal Network (CMN) linking the root systems of wide areas of plants with interwoven fungal hyphae.[26, 27, 28] As one researcher put it, "CMNs increase the bioactive zones of infochemicals by serving as superhighways directly connecting plants below ground."[26]

Mycorrhizae are fungal-plant symbioses now known to be close to ubiquitous in healthy soil ecosystems, in which the fungal hyphae either encase the rootlets ("ectomycorrhizae") or as in most cases actually infiltrate the plant tissue ("arbuscular mycorrhizae"). The fungi, consummate decomposers, are able to provide bioavailable nutrients, notably phosphorus, to the plants, as well as the transfer of water, and the plant in exchange provides surplus carbohydrates, the product of photosynthesis, to the fungus.[29] We are now learning however, that the networks created by the interlacing of fungal hyphae and mycelium between plants provides not only a communication network as described above, but a venue for sharing resources between the plants themselves. In 2016 researchers from the University of Basel published findings showing that Norway spruce trees (*Picea abies*) share carbohydrates along the CMN not only with neighboring spruces but also with other species including beech, larch, and pine trees, and that "up to 40% of the carbon in the fine roots of one individual may be derived from photosynthetic products of a neighbor."[30] Although the authors of this study claimed this to be a novel finding, it is not. For several years Suzanne Simard and others have been publishing similar findings among the Douglas fir trees (*Pseudotsuga* menziesii) of Pacific Northwestern North America.[29, 31]

This of course has profound implications for how we view plant life. No longer can we continue to view plants as mere individuals competing for resources; they are clearly members of a community. As in human and other animal communities, competition exists, but alongside mutualism and sharing. Plants are social.

But community is not the only way in which plants relate to each other. As with animals, plants exist in families. By this I am not referring to the taxonomical classification of family as a grouping above genus but rather to the colloquial and common meaning of the word family as we use it among ourselves: *kin*. One of Suzanne Simard's more profound discoveries is that mother Douglas fir trees will feed their young saplings, again through the mycorrhizal network, when those saplings are in need of additional nutritional support.[31] Several species of plants, such as *Impatiens pallida* and *Cakile edentula*, have now been found to be able to recognize fellow plants of the same parentage, i.e. siblings, through their root systems, and adapt their behavior to be less competitive and more cooperative than with neighboring plants of the same species but differing parentage.[32, 33] Kin recognition is being increasingly found among plants the more it is looked for.[34, 35]

Lastly, forest trees have been repeatedly shown to keep neighboring dying and dead trees, even stumps, alive by providing them carbon and other nutrients, in some cases for many years.[36, 37, 38]

Plants speak to each other, warning each other of potential danger. They share food and tend to each other. We can be tempted to be overly romanti. As stated above, competition is clearly part of life; some plants, such as the dodder discussed earlier, parasitize other plants. That said, just as with social animals such as ants, bees, geese, and humans, plants live amongst their kin and fellow community members. Individuals benefit when the community they live in remains vital. Natural selection favors symbiosis and mutualism at least as much as competition, if not more.

III: Co-Evolution and Mutualism Between the Animal and Plant Kingdoms

In addition to communicating to each other, plants regularly communicate and interact with animals. As mentioned above, some flowering plants engage in "buzz pollination" in which they increase their production of pollen upon detecting the vibrational wing beat of their approaching pollinators such as bumble bees. Conversely, bumble bees can accurately identify plant species by sensing the species-specific weak electric field generated by the plants.[39] No organism evolves in a vacuum; all species influence and shape each others' evolutionary path as we cooperate, compete, and interact across time. There are orchids, for example, that have the appearance and odor of mushrooms to attract flies seeking mushrooms on which to lay their eggs. Other orchids known as "bee orchids", such as *Ophyrus apifera*, mimic female bees including the emitting of pheromones to attract make bees to mate - which then results in pollination. In a twist, there are species of mantises that mimic orchid flowers to attract would-be pollinating insects, which they then proceed to eat.

As plants and animals co-evolve, flower and pollinator shape and structure often evolve to fit hand-in-glove, the most famous example being another orchid, the Darwin Star orchid (*Angraecum sesquipedale*) of Madagascar, and its pollinating moth (*Xanthopan morganii praedicta*). When Darwin studied the unusually long nectar tube of the orchid, he proclaimed "*Good Heavens what insect can suck it?"* and correctly hypothesized the existence of a moth with a proboscis specifically suited for this unusual flower. He was ridiculed for this, and the moth was not discovered until after his death.[40]

Examples abound of how animals and plants have co-evolved, in many instances symbiotically but in other instances antagonistically or competitively. Both the morphology and chemistry of animal and plant life is interwoven within this parallel evolutionary process. Modern Western culture trains us to think of ourselves as individuals, but recent research on both animals and plants is now challenging us to replace the Self with Community as the basic unit of Life.

Lynn Margulis first theorized in 1970 that several of the organelles found in all eukyarotic life, including chloroplasts in plants and mitochondria in both plants and animals, are products of ancient endosymbiosis. In other words, the chloroplasts in plant cells that use the energy of sunlight to convert carbon dioxide and water into glucose, with oxygen as a byproduct, originated over one billion years ago as independent photosynthesizing cyanobacteria. Likewise, the mitochondria in our cells that utilize photosynthesis-derived oxygen for the conversion of photosynthesis-derived glucose into adenosine triphosphate (ATP), also originated as independent bacteria eons ago.[41] Although Margulis' ideas were rejected for many years, this is now accepted science.

The other theory that Lynn Margulis is most well-known for, together with James Lovelock, is Gaia theory, now also referred to as Earth System Science or geo-physiology. What Gaia theory posits is that life is not merely adapting to the planetary environment, but rather is responsible for actively shaping and maintaining that environment to be most conducive to life.[42] For example, our atmosphere would not be high in nitrogen and oxygen, and low in carbon, were it not for living organisms continually pumping carbon out of the air and nitrogen and oxygen back into the air. In other words the atmosphere our type of life relies on would not exist if life itself were not making it so. There are many other examples. As some describe it, it is a sort of co-evolution of life and planet, and other thinkers through the centuries and millennia have had similar ideas. Indeed, James Hutton, considered the founder of the modern science of geology, wrote in 1785, "I consider the Earth to be a super-organism and that its proper study should be by physiology."[43]

How much of modern-day illness is caused or at least exacerbated by a disassociation from our true biological reality? What could be more profoundly lonely than to view ourselves as discrete individuals – a belief system which not coincidentally supports our current economic structure - rather than as communities of cooperative organisms from the microscopic level all the way up to the planetary? Over two thousand years ago the Buddha taught that the *Self is Illusion*, and that suffering results from believing in that illusion. We now know that approximately 8% of the "human genome" is in fact viral in origin.[44] There are more bacteria in our guts and on our skin than human cells in our bodies. As discussed above, our "human" cells themselves are a product of multi-species symbiosis. Thankfully more and more scientists are breaking the bonds of anthropocentrism that has impeded our understanding of who and what we are, and how we relate to the other beings with whom we share the planet. Current research into plant intelligence, zoopharmacognosy, the microbiome, and Gaia all have the potential to have a profound impact on how we view our health and well-being, our work as holistic practitioners, and ultimately our relationship with all life and the Earth itself.

"What is man but a mass of thawing clay? The ball of the human finger is but a drop congealed. The fingers and toes flow to their extent from the thawing mass of the body. Who knows what the human body would expand and flow out to under a more genial heaven? Is not the hand a spreading palm leaf with its lobes and veins"? -H.D. Thoreau, Walden

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