However, Fouke (2011) uses morality in much the same way that other agricultural philosophers have done in the past, which is a very anthropocentric way of relating to soil (through human-conceived morals) in order to justify its demand on our attention (see also Paden, 1990). While admirable in their intentions, many of these efforts succumb to problematic assumptions, so rooted in Western culture, as to be inherent in the language used to try and talk about these problems. Even though it is true that 'soils provide services worth trillions of dollars annually', to frame it in such a way is problematically anthropocentric because it portrays soil not as a collection of innumerable beings, but as an object in service to humans, to say nothing of the issue of its commodification (Fouke, 2011: 149). While we might risk 'getting into the weeds' over the debate around genetic engineering, it should be noted that there is a tension between the ideas of 'healthy soil [as] a self-organizing system' and the soil ecosystem as 'one of the richest sources of compounds for biotechnology' (ibid), even though biotechnology is intrinsically *against* self-organisation. If we view soil as a vessel for possible biotechnological pursuits, through which humans reorient organisms towards particular aims that are of interest to themselves, isn't it *by definition* no longer *self*-organising?

Another example of academia's struggle to accurately articulate human/soil relationships can be found in inherited language. Kirschenmann (2009) writes about the necessity of having a conversation with the soil, thereby granting the soil some agency through its ability to enter into a conversation with humans. However, elsewhere in the same article, Kirschenmann (ibid) uses the term *soil management*, even though it is obvious that this term betrays the very intent of his theory. It should be noted, however, that Kirschenmann has a long record of working with numerous stakeholders around issues of soil, and so concessions should be given, knowing that the use of language like *soil management* would be the norm for most players in the modern agricultural system. These concessions are especially warranted when the position that Kirschenmann is ultimately asking farmers to take is a revolutionary one: 'we can only engage farmers in a process that involves them in conversation with their own soils' (ibid: 237).

Nonetheless, this invokes a quintessential dilemma for environmental ethics, best typified in the last page of Bateson's (1972) book of essays, *Steps to an Ecology of Mind*: 'Is it important that the right things be done for the right reasons?' (ibid: 512). There is a distinct possibility that using the term 'management' reinforces a particular understanding *of* and relationship *to* soil. For example, if a conversation is taking place and one party is attempting to 'manage' the other, then what is the quality of that conversation? Even advocates of true agriculture reform still find themselves caught within this ethical dilemma and way of thinking, in which they partially rely on, and give power to, the worldview of industrial agriculture through their language. This dissonance is also an indication of society's current transitional period, where culture is trying to break free of dualism. A good example of this conscious attempt to liberate society from a one-dimensional framework can be found in Robin Wall Kimmerer's work. As Professor of Environmental and Forest Biology at the State University of New York College of Environmental Science and Forestry, Kimmerer advocates for using the term *Ki* when referring to an individual of another species (especially where the gender is unknown) with *Kin* being the plural, as a way of avoiding the word 'it', which has a connotation of a dead object as opposed to living subjects (Storrs, 2018). With this language, the life in the soil becomes our *Kin*.

Part of the reliance on dualistic language comes from the use of modern science as the sole legitimate epistemology. The nature of this problem, and eco-psychology's usefulness as an antidote, will be addressed later in this chapter. It will suffice here to mention a very succinct, yet inclusive, characterisation of the problem as a way of highlighting the issue before moving beyond it. The philosopher David Ray Griffin (1988) put it this way:

> Recognition that the scientific community seeks truth is fully compatible with the recognition that the truths it seeks are selected according to various interests and prejudices. Recognition that science has discovered a wide range of truths is compatible with the conviction that a wide range of truths it has *not* discovered exists, and that its formulations of the truths it *has* discovered are one-sided, presenting only abstractions from the full truth. Recognition that there must be some truth to the 'modern scientific

> worldview', which supports and is supported by the select truths of modern science, is fully compatible with the view that other worldviews exist that, all things considered, correspond equally well or even better to the full nature of reality.
>
> *Griffin (1988: 9–10, emphasis in the original)*

FROM 'INNER SOIL' TO BEING SOIL

In another attempt to shift away from the dualistic, one-dimensional paradigm of academia, Patzel (2009) unearthed some of the subtler relationships between soil scientists, farmers and soil itself. His discoveries went a long way towards making the conversations between these entities less one-sided by highlighting the various ways that different individuals conceived of their connection to soil, using terms such as 'Mother Earth' or as working with 'the vital forces or spirits' to describe the relationship (ibid). In these exchanges, people were tending to their 'inner soil', meaning they were working with a fuller conception of their humanity and their relationships to the deeper aspects of soil, just as much as they were relating to the 'outer soil', the physical soil itself. For instance, the early European organic farmer, Hans-Peter Rusch (1906–1977), understood that reductionism provided an insufficient understanding of soil, or in his words, 'holy Mother Earth' (Patzel, 2009: 207). Another early European organic farmer, Mina Hofstetter (1883–1967), in Patzel's (2009) characterisation, 'claimed the importance of a spiritually receptive attitude towards Mother Earth' (ibid: 208), seemingly in an effort to create the kind of conversation that Kirschenmann (2009) advocated (see the previous section). When an individual adopts this co-creative outlook while in conversation with soil, Hofstetter notes, 'then suddenly, she [soil, or mother nature] starts talking and becomes understandable' (Patzel, 2009: 208).

From a farmer's perspective, British progenitor of organic agriculture, Lady Eve Balfour (1898–1990), composed the *wholeness approach*, which argued that every part of a whole had a right to exist, stating that 'the biota is a whole, of which we are a part' and 'if I am right, this means that we cannot escape from the ethical and spiritual values of life for they are a part of the wholeness' (Patzel, 2009: 217). This mindset wasn't exclusive to farmers; many scientists embraced it as well. Russian soil scientist Vasily Vasilyevich Dokuchaev advocated the study of holistic soil science and stated that 'all its principal elements must be *revered* and studied alike' (Patzel, 2009: 215, emphasis added). Acknowledging that soil has its own right to exist creates the theoretical foundation necessary to initiate and establish an eco-psychological relationship to soil.

However, even Patzel (2009) recognised possible discrepancies when it comes to relating to the 'inner soil'. He gave the example of two preeminent soil scientists, Fallou (the German founder of modern soil science working in the first half of the nineteenth century) and Jenny (former President of the Soil Science Society of America working throughout the twentieth century), who exhibited an 'inner soil' understanding, but with 'the polarity between the emotional and feeling approach on the one hand, and the fascination with rational order on the other hand', the 'inner soil' experience was discounted or ignored: 'In fact, this had been widely the case, and one might argue that this contributes to the accelerated and ongoing soil deterioration and destruction in large parts of the world' (Patzel, 2009: 216). Jenny (Patzel, 2009) continued to advocate that:

> [The soil] speaks to us through the colours and sculptures of its profile, thereby revealing its personality; we acknowledge it by giving soil a name, albeit in a foreign tongue, but we don't mention our emotional involvements. In fact, our soil language is lifeless.
>
> *Patzel (2011: 216)*

One could further argue that the division of the emotional and the rational is just another manifestation of dualism at work. Patzel (2009) ended his essay by returning to the question posited earlier:

> How could we personally and scientifically relate in an appropriate, fruitful, and sustainable way to our 'inner soil', so that it does not lead us to ideological one-sidedness and dogmatism, but may bestow on us the right idea at the right moment, the energy and guiding symbols to follow our path to what our culture needs next?
>
> *Patzel (2009: 223)*

The current author believes that looking at soil from an eco-psychological perspective is the right idea, for this moment.

HUMANS AS HUMUS: AN ECO-PSYCHOLOGICAL LOOK AT HUMAN/SOIL RELATIONSHIPS

As discussed previously, identifying a full and clear definition of eco-psychology can be a difficult task and one that is not necessary here. For the purposes of this chapter, the focus will be on three concepts that help constitute eco-psychology: non-dualism, non-anthropocentrism and alternative epistemologies that support these two former concepts. This definitional framework will help avoid some of the issues encountered by previous attempts of relating to soil. These three concepts seek to address the 'core issues' of psychology in general: 'Where is the "me"? Where does the "me" begin?, Where does the "me" stop?, and Where does the "other" begin?' (Hillman, 1995: 17). Furthermore, and specifically for the project of eco-psychology, 'defining the self-world connection' (Conn, 1995: 157) should be obvious: dualism is transcended by the non-dual; human selfishness is muted by non-anthropocentrism; and scientific materialism is negated by a recognition of multiple ways of knowing.

If, at this moment, paradoxical questions are forming in readers' minds, then this chapter is so far meeting with some success. Non-duality, when experienced from within the perspective of duality, is often paradoxical. For instance, Hillman (1995) discussed previous ecologically destructive attempts at cutting the boundary of 'self' and 'other' and highlighted the 'uncertainty about making the cut at all', only to end up saying 'we do need to see, however, that the cut between me and world, arbitrary as it is, nonetheless has to be made' (p. xix). From a dualistic perspective, of course the division has to be made: it is the very nature of human existence – we are not the trees (which is why it is so easy to cut them down). However, from Westernised eco-psychological perspective,

> we have, in short, cut ourselves off from our connection to the Earth so thoroughly in our epistemology and our psychology that even though we are 'bleeding at the roots', we neither understand the problem nor know what we can do about it.
>
> *Hillman (1995: 161)*

In a non-dualistic reality, individuals continually revise the boundaries of 'self' as necessary given their particular worldview and as the context demands. Not only is there an individual 'self', but that 'self' is also holonic, a part of many 'selves' that exist within a whole system: 'family, a community, a bioregion, or the living planetary ecosystem' (ibid: 164). Or, to take non-dualism to its further reaches, 'We are nature with a concept of nature. Nature weeping. Nature speaking of nature to nature' (Griffin, 1978: 226).

Thus, from a non-dual, eco-psychological perspective, one could simultaneously talk about knowing soil on *its* own terms, that humans *are* soil, and about humans having a healthy relationship *with* soil. Greenway (1995) discussed the *wilderness effect* and how extended wilderness experience programmes can facilitate transpersonal experiences of a non-dual 'self', but also points out that some programmes 'are not experiencing wilderness on its own terms' (p. 133). This is not an epistemologically problematic assertion in eco-psychology. Indeed, it is believed possible to experience an 'other' on its own terms. Like Hillman (1995), Greenway (1995) is acutely aware of the fact that the human ability to:

> Make distinctions, and 'self-reflect', now appears as a beautiful capacity run amok, proceeding from distinction to disjunction, from reflection to alienation, and from alienation to the kind of full blown split between subjects and objects (or between the poles of any disjunction) termed 'dualism'.
>
> *Greenway (1995: 131)*

Greenway (1995) recognised that yet another way to relate, in the case of this chapter, to soil would be to 'shift from culturally reinforced, dualism-producing reality processing to a more non-dualistic mode' (p. 131), whereby humans honour the Earth by their self-awareness as humus. Even the middle ground between these two 'poles of disjunction' is celebrated in eco-psychology, where 'healthy relationships (between distinct beings) are not an esoteric goal. It is a matter of our very survival and the survival of most of the life upon this Earth' (O'Connor, 1995: 151). In fact, from an eco-psychological lens, it is possible to see all three of these perspectives in enterprises of the soil, such as gardening and farming, 'activities in which people and wild nature intermesh and begin to co-evolve', like 'the physical embodiment of symbiosis and co-evolution' (Harper, 1995: 198).

The non-dual aspects of eco-psychology overlap significantly with its non-anthropocentric aspects. To talk about relating to soil on *its* own terms is to attempt to remove the human projections onto soil and the projections onto the beings which comprise it and allow soil to present itself as it is. To talk about holistic human relationships *with* soil is to invoke the symbiotic nature of those relationships which facilitate the well-being of *both* humans *and* soil. Furthermore, to talk about humans *as* soil is to invoke a level of relationship that transcends the boundaries of human and soil and to see the unity at the core of their separate existences, both ontologically and through time and space.

In case this all seems too esoteric, Roszak (1995), who coined the term eco-psychology, explicitly counters that mischaracterisation:

> Some are quick to see elements of sentimentality or romanticism in our growing appreciation of the sacred ecologies that guide traditional societies [which are significant contributors to the discipline of ecopsychology]. This is mistaken. There is nothing "mystical" or "transcendent" about the matter as we might understand those words. It is homely common sense that human beings must live in a state of respectful give and take with the flora and fauna, the rivers and hills, the sky and soil on which we depend for physical sustenance and practical instruction.
>
> *Roszak (1995: 6)*

Or, as Liberty Hyde Bailey (as cited in Cox, 2014: 50), Dean of Agriculture at Cornell University from 1903 to 1913 and pioneer of the US National Extension Service, put it: 'The good spiritual reaction to nature is not a form of dogmatism or impressionism. It results normally from objective experience, when the person is ready for it' (p. 52).

These sentiments, as stated by both Roszak (1995) and Bailey (as cited in Cox, 2014: 50), that non-dual, non-anthropocentric ways of relating to soil are 'common sense' and 'result normally from objective experience' obviously invoke a discussion around alternative epistemologies, where one moves from 'standard resource management models' which 'are almost entirely anthropocentric and utilitarian' towards multiple understandings, including animistic, relating to 'the world no longer as a conglomerate of dead material objects but as ensouled, alive and animate' (Perluss, 2014: 8; Rees, 2010: 28), as well as non-dual, which 'allows eco-psychology to recognize that an individual person is always a part of a greater ecological whole' (Soule, 2014: 29). Indeed, these relationships, and ways of knowing, are so ecologically and psychologically complex as to begin to call into question even the concept of the individual, egoic 'self'.

As an example of our visceral interconnectedness, Professor John Cryan (cited in Wheeler, 2012), Chair of the Department of Anatomy and Neuroscience at the University College Cork in Ireland, believes that his research findings suggest that our thoughts could be directly influenced by

the microbiome in our intestines. He undertook experiments with rats[1] and probiotics, with results showing that rats fed probiotics survive longer in standard stress tests (almost double in some cases). This increase in stamina was isolated to the probiotics by cutting the vagus nerve (which runs from the intestines to the brain) in a subsequent experiment, whereby those rats fed probiotics but whose vagus nerve was cut reverted back to a regular stress test endurance. One philosophical extrapolation of these findings is that even the human sense of 'will' may not be entirely human! When rats fed probiotics tried to endure the stress test for longer periods of time, those who have had their vagus nerve cut returned to normal levels. This suggested to Dr. Cryan that the biotic community in the rats used the vagus nerve to stimulate a longer sense of self-preservation. So, shouldn't an understanding of what a rat 'self' is, and by extension a human 'self', include those very same beings who contributed to the rats' and to human preservation?

However, with the one-sided epistemology of a rational, empiricist scientism, there is little chance of understanding the complexity of this non-dual relationship. Eco-psychology, on the other hand, emphasises the necessity of multiple epistemologies. Metzner (1999) incorporated alternative epistemologies as an integral part of his 'green psychology' (p. 175). Sewall (1995) goes so far as to delineate the ways in which alternative perceptions can assist in the task of reconnection: 'We begin to care for that which we see, and ideally, we find ourselves loving the material world, our Earth. Because love alters behaviour, honouring sensory and sensual experience may be fundamental to the preservation of the Earth' (p. 203).

One often-overlooked implication of the singular emphasis on empiricism is the subtle materialism that results, which only continues the dualistic paradigm. Cox (2014) articulated the concept of subtle materialism, building on the concept of Esbjörn-Hargens and Zimmerman's subtle reductionism, 'whereby ecological relationships are principally conceived as relationships between material objects that lack a subjective, interior mode of existence' (p. 96). This subtle materialism, which even Aldo Leopold occasionally recapitulates, has two negative results. One is anthropocentric in that interiority is only ascribed to humans. The other is that relationships between beings are only depicted in materialistic terms.

The roots of this reductionism in ecology theory can be traced back, in part, to Arthur Tansley (as cited in Cox, 2014: 113) who, in 1935, made an explicit effort to move ecology away from 'communities' and instead coined the term *ecosystem*. Worster (1985) expressed:

> The often-repeated notion that the plant assemblage is more than the sum of its parts, that it forms a whole which resists reductive analysis, he took to be a fiction worked up by an overexcited imagination… In short, Tansley hoped to purge from ecology all that was not subject to quantification and analysis, all those obscurities that had been a part of its baggage at least since the Romantic period.
>
> *Worster (1985: 301)*

However, when it comes to the history of alternative agricultures, alternative epistemologies are almost always invoked alongside alternative practices (Cox, 2014: 56). Two quotations will suffice here for the purposes of illustration. The first is Wes Jackson (cited in Cox, 2014), who discussed inherited worldviews in ways similar to the discussion above: 'Here lies my worry. Most proposals for bringing about a sustainable agriculture and culture carry the fingerprints or markings of the Baconian-Cartesian worldview. At best, it amounts to Smart Resource Management' (p. 51). The second is Wendell Berry (also cited in Cox, 2014), who is overt in his mistrust of reductionism: 'Reduction does not necessarily limit itself to compacting and organizing knowledge; it also has the power to change what is known' (p. 123). Thus, eco-psychology, which is partially constituted by its inclusion of alternative epistemologies, pairs extremely well with alternative agricultures, which also are made up of ways of knowing that go beyond scientistic empiricism and subtle materialism.

[1] This author wants to acknowledge that this example is problematic as an example of human interrelationship to the more-than-human world, given that it involves rats being used in very instrumental ways.

OTHER NON-DUAL PERSPECTIVES: BUDDHIST, ECO-FEMINIST AND INDIGENOUS

Because non-duality is inherently difficult to comprehend, especially from within many Western cultures which are impeded by dualistic concepts, the enterprise of encouraging a non-dual relationship to soil would benefit by highlighting other non-dual frameworks, such as Buddhism, eco-feminism and indigenous perspectives.

Buddhism is fundamentally interested in non-duality because 'non-duality is a concept central to the notion of enlightenment' (Sadakata, 1997: 79). As such, various sectors of Buddhism have created numerous ways of understanding this concept. Perhaps one of the easiest, if not one of the most poetic, interpretations comes from Zen master Thich Nhat Hanh, as expressed by Kornfield (1993):

> If you are a poet, you will see clearly that there is a cloud floating in this sheet of paper. Without a cloud there will be no water, without water, the trees cannot grow; and without trees, you cannot make paper. So the cloud is in here. The existence of this page is dependent on the existence of a cloud. Paper and cloud are so close. Let us think of other things, like sunshine. Sunshine is very important because the forest cannot grow without sunshine, and we as humans cannot grow without sunshine. So the logger needs sunshine in order to cut the tree, and the tree needs sunshine in order to be a tree. Therefore, you can see sunshine in this sheet of paper. And if you look more deeply, with the eyes of a *bodhisattva*, with the eyes of those who are awake, you see not only the cloud and the sunshine in it, but that everything is here, the wheat that became the bread for the logger to eat, the logger's father – everything is in this sheet of paper… The presence of this tiny sheet of paper proves the presence of the whole cosmos.
>
> *Kornfield (1993: 202)*

Buddhism, like eco-psychology, is not consumed by the perspective of unity; it can also 'honor our individual or personal destiny, our self for this life' (Kornfield, 1993: 207). Here again, there is a framework that encompasses the ideas of non-duality (i.e. humans are humus), subjectivity (i.e. a respect for all beings) and relationship (i.e. the interaction between my personal destiny and that of other beings).

Eco-feminism is another such framework. One of the mothers of eco-feminism, Charlene Spretnak, does a fantastic job of delineating the seemingly ineffable in her article 'Radical Non-duality in Eco-feminist Philosophy'. In it, she highlights the difference between minimal and radical non-duality, discusses non-duality's relationship to oppression and explores non-dual conceptions of 'self'. Her definition of non-duality is 'a dynamic system of relations wherein any particular manifestation functions simultaneously as a distinct part and the unbroken whole' (Spretnak, 1997: 427). With that understanding, she notes a difference between minimal non-dualism, which posits autonomous subjects in interdependent relationships, where this idea still partakes of scientific materialism, and radical non-duality, which posits 'the existence of unitive dimensions of being, a gestalt of a subtle, unitary field of form, motion, space, and time' (Spretnak, 1997: 425). This perspective takes the human/humus relationship even deeper, beyond an understanding of connection based on constituent elements across space and time. It asserts a unity that also exists on an ontological level, thus giving even more credence to the enterprise of recognising human's essential relations *with* soil.

As important as this understanding is, Spretnak (1997) acknowledges that there can be a danger in how it is applied. Historically, unity (or non-duality) could be used to erase difference, for the benefit of those in power. But that is not the case here, because eco-feminism is an inherently liberationist undertaking, which understands the 'self' as relational and therefore constituted by interactions with 'other' beings and celebrates these aspects of 'self': 'genetic inheritance', 'cognitive functions', 'bodily experience…[and] the self-regulating dynamics of the body-mind', 'exposures to strong and weak electromagnetic fields', 'other relational dynamics that lace the universe' and 'the influences of landscape, weather, and "other dynamics of one's bioregion on imagination and

mood'" (Spretnak, 1997: 433). In future, when non-dual understandings become more common place, as necessitated by our current social and ecological crises, the non-dual relationship of humans and humus will need to be an explicit component in any list of aspects of 'self', such as the list above. Indeed, as these 'ontolog[ies] based on dynamic and admittedly partial knowledge[s] *as well as* awe toward the complexity of embodied and embedded existence… contribute substantially to the profound social transformation that is needed' (Spretnak, 1997: 435, emphasis in original), soil will need to be ever present as the very foundation of this work.

Finally, many indigenous belief systems are also non-dualistic in their orientation, though 'non-dual' might not be the preferred term. Nancy J. Turner (2005), author of *The Earth's Blanket: Traditional Teachings for Sustainable Living* and researcher who has worked with indigenous communities for over 40 years, cited a term from the Nuu-Chah-Nulth Nation, *Hishuk ish Ts'awalk*, which translates approximately to 'everything is one' (p. 179) when generalising about indigenous understandings of human/nature relationships. In her exploration of Navajo sand painting, Griffin-Pierce (1992) used 'interrelated totality' (p. 66), while Cajete (1999) encapsulated these complexities in the phrase the 'theology of place' (p. 66), which, 'while focused specifically on [a] place, extended to include all of nature' (p. 5).

While the language used to express these indigenous, non-dual understandings may differ significantly, the commonality is a stance against Western dualism. In example after example, Turner (2005) juxtaposed the 'compartmentalize[d]' approach of 'western society', which separates forestry and fisheries into different administrative and academic units, against 'First Nations' which '*lived* this interconnectedness between their landscapes and resources, relying fully on all of the components and their associations simultaneously' (p. 180, 183). She ended her exploration by invoking the Haudenosaunee Thanksgiving Address, which is a litany of all the beings that humans are in relationship *with*, offering gratitude and thanks for the ways these 'other' beings help to constitute human beings. Turner (2005) stated, 'this prayer…epitomizes a world view in which everything is one, and it emphasizes our need to recognize and express our appreciation to all the elements of our universe' (p. 206).

Griffin-Pierce (1992) offered a contrite summary of the issue of dualism: 'What Anglos call the pairing of opposites Navajos conceptualize as the halves of a whole, with each half necessary for completeness' (p. 66). She went on to quote a participant in her research as saying, 'When you say "opposites" it sounds like each part is whole by itself. It misses the point because you need to include them both' (p. 66). In other words, when humans conceive of themselves as something separate from soil, what gets lost is the larger and equally valid perspective where humans *are* humus.

Cajete (1999) articulated the lived experience of native people living under this dualism, which shows up as alcoholism, depression and many other forms, in very stark terms, 'Tewa people call this state of schizophrenic-like existence *pingeh heh* (split thought or thinking, or doing things with only half of one's mind)' (p. 17). But, Cajete (1999) doesn't believe that healing this split is the exclusive task of indigenous peoples; rather, 'it is also the task of others who consider themselves people of place' (p. 17), or perhaps people of the soil. According to Cajete (1999), even the word indigenous

> is derived from the Latin root *indu* or *endo*, which in turn is related to the Greek word *endina*, which means 'entrails'. 'Indigenous' means being so completely identified with a place that you reflect its very entrails, its insides, its soul.
>
> *Cajete (1999: 6)*

CONCLUSION

All human beings, even those living in modern, dualistic cultures, are indigenous to soil, with its microbiotic community finding expression in our entrails. Many recent Western understandings of soil belie that connection and, unfortunately, many attempts to reconnect humans and soil have

inadvertently recapitulated to the dualism that separate the two. Eco-psychology has the power to synergise the human and the soil, through its non-dualistic, non-anthropocentric and alternative epistemologies. This allows humans to connect *to* soil on its own terms, to have a holistic relationship *with* soil and to see humans *as* soil. But eco-psychology isn't the only system of thought that has the ability to do this. Buddhism, eco-feminism and multiple indigenous belief systems can also reorient human beings towards the non-dual, which is ultimately what I am advocating here: the ability to see humans as humus.

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6 A New Science from a Historical Figure
Goethe as Holistic Scientist

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CONTENTS

INTRODUCTION

It might seem odd, in a book about the cutting edge of agroecology, to look back to a historical figure. However, it is worth indulging this narrative because Goethe's scientific work sowed the seeds that may now be brought to fruition. In radically rethinking agriculture, we are rethinking our relationship with nature and with the world, and there are early indications of a holistic approach in Goethe's work that could guide us here. As an early objector to the mechanistic and dualistic direction that science was taking, he lived through a fulcrum period in Western history and created a different path, one that we could have followed and may still yet. To build a historical bridge between Goethe and the current discussion, I will also discuss Rudolf Steiner's research into Goethe and the example of Barbara McClintock's scientific work with maize.

Johann Wolfgang von Goethe's dates are 1749–1832, which place him chronologically at the watershed between the study of what was then called natural history and the new science of biology. His scientific approach countered both vitalism[1] and mechanistic ways of seeing the world which dominated the science of his time (Steiner, 1985: 92). Although most famous for his literary work, he believed his scientific endeavours were the most important (Seamon and Zajonc, 1998: 1), and there are many complete historical accounts of these contributions (e.g. Nisbet, 1972). The purpose here is not to repeat them but to contextualise key elements of his approach so that we can see why he might be relevant today.

Goethe's scientific work covers the areas of geology, meteorology, osteology and botany and the study of colour. He was also an early exponent of the history of science as a discipline in itself (Fink, 1991: 70). Working across a wide range of subjects seems strange to our ever-more specialised contemporary approach to science. Why would someone hop from one realm to another and risk being labelled a dilettante? Even in the late eighteenth century, this would have seemed to be spreading

[1] Vitalism has different versions, both ancient and modern, but in Goethe's time, it was characterised by belief that organic entities were infused by a mystical/imperceptible life force or spirit. It gained popularity and adherents as a bulwark against purely mechanistic views.

DOI: 10.1201/9780429440939-7

oneself too thinly to make any progress in any field of science. To understand this and to make sense of Goethe's scientific writings and discoveries, we have to understand him as embracing a form of holism, of seeing nature as one, and investigating sides of that whole in order to see it in its fullness.

In order to present a picture of his approach, I will focus on three aspects of Goethe's science: the rejection of an over-reliance on theory; the grasping of nature as being in flux; and the role of human faculties in understanding nature. In all of these aspects, he was neither representative of his own time nor foreshadowing the direction that science was to follow. Furthermore, although he did have an early fascination with alchemy, and draws on it in his literary work (Gray, 1952), what he was doing here was something new.

THE REJECTION OF OVER-RELIANCE ON THEORY

At the time that Goethe was writing, mechanistic, reductionist ways of thinking were becoming prevalent in society and science, and these were leading to impressive discoveries and inventions. However, for Goethe, these discoveries were often misunderstandings and science itself was being driven up a blind alley. One aspect of the practice of science on which Goethe writes extensively is the movement towards an over-reliance on theory. What happens is that we no longer see the phenomenon we seek to understand; we see only our own construct. As Goethe argued:

> Someday someone will write a pathology of experimental physics and bring to light all those swindles which subvert our reason, beguile our judgement and, what is worse, stand in the way of any practical progress. The phenomena must be freed once and for all from their grim torture chamber of empiricism, mechanism, and dogmatism; they must be brought before the jury of man's common sense.
>
> *von Goethe (1995: 309)*

Goethe is not saying that theory or hypothesis has no role in scientific investigation; he does, however, want to rein it in and sees it as a tool that needs very careful handling. Goethe rejects both the over-reliance on theory to determine what to look for and the habits of mind that construct phenomena in the way suggested by the preconceived theory. A strong example of this criticism can be seen in the following quotation:

> To rid the human mind of an hypothesis that has unduly restricted it, forcing it to observe erroneously and to combine falsely, to muse instead of seeing, to sophisticate instead of judging, is already to render it an inestimable service. Henceforth it sees the phenomena with greater openness of mind, in other relations and interconnections, orders them after its own manner, and once more gets the chance to err after its own manner, a chance that is invaluable if it soon succeeds in perceiving its error.
>
> *Goethe, Naturwissenschaftliche Schriften Vol 4, Part 2, cited in Heinemann, (1934: 68)*

The method by which one is to 'rid the mind' of constricting hypotheses is to approach the phenomenon from all directions. One of these directions will be prior hypotheses, but that is only one direction amongst many diverse approaches. Apart from the importance of a full investigation of the phenomenon as experienced by the scientist, there is also, as the latter part of the quotation reveals, the conscious attention to the action of theory, hypotheses and opinion on perception itself. Thus, the scientist has to investigate his/her own mind as well as nature to ensure that the necessary openness is maintained and to let the mental faculties be guided by nature.

Out of the many scientific works by Goethe across a range of fields, he finds certain principles that are evident in nature and these, for him, help to explain its endless creativity (Tantillo, 2002). Rather than having strict laws circumscribing what is possible, these four principles are better seen as ways of capturing the way nature does what it does. They are as follows:

Polarity: Goethe's term for the way nature is creative through the juxtaposing of opposites; it remains in flux by breaking apart and rejoining.

Intensification (*Steigerung*): Goethe's term for the way all of nature seems to be striving or overcoming itself through increasing complexity.

Compensation: This recognises that nature creates within limits; forms can develop and change, but they are always sacrificing something to develop something else; for example, adaptability is sacrificed for specialisation.

Generativity: This is the principle Goethe recognises to explain the way an organism's parts can work together or even compete, in some sense, to grow. For example, a plant can produce more of itself vegetatively or sexually and these two impulses are both working generatively and express an inner vitality in the plant. Goethe considers that an abundance of generativity suggests a radical freedom at work, as opposed to a hierarchy where certain parts direct development.

These principles operate for Goethe in the way that a theory or hypothesis operates, although they are, he maintains, found in nature, not created by scientists for their convenience nor to constrain or shape what we are seeing. If we approach nature as a machine, we will find machine-like aspects, not because nature is like a machine but because that is the lens we look through. These principles are for Goethe a means to capture something of nature for the human mind to grasp, but they are, like nature itself, ever malleable and undergoing change. One way to understand these principles is as guides for reasonable ways of adding the non-physical meaning aspects of a phenomenon, through contemplation of the phenomenon in the light of these principles.

ALL IN FLUX: TIME AND A SENSE OF MOBILITY

An aspect of Goethe's science that seems unusual for the time he was writing was his appreciation of nature as continuously in flux. The project of biology in the eighteenth and early nineteenth centuries was to catalogue and order nature. Nature was understood as created by God, and the human task was to know what was there and to order its objects into static tables. Taxonomy: Putting things in the right boxes was the order of the day. Goethe, as we see from the principles above, is more interested in nature as a whole and how it generates itself. Indeed, his first published scientific discovery in 1786 of the intermaxillary bone in humans upsets one of the most fundamental divisions: that between humans and other animals. This bone in humans is fused with the maxillary bone, whereas in other animals (even apes) it is freer. Goethe can see this fusing, as opposed to seeing one discrete bone, because his scientific question is not 'which box does it fit into?' but rather, how does dynamic nature shape bones? He was seeing the hard material of bones more fluidly without preconceptions driven by a theory that must separate humans. This fluidity was so new as a concept that Goethe needs to introduce a new term for it, and in 1796, he used the term 'morphology' for the study of the transformation of organisms (Jensen, 2019).

Morphology also suggests the need for a kind of lively apprehending, not only to see the whole form, but to understand it as a whole. The organic, for Goethe, has no fixed form (von Goethe, 1995: 64). Thus, the organism seen in everyday consciousness is not the organism as a living thing; to see this, we need to bring to it the sense of flux that it is engaging in.

With plants, the picture is even clearer. Unlike his contemporaries, Goethe does not stick to studying plants as dry preserved specimens in herbarium samples. As he discovers, particularly on his extensive and life-transforming trip to Italy (von Goethe, 1989), the way a plant grows reflects aspects of its environment such that there can be no stable sample of a plant – its size and development are shaped by where it grows. In *The Metamorphosis of Plants,* Goethe sets out his insight that the plant develops by transforming its material through time by shaping and reshaping itself. It does not unfold to a strictly determined plan, but it does express a vitality and a drive to develop and reach a point of fruition, when circumstances allow. His cryptic statement 'all is leaf' means that the plant substance, which might now be expressed as leaf, undergoes a transformation (akin to reproduction) to become the other plant parts: sepal, petal, carpal, stamen, etc. Nature's creative

process is visible to us once we shift our attention from static form to fluid process. This insight he attributes to encountering the discontinuous metamorphosis in the shape of leaves, which he first noticed with the dwarf palm (*Chamaerops humilis L.*) in the botanical gardens in Padua in 1786 (Arber, 1950: 42).

THE ROLE OF THE HUMAN BEING

The third aspect of Goethe's approach to science that needs some explication is the role the human being plays in scientific investigation. As Goethe says, to understand the whole as a metamorphosing possibility we need to 'remain as quick and flexible as nature and follow the example she gives' (von Goethe, 1995: 64). What does he mean by this exactly? The bridge that Goethe uses to make the sequential connection from one instance to another, from one leaf to another, from one plant to another, etc., is that of the human imagination. Rather than seeing human faculties such as imagination, or indeed intuition, as impairing scientific objectivity, Goethe sees these human faculties as the means to really understand nature. By allowing nature to work with the human faculties, he thought we can begin to see with the mind's eye and thus make connections and reveal the workings of nature that are not initially or easily apparent. For Goethe, the supersensible dimension would be that which we can see once we know how to look and bring that looking into our thinking, to contemplate and use the mind's eye (Stephenson, 1995: 13). He is resistant to the notion of a free-floating idea or concept that is not tied to, or indeed given by, the sense perceptible to the human mind through what seems like a shared contemplation (Stephenson, 1995). The observation and identification of key aspects of nature and an open contemplation of them helps to reveal nature as a whole, and this activity, in Goethe's view, is crucial for the progress of science. His use of the term *Anschauung* captures this well although it is not directly translatable. Agnes Arber,[2] commenting on Goethe's work, renders it as 'intuitive knowledge gained directly through contemplation of the visible aspect' (Arber, 1954: 122).

Goethe's lively discussion of philosophical problems with the activity of scientific investigation helps to fill out the picture of how he worked and what he thought was possible. Accounts of Goethe's own perceptual abilities abound (Amrine et al., 1987: 379), and he acknowledges that he was naturally very perceptive, but also believes in the development of one's faculties. It is clear that he thought the human sensorium was capable of improvement when he discusses the idea of scientific work opening 'new organs of perception'. 'The human being knows himself only insofar as he knows the world; he perceives the world only in himself, and himself only in the world. Every new object clearly seen, opens up a new organ of perception in us' (von Goethe, 1995: 39). The means to improvement was the exercise of looking at nature. He seems to invoke a cycle of looking at nature, examining oneself, looking at nature again and so on. The procedure then becomes a spiral of enhancing capabilities through experience and closer and closer relationship with the aspect of nature studied. For Goethe, this is the activity of science, he says: 'Insofar as he makes use of his healthy senses, man himself is the most exact scientific instrument possible' (von Goethe, 1995: 331). That sense of having to live into, to merge with, the thing studied comes through in his writing.

Thus, we have a scientist very alive to the problem of presuppositions and human tendencies to shape the world to themselves and yet endorsing faculties such as imagination and intuition to arrive at insights about the workings (or rather the being) of nature. To highlight that seeming conundrum, he talks of the kind of approach that is needed as a 'delicate empiricism'. He says, 'There is a delicate empiricism which makes itself utterly identical with the object, thereby becoming true theory. But this enhancement of our mental powers belongs to a highly evolved age' (von Goethe, 1995: 307). This delicate empiricism is *Anschauung:* where contemplation leads to intuitive insights by

[2] Agnes Arber was a twentieth-century botanist and philosopher/historian of biology who was an insightful interpreter of Goethe's scientific work.

allowing nature to speak because we have placed our faculties at her disposal. Such an enhancement would perhaps allow us to become, for a moment, that which we study, for example, to experience vegetative growth or even photosynthesis. Moreover, it allows us to bring the wider picture of relationships and forces in nature to bear on our perception.

To build a bridge between Goethe's time and our own, I will look at two separate developments. One is the connection between Goethe and Rudolf Steiner (whose work was the impulse behind biodynamic agriculture). The other is a twentieth-century scientist, Barbara McClintock, whose work highlights both attending to nature as in flux and the feeling capacities that the human being can bring to the scientific endeavour.

GOETHE, STEINER AND BIODYNAMIC AGRICULTURE

Biodynamics, as a cosmologically informed farming method, is discussed elsewhere in this book; the purpose of this section is to look at how Goethe informed Steiner's work. Rudolf Steiner claimed to have been, from childhood, able to perceive the supersensible world. As he grew up, he was able to discriminate between those perceptions that he could share with others and those that would draw blank looks. As a student in Vienna, the problems of equating the scientific theories he was being taught, such as the wave theory of light, with his own way of perceiving, became a problem; what he was expected to learn was in direct contradiction to his own perception. Starting from a firm belief that an unprejudiced examination of phenomena would yield the truth and thus solve these contradictions, Steiner began a detailed study of light and colour. Professor Karl Julius Schröer, who had already shared his enthusiasm for Goethe's poetry with Steiner, was able to see that the ideas this student was developing were close to those in Goethe's *Theory of Colours,* so he drew Steiner's attention to this text.

Thus began Steiner's lifelong interest and interpretation of Goethe's scientific work, which led to him being asked to edit Goethe's scientific writings for the *Deutsche National-Literatur* (Steiner, 1978). At that time, Steiner was also reading Schiller and drawing from him the idea of different stages of consciousness. Together, these ideas suggested to Steiner that the 'impassable limits' of science were only impassable in an ordinary state of consciousness. If other states could be actively schooled and used with the same rigour, as he believed to be foundational to science, then a science of nature that included the supersensible could be developed. For Steiner, Goethe was someone who showed how it would be possible to perceive something of this supersensible realm, not from natural clairvoyance, but by developing one's own faculties to understand the nature of physical phenomena. This would mean that the way was open for others to share in his way of seeing, and indeed by working through Goethe's method, Steiner was able to ground his own supersensible perceptions as part of his development.

It is, of course, valid to ask if Goethe saw glimpses of the same world. Some historians, such as Karl Fink, see in Steiner's work on Goethe a one-sided or overemphasised view which does not equate with the bulk of Goethe's scientific work (Fink, 1991). Steiner's work certainly developed Goethe's scientific insights, yet there were already features such as a living richness and a clear divergence from the mechanistic/reductionistic orthodoxy, plus a new working method. Steiner's interpretative work of the scientific works of Goethe is a key inspiration for contemporary Goethean scientists, such as Craig Holdrege (2013), Jochen Bockemühl (1985) and Arthur Zajonc (1998). Goethe's science, in particular his way of approaching phenomena with the human faculties operating in a disciplined 'objective' way – a form of schooled subjectivity – is emphasised repeatedly in the various fields developed out of Steiner's spiritual science, which he called anthroposophy, including Waldorf education, anthroposophical medicine and, of course, most relevant here, biodynamic agriculture.

Thus, there is a clear lineage between Goethe and biodynamics through the work of Steiner, but a lineage should not be necessary. If Goethe is right that the best method of working is drawn from the phenomena themselves, it should be possible to stumble upon this way of working simply by trying to work with whole plants and one's full human faculties. In this last section, I want to examine just such an example.

BARBARA MCCLINTOCK'S UNDERSTANDING OF ORGANISMS

Barbara McClintock's work on maize in the 1940s–1950s, as presented in Evelyn Fox Keller's 1983 biography *A Feeling for the Organism*, shares many features of a Goethean approach. Both the way she went about her work and her concept of the task of science could be described as Goethean. The key similarity, which she so clearly exemplified, was her aim and her ability to 'get to know' the organism with which she worked. It is this aspect of her approach that I will primarily focus on.

Barbara McClintock's career spans many changes in the field of genetics. When she began her life in science, the maize plant was the preferred plant for looking into the action of genes. The colours of the kernels on a cob of maize display genetic traits very clearly. Thus, a yearly crop of this higher plant was seen as the obvious choice for study in an older style of biological research that still focused on the whole organism. Although the study of genetics then moved on to the examination of simpler organisms, with more rigid theoretical models about the behaviour of genes, McClintock continued to study maize. Her determination to stick to a complex organism and older styles of research (1983: 101) was finally vindicated when her work became widely acknowledged as a 20-year precursor of where genetics had reached by the late 1970s. In 1983, she was awarded the Nobel Prize for her work on gene transposition.

As an examination of the pressures at play in the world of science, McClintock's story is an interesting one. However, here her story is used as an example of someone working with a plant for decades and coming to know it. Fox Keller asks the question 'What enabled McClintock to see further and deeper into the mysteries of genetics than her colleagues?' She answers that question with the following:

> Her answer is simple. Over and over again, she tells us one must have the time to look, the patience to "hear what the material has to say to you", the openness to "let it come to you". Above all one must have "a feeling for the organism".
>
> *Fox Keller (1983: 198)*

McClintock's work involved the microscopic examination of chromosomes, but her trips to the field to gather the cobs to be tested allowed her the opportunity to 'guess' what their later examination would show. She became adept at 'seeing' in the plant what a microscopic examination would later reveal. The kind of seeing she recounts was not fully conscious:

> It is done with complete confidence, complete understanding. I understood every plant. Without being able to know what it was I was integrating, I understood the phenotype.
>
> *Fox Keller (1983: 103)*

It could be suggested that she was, through her engagement with the plant, 'developing new organs of perception'. McClintock's experiences with maize demonstrate the ideal of really engaging with the phenomenon: engaging not just with the end product on the bench, but with the living organism in its context through its whole cycle, many, many times.

Her ability with this one plant could also be seen as a training of her observation powers in general. Once she knew she could trust the intuitive flashes of insight, she could apply her abilities to a new problem. In 1944, she helped a colleague by working for a time on a mould (*Neurospora*) with chromosomes so small that they had not been individually identifiable. Once in her stride with this new organism, McClintock was able to work with it, and her account, reported by Fox Keller is revealing in terms of living into the organism. She said:

> I found the more I worked with them the bigger and bigger [they] got, and when I was really working with them I wasn't outside I was down there. I was part of the system. I was right down there with them, and everything got big. I even was able to see the internal parts of the chromosomes—actually everything was there. It surprised me because I actually felt as if I were right down there and these were my friends.
>
> *Fox Keller (1983: 117)*

Once connected to the new organism in this way, she could recognise and follow the development of chromosomes through the meiotic cycle.

However, McClintock's credentials as a scientist, whilst eventually vindicated by her results being corroborated by others, were sometimes doubted. She was working against the flow of developments in genetics and was seen as personally eccentric. If we examine her outlook on science in general, it is possible to find other resonances with Goethe's approach. I shall briefly outline five points that demonstrate a concurrence in their approaches to science which could explain why McClintock's 'feeling for the organism' sounds 'Goethean'. These are as follows:

1. *The Recognition of Models as Models*: McClintock was resistant to what she saw as the dogmas in genetics. Examples of these would be the following: the integrity of genes; the usefulness of bacteriophage because it is simple and one can apply the laws revealed to complex organisms; and the inability of the environment to affect the genome. She had a deep mistrust of theoretical models when they are used as more than, as Goethe would say, the temporary scaffolding. As Fox Keller explains:

> For McClintock it was what she calls "tacit assumptions"—*an* explicit adherence to models that prevents people from looking at data with a fresh mind. These tacit assumptions impose unconscious boundaries between what is thinkable and what is not. Even glaring lapses in logic become invisible: "They didn't know they were bound to a model and you couldn't show them".
>
> *Fox Keller (1983: 178)*

2. *An Openness of Approach*: Not only was McClintock open to the organism as a part of her practice, but she also advocated a more open approach to other ideas as necessary for science. This is particularly clear from her criticism of her colleagues' dismissal of a presentation on extrasensory perception. She said, 'If they were as ignorant of the subject as I was, they had no reason to complain' (1983: 202).
3. *Dealing with Whole Organisms*: The holism of her approach can be seen in the way she professed to a strong sense of the oneness of all nature. On a practical level in her work with the whole cycle of the plant, the sense of engagement with a continuous process comes through. She felt that it was an important aspect of science that one had the wider picture. 'Basically everything is one. There is no way in which you draw a line between things. What we [normally] do is to make these subdivisions, but they're not real' (1983: 204).
4. *Using an Emotional Engagement with Phenomena*: Part of the openness to the organism which she cultivated was dependent on an emotional engagement with the object of study, but also a distancing of self. The exacting rigour of her work seems to come from a respect for the organism studied rather than an idealised distancing of the 'less objective' aspects of the scientist. Of the creative points in her life, the intuitive flashes, she says that they come about with an emotional intensity and a losing of one's self. It is as if, as she says, 'I am not there'. An account of the experience which Fox Keller cites is as follows:

> Beneath these trees she found a bench where she could sit and think. She sat for half an hour. "Suddenly I jumped up, I couldn't wait to get back to the laboratory. I knew I was going to solve it"… She doesn't quite know what she did as she sat under those trees. She remembers she "let the tears roll a little", but mainly, "I must have done this very intense subconscious thinking. And suddenly I knew everything was going to be just fine".
>
> *Fox Keller (1983: 115)*

5. *Putting Process into Observations of a Static System*: Her understanding of the maize plant was aided by her approach to it as a whole, developing, growing organism. Seeing

> things in process rather than as static results perhaps contributed to her ability to see genetic processes as dynamic, as life in the process of living, rather than as mechanism. Fox Keller provides an account of her watching the meiotic cycle of the Neurospora.
>
> > Her description of what she had seen 35 years earlier still today holds a vivid narrative quality. It is easy to forget that she had to reconstruct the process from separate slides, that she did not see it unfolding in 'live action' (1983: 115).

These five interlocking points demonstrate the extent to which McClintock's approach to science and the way she explores phenomena share something of the Goethean approach without, as far as is known, any direct lineage. She was simply trying to understand the organism and not following trends in science that, to her, seemed to be getting in the way.

CONCLUSION

We have seen from the preceding sections that Goethe was able to bring together careful observation of the sense-perceptible aspects of a phenomenon with the supersensible aspects as revealed by a schooled use of the imaginative and intuitive faculties that are themselves informed by the sense-perceptible phenomenon. Historically speaking, this is important as it avoided the errors of two conflicting approaches that were informing the science of his time: vitalism and the mechanistic approach. For Goethe, vitalism gives away the self-generative power of organisms and of nature herself to a vague mystical idea of some free-floating force and is thus a kind of obfuscating mystery mongering, whereas the mechanistic approach ignores the complexity of the intertwined relationships in nature and denies the generative power of organisms in their full majesty. Science, as it developed from the eighteenth and into the nineteenth centuries, rejected vitalism and embraced mechanism with gusto. This ignored the possibility that other options were available.

To address the problems we face in the twenty-first century, we need a way of working with nature, one that does not destroy it or replace it with some limited imaginings. The approach of Goethe and of those who continued developing his insights and carrying out his suggested method of working could have much to offer. In a later chapter, I set out what that method is and how one might examine a phenomenon to develop 'new organs of perception' such that we could have 'delicate empiricism' as a practical approach to researching a more holistic variant of agroecology.

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7 From Quantum Biology Towards Quantum Consciousness

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CONTENTS

INTRODUCTION

Today, perhaps the most dynamically expanding branches of science are genetics and molecular and cellular biology, which are amassing impressive reams of data well ahead of scientists' capacity to fully analyse it all. Computational biology is emerging gradually as a response to the challenge of big data analytics. Quantum biology, on the other hand, is positioning itself to explain not so much the huge amounts of data but, like physics a century ago, a limited number of important, yet poorly understood phenomena such as photosynthesis, bioenergetics, vision, olfaction and bird navigation. Yet, the grandest challenge of all is to explain how the human brain works and, in particular, how conscious behaviour emerges from the structure and function of the human brain and its cellular and sub-cellular components. In this chapter, I revisit some historical issues in the development of quantum physics and then look at the emergence of quantum biology and finally quantum consciousness, aiming to provide new insights into these topics from both a physical and a historical perspective.

The birth of modern physics can be traced back to the reluctant introduction of what turned out to be a fundamental constant of nature, the so-called Planck constant, i.e. $h = 6.6 \times 10^{-34}$ Js. Its introduction in an energy quantisation formula was the only solution to the problem of the heat emission spectra experimentally determined for physical objects at various temperatures. Max Planck postulated that these spectra originate from a discrete nature of energy levels in physical systems that can be quantised by the general relation:

$$E_n = (n + 1/2)hf \tag{7.1}$$

where n enumerates the energy levels and f is the characteristic frequency of internal oscillations. This led to a revolutionary transformation of physical principles departing from the mechanistic laws of Newtonian physics to provide wave function descriptions of quantum physics that were developed in the decades that followed. In quantum physics, objects possess both a wave aspect and a particle aspect, a view of the physical world known as the principle of wave–particle duality, or

DOI: 10.1201/9780429440939-8

complementarity. According to the Copenhagen interpretation of quantum mechanics, all the information about a particle or a system of particles can thus be described in a wave-like manner that is denoted mathematically by a wave function, $\phi(x, t)$. However, wave functions behave like waves and can diffract, and interfere together forming superpositions, implying that quantum particles simultaneously exist in multiple spatial locations and states. When a measurement is made, one of the multiple states is chosen and the quantum superposition of states ends being reduced to a classical state in a process known as the collapse of the wave function.

While quantum mechanics was developed with elementary particles in mind, its subsequent applications extended its validity to systems of many particles such as those encountered in condensed matter physics, e.g. in the description of the conduction electron 'sea', excitons, magnons, polarons, polaritons, etc. These types of quantum properties of macroscopic physical systems are called collective excitations. A system of many particles under specific conditions cannot be separated into individual wave functions for each particle; rather, the system is described by a single wave function describing its collective behaviour. This physical property is called quantum coherence, and it is characterised by individual particles losing their separate identities so that the entire system acts as a whole. Particles that were once unified in a common quantum state remain physically connected even at a distance. As a consequence of the collective behaviour of many-body systems, hallmarks of quantum mechanics can be seen in the properties of macroscopic objects such as crystals or ferromagnets, even above room temperature. There are also more exotic direct manifestations of quantum behaviour in macroscopic systems such as superconductors (with no measurable resistance to electrical current and ideal diamagnetism) or superfluids (with no viscosity and infinite vorticity). However, these latter two examples have so far been limited to very low temperatures. The precise location of the boundary (in terms of both the object's size and ambient temperature) between quantum and classical regimes is still under debate.

FROM QUANTUM CHEMISTRY TO QUANTUM BIOLOGY

Extensions of quantum mechanics to chemical compounds and chemical reactions proved to be exceedingly successful, and an entire field of quantum chemistry was developed as a consequence. In order to understand the creation of chemical bonds, especially covalent bonds in which electrons are shared between atoms of a molecule, a quantum mechanical wave function was introduced into the formalism as one of the postulates of quantum mechanics. All chemistry, including biochemistry, is based on the creation and destruction of bonds between atoms and hence on quantum interactions. Hence, by extension the structural stability of all living systems, like non-living systems, depends on quantum states at the level of chemical bonds. However, the quantum effects are commonly claimed to be washed out due to decoherence taking place at scales larger than individual atoms or sub-atomic particles, at higher temperatures and in aqueous media, which provide a noisy environment for particle interactions. Thus, the likelihood of quantum states playing functional roles at macroscopic scales in 'warm, wet and noisy' biological systems seems problematic due to environmental decoherence effects. On the other hand, it is reasonable to expect that evolution, through the process of natural selection over billions of years of experimentation and countless parallel attempts of trial and error, may have solved the decoherence problem so that quantum states may be essential features of biological systems (Rosa and Faber, 2004).

Erwin Schrödinger, Niels Bohr, Werner Heisenberg, Eugene Wigner and their contemporaries all offered speculations about quantum effects in living systems, while Schrödinger's famous book *What Is Life?* (Schrödinger, 1944) actually paved the way for the birth of molecular biology in the 1950s. What is still very much a mystery, however, is the perfect synchronisation of biological processes across spatial and temporal dimensions that connect the hierarchical organisational scales of a living system. Here, quantum mechanics may indeed come to the rescue, if only we could explain the required absence of decoherence.

Unfortunately, biological systems are so large and complex compared to standard physical systems that it is hard to separate 'pure' quantum effects from a large number of essentially classical processes that are also present. Thus, there is plenty of scope for disagreement about the extent to which life utilises non-trivial quantum processes. Given that the basic processes of biology take place at a molecular level, employing quantum effects for greater efficiency does not seem *a priori* implausible. Quantum coherence, collective modes of excitation and condensation phenomena, also offers attractive features that could shed light on the mechanisms of robustness and integrity of biological organisms. However, it is reasonable to expect that some of life's processes have evolved to the 'quantum edge', where a compromise may be struck between speed and accuracy. Since both physics and chemistry crucially depend on the power of quantum mechanics to provide fundamental insights into the world around us, it is natural to inquire whether biology offers examples of phenomena where quantum mechanics is the only viable explanation. This is indeed becoming increasingly clear, although examples of quantum effects in biology can so far be considered only a minor part of life processes as we know them.

G. Albrecht-Buehler (1992) found by clever experimentation that living cells perceive infrared electromagnetic waves with the peak of their sensitivity close to the wavelength of 1,000 nm. He hypothesised that mitochondria, by proton transfer involved in energy production, release photons. Conversely, centrioles, dubbed by him the eye of the cell, are intricately structured to absorb these photons and trigger a signalling cascade. G. Albrecht-Buehler has been advocating a theory of cell functioning based on his conviction that the centriole plays the key role in orchestrating cellular activities by being both an eye and a brain of the cell. Cell movement is not random but directed and intentional. This is a crucial characteristic that distinguishes living from non-living matter. Cells control the movement of every part of their body. Furthermore, various parts of the cell can be likened to parts of the human body in their functional roles. Plasma membrane and cortex correspond to the skin and the musculature of a cell, which consists of small autonomously moving 'microplasts'. Their autonomy implies that cells contain a control system preventing the autonomous units from moving independently and randomly. The bulk cytoplasm including the mitochondria, organelles and intermediate filaments comprises the actual cell body excluding the nucleus, and corresponding to the 'guts' and 'innards' of the cell body. Its main cytoskeletal components are the intermediate filaments although microtubules (MTs) traverse this compartment everywhere. MTs mediate between the control centre (the centriole) and the autonomous domains. The control centre detects objects and other cells by pulsating near-infrared signals. Cells have structures functioning essentially as their 'eyes' in the form of centrioles. They are able to detect infrared signals and steer the cell movements towards their source. Evidence has been put forward that the signal detection is strongly localised in a narrow band of the near-infrared spectrum. If cells can detect light sources and measure space and time variables such as angles, distances, curvatures or durations, they must be able to derive these abstract quantities from the physical objects or signals of their environment. In response to exogenous signals, the centrosome may send destabilising signals along its radial array of MTs. The observed destabilisation is the signal that is propagated along the MTs like along nerves.

Engel et al.'s 2007 study of photosynthesis was a game-changer in the emerging field of quantum biology. Photosynthesis is a highly complicated and sophisticated mechanism that harvests light energy to split water by using individual photons to create a cascade of reactions. The process is extraordinarily efficient and represents a classic example of how evolution has fine-tuned the design of a physical system to attain near-optimal performance. The primary receptor of the light energy is a complex of pigment molecules known as chromophores that can become excited, and pass on the energy of excitation in a multi-stage process to the final reaction centre where charge separation occurs. Because the wavelength of the photon is much larger than the molecular assemblage, a superposition state of many excited pigment molecules is initially created and proceeds to evolve over a timescale of some hundreds of femtoseconds. Fleming and his group (Engel et al., 2007) used laser excitation and probe pulses to study the relaxation pathways of these light-harvesting

complexes and observed a 'quantum beating' effect in which the maximum amplitude of the excitation visits and revisits different molecules in the system coherently. Fleming claims that, with appropriate timing, the system can 'grab' the coherent excitation (which persists for a few 100 fs) with greater probability than if it was merely distributed according to classical statistical mechanics. He believes this could lead to a multiplying of the speed of the energy transfer. An important feature of photosynthesis is that the molecular architecture involved is structured in a highly unusual and compact manner, suggesting it has been 'customised' to exploit long-range quantum effects (Blankenship and Engel, 2010). It could be that the particular configuration is efficient at preserving coherence for surprisingly long durations, enabling the system to 'explore' many pathways simultaneously and thus speed up a 'solution' (i.e. delivering energy to the reaction centre). In the light-sensitive complexes, reaction centres capture individual photons and transfer exciton energy by tunnelling avoiding decoherence even at room temperatures, which has been invoked on numerous occasions as a serious impediment to quantum biology (Tegmark, 2000) but also defended on various grounds (Hagan et al., 2002).

Beck and Eccles (1992) argued that the process of neurotransmitter release in the functioning of synapses is governed by the quantum uncertainty principle and involves quantum tunnelling. They further suggest that the introduction of quantum indeterminacy into neurotransmitter release mechanisms would allow for human free will of action. Their notion is that a quantum process, such as an electron tunnelling through an energy barrier, triggers exocytosis. The sheer size of the vesicle and the large number of neurotransmitter molecules contained in it make it next to impossible to lend itself to quantum tunnelling processes. Although the Beck–Eccles model contains very attractive ideas, the crux of the theory is incompatible with the present-day molecular biology of vesicular neurotransmitter release (Smith, 2009). Lowenstein (2000) made a powerful argument for the usefulness of quantum processes in receptor functions involving molecular recognition. All sensory inputs depend on this type of activity (olfaction, vision, sound, touch), and they all involve single molecules being triggers for amplification of these signals up to the neuron level and eventual brain activation. This amplification mechanism of the quantum signalling connects the microscopic and macroscopic levels which is critical to our understanding of the binding problem.

At the level of organs and tissues, it has been demonstrated that the human eye is capable of detecting light at an extremely low threshold, perhaps as few as two to three photons at a time (Hecht et al., 1942). Similarly, recent work by L. Turin, M. Stoneham and collaborators (Brookes et al., 2007) has provided strong support to the claim that the sense of smell (olfaction) is based on a quantum resonant energy transfer mechanism involving vibrational degrees of freedom of aromatic molecules and receptors in the membranes of olfactory nerves.

Special attention must be paid to the structural hierarchical organisation of biological systems, which in turn translates into an interlocking hierarchy of timescales. Faster timescales may inform processes at slower timescales about rapid processes taking place at a small spatial level. Amazingly, neural rhythms operate on timescales that vary from milliseconds to seconds, synchronise the forebrain and are mediated by neurotransmitter systems such as acetylcholine, norepinephrine and serotonin (Woolf et al., 2010). The neurotransmitter systems further fluctuate according to endogenous, circadian rhythms that also fluctuate according to the season of the year, which ultimately leads to an enormous range of timescales spanning between eight and ten orders of magnitude. Since neural events at the millisecond timescale can affect neural states at the circadian level, by extension it is entirely possible that quantum states at the picosecond scale could affect neural activity at the millisecond scale and above. Coupling between scales and amplification effects may offer a solution to some of these issues.

TOWARDS QUANTUM CONSCIOUSNESS

Does study of consciousness belong in the realm of natural sciences or is it a philosophical or even metaphysical area of inquiry? These questions have been pondered by many scientists, philosophers and spiritual leaders whose opinions diverge largely due to the subjective nature of consciousness.

Obviously, the existence of this phenomenon cannot be denied as we all experience it as sentient humans. The author of this chapter firmly subscribes to the point of view that not only is consciousness a valid topic for scientific research but, in fact, it is also one of the most important unsolved scientific problems of our time. The problem of consciousness has defied conventional approaches, which view the brain as a classical computer, with neurons and synapses playing the roles of bit states. Specifically, the following enigmatic features remain unexplained: (1) the 'hard problem' of the nature of conscious experience, for example addressing the experience of 'qualia', our inner life; (2) the binding of disparate brain processes into unified concepts, objects and sense of self; (3) transition from preconscious processes to consciousness itself; (4) free will, or non-algorithmic (e.g. intuitive) processes; (5) the subjective flow of time; and (6) non-locality, i.e. paranormal connections between humans and also between humans and non-human species across large spatial and temporal domains (e.g. precognition, telepathy). Conventional neuronal-level computational approaches suggest conscious experience 'emerges' at a critical level of computational complexity. Binding is proposed to be accounted for by temporal synchrony (e.g. coherent 40-Hz oscillations) but, with no sense of the nature of conscious experience, temporal synchrony is merely correlative rather than explanatory. Perhaps the most potentially tractable problem is the transition from preconscious processes to consciousness itself. It is generally agreed upon that the vast majority of brain processes are non-conscious and that consciousness is the tip of an iceberg of brain activity. However, no specific brain area houses consciousness; neural activity in a given area may be non-conscious at one moment and correspond with consciousness at another. The classical approach suggests a critical level of computational complexity results in the transition via the emergence of consciousness, but again no threshold, biological correlate nor testable prediction has been put forth. Free will, subjective time flow and non-locality have not been seriously addressed by conventional approaches. Another shortcoming of conventional approaches is that neurons and synapses are considered as simple switches, whereas real biological cells are far more complex. For example, single-cell organisms such as *paramecium* swim, avoid obstacles and predators, learn, and find food and mates, all without possessing a single synapse. These cognitive functions can potentially be accomplished by the cell's cytoskeletal structures, primarily MTs.

Perhaps the first attempt to describe the brain using the terminology of quantum physics was made by Ricciardi and Umezawa (1967). Based on experimental observations of brain activity, they proposed that the brain could be conceived of as a spatially distributed system placed into particular quantum states by stimuli from the external environment. Thus, information can be thought of as being coded into the brain in the form of metastable excited states representative of short-term memory. This code would then be later on transferred to the ground state of the system by in the manner of Bose–Einstein condensation, which would account for learning and long-term memory. This model proposes that brain functions are manifestations of spontaneous symmetry breaking in the dynamics of the brain and regulated by long-range correlations. The model put forth by Ricciardi and Umezawa (1967) relating macroscopic quantum states to brain function, specifically memory, was later extended by these authors who proposed that the brain is a mixed physical system. In this model, the brain is considered to consist of two distinct interacting parts, the first part where the classical electrochemical interactions of the neurons of the brain occur, and the second being the macroscopic quantum state responsible for the creation and maintenance of memory.

R. Penrose (1989, 1994) hypothesised that quantum effects play a fundamental role in human consciousness by enabling the brain to perform non-computable computations. In his explanation of how the new physics can explain the mind and consciousness, he examined the division between classical and quantum physics, specifically the measurement problem, and related the collapse of the wave function to conscious events using the notion of objective reduction. This led to the suggestion that MTs within neurons provide the brain with structures capable of orchestrating the collapse of the wave function via quantum computations. This combination has become known as the Penrose–Hameroff orchestrated objective reduction (Orch OR) theory (Hameroff, 1998; Hameroff and Penrose, 2014). The basic idea on which Orch OR rests is that MTs within the brain's neurons

function as quantum computers, with MT protein subunits (tubulins) existing transiently in quantum superposition of two or more conformational states (i.e. as quantum bits, or 'qubits'). The quantum state reductions yield conscious perceptions and volitional choices, which then govern neuronal actions. This is essentially the same idea on which technological quantum computing is based, except that in Orch OR the proposed qubits are tubulin protein conformations, and the reduction/collapse occurs due to a specific objective threshold (objective reduction) rather than environmental interaction. The theory considers a conscious event as a quantum computation, which concludes via objective state reduction. The biological conditions in the brain, including synaptic activity, are considered to influence the quantum computations, thus orchestrating the collapse of the qubits and giving rise to a conscious event. 'Orch OR' is an attempt to place consciousness within the empirical sciences as a fundamental concept in science. The central postulate of the Orch OR theory is that the site of action of consciousness is located within the brain's MTs which operate at the interface between classical neurophysiology and quantum gravitational forces. These are very bold claims that have found both ardent supporters (Stapp, 1995) and vocal critics (Seife, 2000) in the scientific community.

There have been many debates concerning whether the quantum description of consciousness is valid, realistic or needed. However, only recently have advances in nanotechnology been made, allowing for serious empirical investigation into the biophysical workings of sub-cellular structures. As such, the lack of evidence in support of quantum brain theories should not be taken as proof against these theories, but rather as an area in need of careful and vigorous scientific investigation. The several enigmatic features of consciousness are still, for the most part, left unexplained by classical theories. The apparent ability of quantum theories to answer these questions may provide new avenues of investigation into consciousness. Macroscopic quantum phenomena such as superconductivity, and superfluidity need to be highly isolated from their environment in order to avoid the effects of decoherence. In order for such phenomena to exist in the brain, nature would need to provide mechanisms to isolate against decoherence. Clearly, these issues are not completely resolved. Thus, investigations into the quantum nature of MTs are still badly needed.

Empirically, a host of studies indicate that the MT matrix in dendrites is structurally reorganised with learning and memory. Using an associative learning paradigm combined with immunohistochemistry, fear conditioning either to tone or to the training context induced significant changes in MT-associated protein (MAP2) in circumscribed regions of the cerebral cortex or hippocampus, with alterations correlating with the type of training (Woolf et al., 1994, 1999). In terms of molecular biophysics, based on their ability to propagate signals through the neuron, MTs and actin filaments can be viewed as computationally relevant nanowire networks that operate within neurons (Woolf et al., 2010). Rather than inputs to neurons being limited to causing discrete responses, this viewpoint offers the possibility of local and global neuroplasticity, based on the cytoskeleton computing and storing templates that translate patterns of inputs across widespread synapses into the 'behavioural' output of the neuron. This behavioural output of the neuron is not limited to axonal firing and dendritic integration of electrochemically mediated inputs. Instead, it includes connecting the cell nucleus with the postsynaptic density, initiating transport of receptor molecules, membrane proteins, organelles and mRNA, regulating neurite motility, restructuring of spines and complex dendrite architecture, the lateral movement of receptor and membrane proteins of neurons, and governing the availability of ion channels in the membrane.

FUTURE OUTLOOK

I foresee major progress in bridging the gap between nanoscience and consciousness in the area of nano-neuroscience where MTs, actin filaments and motor proteins connect between neurophysiology and molecular biology. Studying neural phenomena at a nanoscale could lead to monumental breakthroughs in science and medicine and aid in consciousness studies. Further possibilities involving physically based quantum mechanisms of consciousness should also be considered. The

basic idea is to investigate if there are other quantum network architectures that could be operating in the brain. First of all, quantum entanglement in such a network could provide at least a partial answer to the binding problem of consciousness allowing for a delocalised quantum state involving many neurons. This requires a thorough understanding of quantum networks. It is worth emphasising that quantum networks may lead to quantum memories, whereby entangled states store information such as visual inputs. Moreover, quantum networks could generate communication channels that would transport information and process it performing complex operations. Quantum computation in the brain (Litt et al., 2006) would surely be beneficial from an evolutionary standpoint, and biology has had 4 billion years to solve the decoherence problem.

Recently, an interesting proposal was put forward suggesting direct involvement of nuclear spin in long-lived quantum states attributed to consciousness in the human brain (Fisher, 2017). However, several challenging issues remain to be addressed. First of all, due to thermal fluctuations, a magnetic field of sufficient strength would be required to prepare the spin system in a pure enough state. On the other hand, there are no naturally occurring large magnetic fields and we also know that strong magnetic fields such as in magnetic resonance imaging (MRI) machines do not have a significant effect on the state of consciousness of the person subjected to MRI scans. Regarding quantum communication channels, photon emission and absorption is the best candidate mechanism for such phenomena. Biophotonics is an emerging field in spite of its long history of false starts and intermittent periods of dormancy. A recent review (Cifra and Pospíšil, 2014) summarises the landscape in this field, emphasising a relatively narrow range of wavelengths playing a role in biophotonics, namely between 350 and 1,300 nm. The generation of photons inside living cells is mainly related to recombination of reactive oxygen species. It is also interesting to consider signal amplification and transmission over macroscopic distances along axons and dendrites of neurons. The tenuous connection between quantum biology, consciousness and electromagnetic fields, if properly supported by precise experimental investigations, could become a nexus for rigorous explorations of how our brain operates beyond the confines of conventional neuroscience.

Understanding the biological basis for sustained quantum coherent superposition and entanglement would not only help solve the enigmatic features of consciousness, but also enable future quantum information technologies.

ACKNOWLEDGEMENTS

The author acknowledges funding support for his research from NSERC (Canada).

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8 Healing Our Relationship with Gaia through a New Thrivability Paradigm

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CONTENTS

INTRODUCTION

Our worsening climate crisis, biodiversity loss and increasing societal challenges are all clear indicators that it is time for us to wise up and grow up. It is essential that we become conscious that the *growth models* that we have adopted for, and which shape, our developmental trajectories are not only unsustainable, but also imminently catastrophic. The resounding calls for a *new paradigm* with *new norms* are accelerating in strength around the world, even more so in the light of our current – at the time of writing – coronavirus crisis. However, underlying each paradigm is a growth model, and unless this model is also transformed, the shift in paradigms will be limited and not generate new patterns for our collective thrivability.

The pursuit of *growth* in the economic domains has typically taken place via policies that only measure the quantitative aspects of growth, leading to extractive and unsustainable practices. In response, calls for degrowth are becoming more widely heard from sustainability movements. What is often missing in the discussion, however, is a deeper evaluation of what we mean by growth. Our usage of the word growth goes beyond the narrow conventional meaning that indicates an increase in size or quantity. We propose to emphasise the *qualitative aspects* of growth that are also developmental, as can be seen in the growth dynamics of living systems. Such growth often results in asymmetry, owing to structural changes between the variables that result from the new growth, which can temporarily perturb the balance of the system. Living systems are responsive, and it is precisely this shift in systemic balance due to growth changes that activates its learning and development. Living systems respond to emerging asymmetries through the formation of new organisational dynamics that enable the system to regulate and adjust to the changes. The formation of new balancing loops and informational flows is a process of systemic learning and development.

DOI: 10.1201/9780429440939-9

Development over larger scales and longer time horizons can thus become an evolutionary growth process (Smitsman and Smitsman, 2020).

Our mainstream growth models have a tendency to focus only on the quantitative dimensions of growth, based on a mechanistic and dualistic worldview of the reality of life and the process of evolution. Instead of seeing life as a unified, interdependent and interconnected reality, life is perceived in a dualistic manner in which the external and internal are regarded as separate realities, and where the world is seen in terms of random events of separate particles. This mechanistic worldview also has a tendency to create extractive degenerative growth dynamics and constantly polarised, win–lose divisions, which have brought not only us but also millions of other species, and even possibly the entire biosphere of Gaia, to the brink of extinction.

Over the last 50 years, we have reduced biodiversity by half (IPCC, 2018; WWF, 2018). The anthropogenic damage to our planetary ecosystems, biodiversity resilience and climate systems extensively evidences that we are triggering the sixth mass extinction event in our planet's history (Meyer, 2019). The recent renaming of our age from the Holocene to the Anthropocene (Zalasiewicz et al., 2016), due to the irreversible human impacts on the geosphere and biosphere of our planet, indicates the urgency for seriously examining how to change our societal models (Bauer and Ellis, 2018).

In order to transform our growth and development models, and our mechanistic, separatist systems, we first need to become aware of and address our dualistic relationship with food and the ecology of life (Haukeland, 2013; Smitsman et al., 2019). The concept of sustainable development was initially adopted to address the impacts of these mechanistic systems, with the Brundtland Commission of 1987 coining the term and defining sustainable development as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Brundtland et al., 1987: 1). Through the years that followed, the concept of sustainable development expanded to include the safeguarding of the Earth's life-support systems on which the welfare of current and future generations depends (Griggs et al., 2013). Whilst this focus on safeguarding is important, it does not invite people to participate in a transformational change process that invokes their own evolutionary development.

We therefore offer the concept of thrivability, or our ability to thrive, as the transformational change process that invites people into a generative and evolutionary model that is both life-centred and future-oriented. To better understand what we mean by thrivability, we offer the following definition by Anneloes Smitsman, based on her PhD research on this topic:

> Thrivability is the Life-intrinsic developmental potential for our self actualizing evolutionary growth. Thrivability as a developmental potential unfolds through an ecosystemic evolutionary learning process. Through this process we develop the future creative capabilities, awareness, and love to enact and embody the actualization of the thrivability potentials within the worlds and systems of which we form part. Embodied, these potentialities become possibilities for further growth and development in a way that is Life generative and creates conditions for each of us, and Life as a whole, to thrive.
>
> *Anneloes Smitsman (2019: 37)*

A thrivability growth model, as will be explained further in greater detail, seeks to safeguard and strengthen the vital conditions of life that should never be sacrificed in the pursuit of food and resource development. With a broader focus, thrivability also invites us to explore the conditions and qualities of food cultivation systems and consumption patterns that honour and support our reciprocity, mutuality and inter-being with Gaia and the larger ecology of life.

THE COST OF CONVENTIONAL PROGRESS

When considered from an ecological whole-system perspective, the question 'what are progress and success?' provides a very different focus and narrative compared to how it continues to be defined by our mainstream economic, political and educational systems (Brewer and Smitsman,

2018; Smitsman, 2019; Wahl, 2016). When we look at living systems, the feedback and feedforward informational loops support the overall thrivability of the whole system in a way that is both collaborative and actualising of consciousness; i.e., it is evolutionary coherent and developmental (Capra and Luisi, 2014; Laszlo and Laszlo, 2016). This is in stark contrast to many of our current societal systems where their progress, development and success come at a huge cost to its members and the environments from which it draws its resources (Scharmer and Kaufer, 2013; Korten, 2015). This cost is still not accounted for, even though international frameworks such as the Global Reporting Initiative (GRI) and Integrated Reporting (IR) are making it possible to broaden the capitalist model and report not only on the financial impacts of businesses but also their impacts on the environment and society (Hutchins, 2019).

Underlying these mechanistic systems that create more deficiencies than prosperity is a growth model that is completely out of sync with life. Unfortunately, many of our modern food cultivation methods are part of this vicious cycle (Haukeland, 2013). Research on modern farming practices is increasingly being linked to the progressive incidence and prevalence of systemic and autoimmune diseases of people and animals, as well as to contamination and degradation of the land (Sandifer et al., 2015). The current coronavirus crisis emphasises this even further, calling for a drastic review of food cultivation approaches as well as our livestock practices (see Van der Poel, 2020). To better understand why this growth model has turned so destructive, we will first explore its underlying worldviews and developmental processes.

COMPARING INDIGENOUS AND MECHANISTIC WORLDVIEWS

To better understand the development of mechanistic worldviews and practices, we offer some key reflections from other worldviews that are founded on a *unity view* of life and our relationship within the natural world. Such worldviews can still be found in the cosmologies and practices of many indigenous communities (Jacobs, 2016; Lane, 2019a; Randall, 2007; Smitsman et al., 2019), where reciprocity and co-dependency are regarded as guiding principles and which take great care to safeguard and honour these reciprocal relationships with the natural systems from which food resources are extracted (Lane, 2019b; Sanchez, 2017).

What we can learn from such indigenous worldviews is the evolutionary perspective of life (Lane et al., 2019). The health and thrivability of our ecosystems depend on the fine-tuning and intricate regulation of complex interdependencies that are nested holarchically – as holons within larger holons (Sahtouris, 2000). The term holarchy was coined by philosopher Arthur Koestler to describe how each whole thing within nature is a holon, a whole made of its own parts, yet itself part of a larger whole (Koestler, 1967). Holarchy also describes behaviour that is partly a function of individual nature and partly a function of the nature of the embedding system (Smitsman, 2019), and contrasts with growth models that developed from mechanistic dualistic worldviews which have hierarchical modes of organisation.

Such mechanistic growth models originate from societal changes that started about 5,000 years ago, when warlike kingdoms or empires started to develop (see Sahtouris, 2000). This period is characterised by aggressive policies for domination and control, driven by zero-sum game, win–lose, competitive dynamics. Empire dynamics still dominate today through geopolitical shifts to the empire of corporations (see Sahtouris and Smitsman, 2019).

The modern dominant conception of progress and development originates from the empire dynamics and its mechanistic worldviews (Smitsman et al., 2019). Restoring a *wholeworld-view*[1] is crucial to see the full picture and take responsibility for the impacts of the growth and prosperity models that we employ today for our societal development. No form of progress can be justified if this entails the

[1] The term *wholeworld-view* is used to differentiate its wholistic understanding of the wholeworld from otherwise fragmented worldviews.

widespread destruction of our planet and the future conditions of our collective thrivability. Cosmologist Jude Currivan describes this emerging wholeworld-view in the following way:

> While retaining the uniqueness of our personal, microcosmic expressions of consciousness, this wholeworld-view embraces the meso-cosm of our collective human experience and the macrocosm of our entire Universe, existing as a finite expression of the infinity and eternity of cosmic mind. When fully realized, such a view of the world does away with the conflictual interactions of duality perception, empowers mitigation of selfishness, and enhances cooperation and altruism, not only with each other but with all life as well.
>
> *Jude Currivan (2017: 229)*

Another fundamental quality of many indigenous worldviews is the emphasis on gratitude for life itself. In all environments, whether abundant or scarce of resources, the expression of gratitude for honouring our reciprocity with nature is a cornerstone in many indigenous communities. For example, in the Quechua language of Peru, the word *ayni* embodies this, offering back to Mother Earth, *Pacha Mama*, in appreciation of what she offers us with such benevolence. The Q'ero shamans in Peru, whose small communities eluded the Spanish invaders over five centuries ago by escaping to the highest and most challenging reaches of the mountains, continue to live by principles of gratitude and honouring reciprocity.

This focus on gratitude and reciprocity can also be found in the indigenous landscapes of the United Kingdom. For example, excavations at Avebury in England, which has been standing as a monument for over 6,000 years, revealed an ancient offering. This offering, 2 ft deep into the chalk bedrock from which flints were extracted, consisted of carefully placed, knapped flint implements and animal bones over 5,000 years old. This suggested to the archaeologists who found it that whoever had extracted the flint had made the offering in gratitude for its valued provision (Currivan, 2004).

Many indigenous traditions, both ancient and contemporary, have a *wholistic* worldview which accepts and honours the existence of multidimensional realms. From the beings known as huldufolk to Icelanders, to the kami of Japan, the apukuna mountain spirits of South America and the other and many names of elemental, devic and angelic entities around the world, such encounters are as old as humanity itself. Contemporary conscious communities such as the Findhorn Foundation in Scotland, founded in 1962, also commune with such realms as natural, everyday, realities. In many indigenous traditions, the honouring of these spirits and deities is regarded as an integral responsibility of growing and consuming food resources. Such realms appear invisible for those who have not developed their full or extra sensory capacities (Baring, 2015; Laszlo and Currivan, 2008).

The impact of our mechanistic worldviews is also apparent in the loss of a sense of the sacred. Land has become a commodity, rather than a living entity with intrinsic rights. Sacred sites are now tourist attractions, and mechanistic industrial farming practices have replaced indigenous ones around the world, which in the Amazon have damaged the rich black Terra Preta soils (Cornell University, 2019; Gibbons, 2019).

One of the first actions of adopting a thrivability paradigm would be a transformation of our current food industry and industrial farming practices. Such a transformation requires a deep understanding of the informational dynamics of healthy living systems, and how to implement this knowledge into design practices for a thrivability-based developmental trajectory. We will unpack those infodynamics in the following section.

WHAT WE CAN LEARN FROM THE INFODYNAMICS OF HEALTHY LIVING SYSTEMS

Thrivability sciences emerge as part of a new twenty-first-century paradigm whereby 'things' are in reality interdependent informational dynamics (infodynamics) within an integral living whole (Bateson, 2016; Laszlo and Laszlo, 2016; Smitsman, 2019). In this new paradigm, scientific laws are

no longer viewed as mechanistic rules regarding the interaction patterns of particles, but rather are redefined and expanded in terms of informational content, coding and processes (Currivan, 2017: 6). This is being revealed at all scales of existence and across many fields of scientific research (Currivan, 2017; Smitsman and Currivan, 2019).

The science of infodynamics has previously been described as *the study of the accumulation of informational constraints during system development* (see Salthe, 2001). Jude Currivan has taken this study further to reinterpret the first two laws of thermodynamics as laws of infodynamics, for a better understanding how our universe evolves as a holographically informed wholeness, where its three-dimensional appearance is actually a holographic projection from the two-dimensional boundary of space (Currivan, 2017; Smitsman and Currivan, 2019). The science of infodynamics focuses on changes and impacts of meaningful in-formational[2] patterns and content in living systems. Based on a universal 'alphabet' of the 1s and 0s of digitised information, it reveals how implicit cosmological dimensions underlie our manifest physical world and *meaningfully* combine these to in-form the forms of complex and living systems. It reveals that our physical world is a semiotically informational world and dissolves the dualistic notion that matter and energy are different. The concept of *information* is more fundamental than energy–matter and space–time and expresses in complementary ways as emergent phenomena of our universe. The science of infodynamics reveals, therefore, how from non-physical causative realms – the infinity and eternity of cosmic mind in Einstein's terminology – a finite universe is created that exists and evolves as a fundamentally interconnected coherent and unified entity (Currivan, 2019: 3).

The study of infodynamics also helps us to deepen our understanding of life as a generative field of possibilities (Sahtouris, 2000, 2013). By studying the infodynamics of life, we can learn how to apply this to the design of generative human systems that are evolutionary coherent and cosmologically informed. For example, this is currently applied to the world design of new economic and educational systems based on the cosmological principles of living systems (see Smitsman and Thurm, 2020; Smitsman and Houston, 2021). Accordingly, we can develop a generative wholeworld-view for guiding the evolutionary development of our world and future (Smitsman, 2019). When we shift our focus to generativity, and not mere sustainability, we start to design our worlds with the cosmological intelligence of life. Hence, our proposed focus on thrivability, as earlier explained in this chapter, as a generative future-creating process.

The study of infodynamics further opens a new, non-dualistic way of looking at causality. Life is a complex system of various interdependent, holarchically nested feedback and feedforward informational dynamics and flows. These flows reveal how we each are an infodynamic pattern within an evolutionary coherent and informing universe that affords possibilities for self-reflection and self-awareness and so allows us to become conscious of our evolution as the infodynamics *for* evolution (Smitsman et al., 2018). The study of infodynamics shows us how consciousness can emerge as an intrinsic quality of life and our universe, where consciousness is not something we have, but *is what we and the wholeworld are* (Currivan, 2017).

This dynamic informational flowing also forms the very conditions for evolutionary learning and development. Evolutionary learning cannot take place without, on the one hand, infodynamic flows that are generated by our activities that are interplaying within the larger whole called life and, on the other hand, the capacity to attune, adjust and respond to these flows (Fogel, 1993, Smitsman, 1997; Smitsman and Smitsman, 2020).

When we now apply this understanding to food cultivation and consumption within the growing field of agroecology, it enables us to deepen our understanding of what is implied by terms such as *integrated farming.* Words such as *integrated* and *integral* imply a multi- and inter-dimensional approach that requires knowledge and understanding of infodynamics. When we grow and consume

[2] 'Inform' and 'information' are sometimes written in this chapter as 'in-form' and 'in-formation' to emphasize how this type of cosmological information plays a key role in the *formation* and manifestation of our physical world.

food, we also create specific informational patterns, and not all of those patterns are conducive for our thrivability and planetary health.

Owing to their lack of reciprocity with the healthy patterns of planetary ecosystems, food produced through systems that inhabit diseased information patterns also produces informational disease patterns that we in turn consume and propagate (Sahtouris, 2013). This gives a whole new meaning to the saying that *you are what you eat*. This understanding of health and disease as specific informational patterns is starting to emerge in the field of holistic medicine (Laszlo, 2017).

In order to better understand which infodynamics to apply for healthy and ecological food cultivation, we first need to understand the infodynamics of thrivable living systems. Living systems, compared to mechanistically created human systems, emerge from and generate healthy and regenerative infodynamic patterns due to the direct resonance and in-tunement with the cosmological intelligence of life.

Currivan's book and research demonstrate that when we reinterpret the first two laws of thermodynamics as laws of infodynamics, we start to see how the universe's informational content increases and diversifies as it spatially expands over time. This gives rise to growing complexity and evolutionary coherence (Currivan, 2017). Understanding evolutionary complexity is essential if we are to address complex issues such as runaway climate change, as indicative of systemic barriers that emerge from harmful complexity and degenerative growth patterns (see Smitsman, 2019).

The cosmological insights about the infodynamics of living systems through this chapter transform our understanding of reality itself – and turn the perception of a material, separate and essentially meaningless world on its head. Our beliefs drive our behaviours, and a wholeworld-view has the potential to empower transformational social change, including our behaviour towards our planetary home.

We will now apply some of these key points to evolutionary systems' design, which can also be applied to the design of evolutionary farming systems and practices. Anneloes Smitsman's PhD dissertation summarises the infodynamics of thrivable living systems as falling into five categories (adopted from Smitsman, 2019: 436):

1. *Embodied Informational Wholeness That Is Holographically Distributed:* Wholeness is a fundamental organisational principle of living systems, which cannot be understood by merely studying the parts of systems (Capra and Luisi, 2014). Thrivable living systems embody the systemic informational wholeness of life in their in-formation, organisation and behaviour. Informational wholeness in living systems gives rise to diversification (variability) that remains evolutionary coherent and unified (integrated) at deeper levels of the system (Smitsman and Currivan, 2019). When living systems grow more complex, their consciousness-actualising capacity also increases (Sahtouris, 2013). This embodying capacity is incredibly important from a developmental perspective of how consciousness as potentiality becomes aware through actualisation, from undifferentiated to differentiated awareness and back (Smitsman and Smitsman, 2020).
2. *Future Creative Attractors:* The future creative capacity of a living system is based on its capacity for renewal through its evolutionary development. The term 'future creative' also refers to a creative process that generates new patterns and new possibilities, i.e. new futures. In living systems, such a future creative process emerges from its evolutionary learning and development capacity. Evolutionary learning and development requires specific systemic attractors, affordances and sensory organs that combined make it possible to explore the infodynamics of the system's activities for new goals and purposes. Accordingly, living systems develop the sensory and attuning capabilities for adjusting their patterns and structures in a way that enables their further evolutionary development. The possibility space of a living system, its future potential, is precisely what acts as the attractor towards this developmental learning process (see Smitsman and Smitsman, 2020).

3. *Consciousness-Actualising Affordances:* The evolutionary coherent complexity of living systems acts as affordance for consciousness to actualise, through developing self-awareness at various scales of being and inter-being. If a system does not afford the emergence and development of awareness, and does not afford the actualisation of consciousness, it is not a thrivability system.
4. *Holarchic Complex Developmental Patterns:* All living systems are complex developmental systems that generate holarchic patterns. A holarchic pattern is an organisational pattern whereby holons (wholes) are nested within larger holons (wholes) (Koestler, 1967). Holarchic patterns of complexity are generative, dynamic and evolutionary coherent. This is in contrast to hierarchic patterns that are degenerative, rigid and divisive. Information distribution in holarchic systems can be accessed at any level of the system due to its holographic nature and is attracted to the realisation of greater wholeness (Smitsman and Smitsman, 2020).
5. *Evolutionary Coherent Behaviours:* This is one of the most important qualities of thrivability systems; behaviour is sourced from the embedded informational wholeness and holographically distributed in a non-localised manner through the entire system. Accordingly, at any level of the system, the parts of the system can remain sourced from wholeness and informed by unity whilst diversification and growing complexity remains in dynamic place. *This is the key to evolutionary coherence.* This has also been referred to as *the unity in diversity principle*. Humanity is yet to master this evolutionary coherence in its behavioural patterns.

By learning from the behaviours of living systems and embedding those fractal potentialities in the design of our societal systems and interactions, we might start to understand how to systemically design for thrivability.

FARMING OF TOMORROW

The study of the infodynamics of healthy living systems, in this chapter also referred to as thrivability systems, provides guidelines for developing the agroecological farming systems of tomorrow. Indigenous science and practice has shown us the importance of including the infodynamics of living systems. If agroecological farming is to become truly wholistic in its practice, then it also requires inclusion of the non-local and multiple dimensions that inform growth in the finite, space–time-bound, local dimensions of our world.

Our current multifaceted global crisis offers an opportunity to enter into a conscious, healing and evolutionary relationship with Gaia. When we start to grow and cultivate our food from a sense of unity with all of life, and honour the integrity of our planetary ecosystems, a new thrivability model can emerge based on a fundamentally different relationship with food, resource cultivation, the land, each other and the larger ecology of life. Through this chapter, we hope to have inspired a deeper envisioning and regeneration of a healed and whole relationship with Gaia, the larger ecology of life and the wholeworld.

ACKNOWLEDGEMENT

We thank Dr Meredith Lowry for her valuable contribution.

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Section 2

The Intersection of Wave-Based Science and Agriculture

9 Electromagnetic Fields Mitigate Adverse Effects of Environmental Stresses in Plants

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CONTENTS

INTRODUCTION

This chapter provides a state-of-the-art overview of the mitigating effects of electromagnetic fields (EMFs) on plants sown under abiotic and biotic stresses and thus their implications for agroecology. It considers static and alternating magnetic fields (MFs) and pulsed fields (PEMFs) ranging from 1.5 μT up to 800 mT in the range of extremely low frequencies (0–300 Hz).

Environmental stress may be defined as an adverse external condition for plant growth and development or productivity of plants, caused by either environmental or biological factors, or both (Verma et al., 2013). Plant stress can be divided into two main categories: abiotic stress and biotic stress. Abiotic stress imposed on plants by the environment may be either physical or chemical (drought, salinity, high temperatures, ultraviolet light, heavy metal toxicity), while biotic stress imposed on plants is a biological factor such as insects, bacteria, viruses, pathogens and weeds (Gull et al., 2019; Verma et al., 2013). Exposure of plants to biotic and abiotic stress induces a disruption in plant metabolism, implying physiological costs (Bolton, 2009; Heil and Bostock, 2002; Massad, et al., 2012; Swarbrick et al., 2006), and thus leading to a reduction in fitness and ultimately in productivity (Shao et al., 2008). Abiotic stress has a great impact on plant growth by causing growth reductions of up to 50% in most plant species and, consequently, is responsible for severe losses in the field (Wang et al., 2003). Still, biotic stress is an additional challenge, inducing a strong pressure on the plant and adding to this damage through pathogen, pest, insect or herbivore attack (Brown and Hovmoller, 2002; Maron and Crone, 2006; Mordecai, 2011; Strauss and Zangerl, 2002). Under natural conditions, concurrent occurrence of two or more different types of stresses, such as drought and salinity, is more detrimental to global crop production (Pandey et al., 2015; Prasch and Sonnewald, 2013; Suzuki et al., 2014). The nature of the interactions between the abiotic and biotic stresses and the duration of stress exposure can lead to a series of effects on plant growth, development and overall yield and also determine the extent of the influence on crop productivity.

DOI: 10.1201/9780429440939-11

It is predicted that, with climate change and especially global warming, environmental stresses will become more intense and frequent in the future. Therefore, maintaining crop yields under adverse environmental stresses is one of the major challenges facing modern agriculture, and plants might react to environmental stress on several levels: on the biochemical, cellular or morphological scale, and at species or population level. However, different studies suggest that static and alternating MFs and PEMFs prevent the huge injuries of abiotic and biotic stresses on agricultural crops and other economically important plants and play a role in triggering plant defence responses and antioxidant defence systems by reducing the oxidative damage in plants caused by stress situations (Anand et al., 2012; Baby et al., 2011; Baghel et al., 2018; Chen et al., 2017; Javed et al., 2011; Karimi et al., 2017; Ruzic and Jerman, 2002; Radhakrishnan et al., 2012; Sen and Alikamanoglu, 2016; Trebbi et al., 2007; Shine and Guruprasad, 2012; Shine et al., 2012).

EFFECTS OF MFS ON ABIOTIC STRESS

Abiotic stress exerts a negative impact on the growth rate and reproduction of a plant (Gull et al., 2019). Drought, salinity, heavy metal toxicity, ultraviolet light and low and high temperatures are examples of abiotic stress factors. It has been claimed that abiotic stress causes the most crop loss of any other factor, causing most major crops to have over 50% lower yields than their potential (Fahad et al., 2017).

Several studies have shown that a magnetic treatment at pre-sowing alleviated the adverse effects of drought, salinity, heavy metal toxicity, ultraviolet light and high temperatures or heat stress in some plant species (Table 9.1).

The results of several investigations indicate that MF can provide protection against the adverse effects of drought stress. For example, when common fig (*Ficus carica* L., cv. Sabz) nodal explants were subjected to static MF of 170 mT for 15, 30 and 60 min every day under drought stress (three concentrations of polyethylene glycol 6000 (PEG): 0, 3 and 6%w/v) in vitro conditions, a protective

TABLE 9.1
Examples of Effects of Electromagnetic Fields of Plants Sown under Abiotic Stress Conditions

Plant Species	Abiotic Stress Type	MFs Applied	Effects Described	References
Glycine max L.	Drought	Static MF, 200 mT for 1 hour	Enhanced plant growth, biomass accumulation, photosynthetic performance, photosynthetic pigment content, efficiency of photosystem II, photosynthesis rate, nitrate reductase activity and yield	Baghel et al. (2018)
Glycine max L.	Salinity	Static MF, 200 mT for 1 hour	Increased plant growth, biomass accumulation and photosynthetic performance. Improved the activity of nitrogen fixation and leghaemoglobin content and hemichrome content in the root nodule	Baghel et al. (2016)
Glycine max L.	10, 20, 30 and 40 mM NaCl	Pulsed MFs, 0.1, 1, 10 and 100 Hz	Increased frequency of shoot and root regeneration and number and length of shoots and roots. Induced greater number of roots and enhancement of root length at 40 mM NaCl	Radhakrishnan and Kumari (2013)

(*Continued*)

TABLE 9.1 (*Continued*)
Examples of Effects of Electromagnetic Fields of Plants Sown under Abiotic Stress Conditions

Plant Species	Abiotic Stress Type	MFs Applied	Effects Described	References
Glycine max L.	Salt stress (10 mM NaCl)	1.0-Hz uniform pulsed MF, 1.5 μT for 5 hours a day for 20 days	Increased calli fresh weight, total soluble sugar, total protein and total phenol contents. Decreased ascorbic acid, lipid peroxidation and catalase activity. Enhanced calli tolerance to salt stress in terms of increase of flavonoids, flavones or flavonoles, alkaloids, saponin, total polyphenol, genistein and daidzein contents. Reduced overproduction of proline.	Radhakrishnan et al. (2012)
Triticum aestivum (cv. Nina and Flamura-85)	60 g/L polyethylene glycol (as a drought stress inducer) or 100 mM NaCl (as a salinity stress inducer)	Static MF, 2.9–4.7 mT for 2.2 and 19.8 s	Improved plant growth. Increased the amount of superoxide radical and hydrogen peroxide in roots under drought stress or salt stress in total chlorophyll, chlorophyll a and chlorophyll b in leaves. Enhanced antioxidant enzyme activities (superoxide dismutase, guaiacol peroxidase, catalase, ascorbate peroxidase and glutathione reductase) and total glutathione and oxidised glutathione contents.	Sen and Alikamanoglu (2016)
Eucalyptus globulus	Heavy metal toxicity (soil containing Cd, Hg, Pb, Zn, Cr and Cu)	Static MFs, 30, 60, 120, 150 and 400 mT	Increased biomass yield. 150-mT MF improved the phytoremediation and alleviated the environmental risk, which shortened the time to purify Cd, Pb and Cu. Higher transpiration rate of plants along with exposure to static MFs induced lower soil moisture content and was beneficial to environmental control	Luo et al. (2019)
Triticum aestivum	Heavy metal toxicity (lead and cadmium)	Static MFs, 200, 400, 600 and 800 mT for 1 ms	Increased germination by 600 mT for 1 ms. Decreased catalase, superoxide dismutase, glutathione reductase activity, glutathione concentration and shoot biomass for 200, 400, 600 and 800 mT for 1 ms	Chen et al. (2017)
Cucumis sativus	Ultraviolet B (3.5 kJ/m^2 ultraviolet B, 315 nm) stress	Static MFs, 0, 0.2 and 0.45 T	Increased germination rate, seedling growth and development, lipid oxidation and ascorbic acid contents. Seed MF treatment increased the sensitivity of cucumber seedlings to ultraviolet-B radiation. Decreased seedling growth and development and actual quantum yield of photosystem II and increased oxidative pressure under combination of ultraviolet-B irradiation and MF	Yinan et al. (2005)

effect was found in treated plants by absorbing more water (23.1%), accumulating more proline (44.1%) in their leaves and increasing the thickness (17.9%) of their leaves. The treatment 170-mT MF for 15 min showed the best results (Karimi et al., 2012). Maize (*Zea mays* L.) plants from magnetically treated seeds with static MF of 100 and 200 mT for 2 and 1 hour and sown under greenhouse conditions significantly enhanced seedling growth (34.3%) and leaf water status (leaf water potential (20.6%), turgor potential (46.9%), relative water content (3.5%) and photosynthesis rate (71.4%)) and lowered the antioxidant defence system (peroxidases (50%) and catalase (66.7%)) of seedlings under soil drought stress (Anand et al., 2012).

Magnetic treatment has been found to provide protection of some plant species against salt stress without adversely affecting the environment. Pre-treated maize seeds with 200 mT of static MF for 1 hour enhanced germination percentage (16%), germination stress tolerance index (23.2%), seedling vigour (70%), growth parameters (plant height (41%), leaf area (18%) and biomass accumulation (137%)), photosynthetic pigments content (46%), the rate of photosynthesis (28%) and stomatal conductance (40%), which resulted in improved yield (29%) of maize plants and decreased hydrogen peroxide (H_2O_2; 32%) under saline conditions (Baghel et al., 2019). A static MF of 35 mT for 0.5 min caused an increase in all tested germination indexes (36.4%), seedling growth (seedling shoot and root length (43.6% and 46.8%), seedling dry weight (23%) and seedling vigour (18%)), relative water content (19.6%), salt tolerance index (10.2%), antioxidant enzyme activity (peroxidase (15.6%), polyphenol oxidase (24%) and chitinase (21.5%)) and field performance characteristics of barley plants (40.6%) in combination with water, proline or arginine under different salinity stress levels (324, 2,000, 4,000, 6,000 and 8,000 ppm; Hozayn et al., 2018).

Enhanced germination percentage (10%–19%) and early seedling growth (root and shoot length (15%–40% and 18%) and vigour indexes (40%)), increased α-amylase and protease activities (15.4%–56.3% and 4%–10.5%) and increased levels of superoxide radical and hydrogen peroxide (13.8%–31% and 9.65–13.2%) under different salinity levels (0–100 mM NaCl) were observed in maize and soybean plants grown from pre-treated seeds with static MF of 200 mT for 1 hour as compared to control plants (Kataria et al., 2017a).

Sweet corn (maize) plants emerging from magnetically treated seeds using weak (15 mT) or strong (150 mT) MFs for 6, 12 and 24 hours showed an increase in germination rate and percentage (5%–25.3%) and plant growth (11.5%–13.4%) and a reduction in proline accumulation (25.8%) by improving water absorption (25.9%) under NaCl stress (0, 50 and 100 mM). The highest germination rate was obtained by the stronger MF; however, the seedlings were more vigorous after treatment with 15-mT MF (Karimi et al., 2017).

Different experimental results have shown that MF treatment can ameliorate heavy metal toxicity stress in some crops. For example, mung bean seedlings treated with 600-mT MF under cadmium stress reduced the concentration of malondialdehyde (23.4%–72.2%), hydrogen peroxide (25%–27.8%) and superoxide radical (3.6%–22.1%) and the conductivity of electrolyte leakage (16.1%–24.6%), while the nitric oxide (NO) concentration (33.3%–39.8%) and nitric oxide synthase (NOS) activity (13.3%–22.2%), photosynthesis rate (13.4%) and growth parameters (13.3%–22.6%) increased compared to cadmium stress alone, indicating that MF compensates for the toxicological effects of cadmium exposure and is related to NO signalling (Chen et al., 2011). A stimulating effect on the growth of spruce (*Picea abies*) seedlings (69%) was observed for 50-Hz MF of 103 μT and aluminium solution (in the form of $AlCl_3$) of 100 μM, while slight positive responses were also found within the range of concentrations between 40 and 160 μM Al^{3+}. These results suggest the importance of the synergistic action of the MF with metal aluminium stressor as well as the existence of physiological windows in addition to the frequency and power ones (Ruzic et al., 2000).

Some results demonstrated an alleviating effect of MF on ultraviolet light stress in plants. Exposure of sorghum seeds to a static MF of strength 125 mT for 6 hours revealed a significant effect on the percentage of germinated seeds (34.8%), speed of germination (40.5%), seedling length (45%) and number of leaves (14.4%), while the MF application followed by immediate irradiation with ultraviolet-C radiation at 254 nm for 30 and 60 min showed no significant effect on germination

and seedling growth, indicating the magnetically untreated seeds with the exposure time 60 min of ultraviolet-C gave the highest seedling growth (Lazim and Nasur, 2017). A static MF of 200 mT for 1 hour reduced the amount of hydrogen peroxide (36%) and activities of antioxidant enzymes such as superoxide dismutase (38%), glutathione reductase (60%) and guaiacol peroxidase (66%) of soybean (var. JS-335) plants that emerged from MF-treated seeds under ambient ultraviolet (280–400 nm) stress compared to the control. The reduction in the hydrogen peroxide content (30%) and antioxidant enzyme activities (40%) after MF treatment and ambient ultraviolet exclusion indicated that solar ultraviolet components exert a significant stress on soybean plants. Similarly, the levels of ultraviolet-absorbing compounds (14.6%–15%) were also decreased by exclusion of both ultraviolet and MF treatment. The results indicate that the exclusion of solar ultraviolet components and MF pre-treatment eliminates the need for defence against the ambient ultraviolet stress (Kataria et al., 2017b).

Some experimental results have exhibited a protective response of the MF against high temperatures or heat stress. The effects of pre-sowing magnetic treatments (MF of 120 mT for 10 min and 80 mT for 5 min) on the growth and yield of tomatoes (cv. Vyta) increased notably root length (18%), fresh and dry root weight (48.2% and 80.7%), stem length (35.9%), fresh and dry stem weight (39.6% and 75.4%), leaf area and foliole dry weight (39.3% and 26.7%), fruit number (21.3%), mean fruit weight (25.5%) and fruit yield per plant (51.7%) and per area (50.8%) under high temperature stress (34°C) and under field conditions (De Souza et al., 2005). A weak sinusoidal and 50-Hz MF of 100 μT alleviated the inhibitory effect of heat stress (40, 42 and 45°C for 40 min) on the growth of cress seedlings (*Lepidium sativum*; 15%) only when applied previously, whereas the application of MF alone and after heat stress did not produce any significant growth effects. It was also evident that with a stronger stress (42°C and 45°C), the MF produced a more potent protective effect than at 40°C, indicating the protective effect of MF against high temperatures (Ruzic and Jerman, 2002). These studies suggest that MF treatment ameliorates the adverse effects of drought, salinity, heavy metal toxicity, ultraviolet light and high temperatures.

EFFECTS OF MFS ON BIOTIC STRESS

Biotic stress in plants is caused by living organisms, especially viruses, bacteria, fungi, nematodes, insects, arachnids and weeds (Gull et al., 2019). These biotic stress agents cause various types of diseases, infections and damage to crop plants and ultimately affect the crop productivity. They depend on the environment and thus vary from region to region, from one agroecology to another, from one country to another country (Suzuki et al., 2014). Biotic stress plays a central role in regulating outbreaks of pests, pathogens, insects and weeds (McDonald et al., 2009; Peters et al., 2014; Ziska et al., 2010). Plants respond to biotic stress through a defence system, and this mechanism is classified as an innate and systemic response. After infection, reactive oxygen species (ROS) are generated and oxidative bursts limit pathogen spread (Atkinson et al., 2012). Several adaptive responses of plants have shown the role of MF on plant defence response under biotic stress conditions (Table 9.2).

Magnetic treatment has been found to protect some plant species against fungi, bacteria, phytoplasma and virus. For example, exposure to 0.2-mT MF for 7 min 48 s, 11 min 42 s and 15 min 36 s on tomato seed infected by *Fusarium* sp. increased the rate of flowering (4.4%), flower number (3.4%), the rate of fruiting (2.8%) and fruit number (11.%), while the combination of MF exposure and seed soaking treatment enhanced flower number, the rate of fruiting and fruit numbers. 0.2-mT MF for 7 min 48 s showed the highest rate of flowering and the largest number of tomatoes, while 0.2-mT MF for 11 min 36 s exhibited the most number of flowers (13.4%) and the highest rate of fruiting (5.1%). However, soaking tomato seeds for 15 min before the 0.2-mT MF treatment gave a better effect by increasing the rate of the plants to form flowers and fruits and increase the number of fruits (Agustrina et al., 2018).

A static MF of 0.1, 0.5 and 1 mT decreased the growth of phytopathogenic microscopic fungal colonies by 10%. At the same time, the number of developed conidia of *Alternaria alternata* and

TABLE 9.2
Examples of Effects of Electromagnetic Fields of Plants Sown under Biotic Stress Conditions

Plant Species	Biotic Stress Type	MFs Applied	Effects Described	References
Capsicum, Zea mays	Phytopathogenic fungi (Fusarium oxysporum conidia, Alternaria alternata and Curvularia inaequalis)	Static MFs, 0.1, 0.5 and 1 mT	Decreased the growth of phytopathogenic microscopic fungi colonies and the number of *Fusarium oxysporum conidia.* Increased the number of developed conidia of *Alternaria alternata* and *Curvularia inaequalis.* MF influenced the formation of conidia	Pál (2005)
Nicotina tobaccum	Tobacco mosaic virus	Pulsed MFs (static MFs of 17 and 13 μT combined with a 10-Hz sinusoidal MF of 25.6 or 28.9 μT)	Increased resistance in plants by a decrease in lesion area and number, particularly after magnetic treatment for 8 hours. Increased ornithine decarboxylase and phenylalanine ammonia-lyase activities involved in resistance mechanisms, in particular for 13-mT static MF plus 28.9-mT, 10-Hz sinusoidal MF for 24 hours. Enhanced hypersensitive response of tobacco to tobacco mosaic virus	Trebbi et al. (2007)

Curvularia inaequalis increased by 68%–133%, but the number of *Fusarium oxysporum conidia* decreased by 79%–83% (Nagy and Fischl, 2004).

The effect of MFs of modulated amplitude square waves in the frequency range 0.5–20 Hz for 24 hours reduced significantly the linear growth (24.7%–56.5%) and biomass gain (30.3%) of *Sclerotium rolfsii* in vivo and in vitro, the number of sclerotia (58.4%), percentage of germination (55%) and germ tubule length (83.3%) of sugar beet plants. The sensitivity of the fungus for 24 hours counteracted the potency of fungus exposed to MFs of 0.5, 5 and 15 Hz which stimulated seedling emergency (7.8%–77.1%) in comparison with non-infested plants (Rizk, 2003).

Application of 10-Hz MF of 25 mT for 1 hour affected the amylase activity of bacteria *Rhodospirillum rubrum*, which was verified by the increase in standard deviations (250%) in distribution of the residual starch concentration. The use of 10-Hz MFs can regulate bacterial activity, and thus, 10-Hz MFs could be used for biotechnological application (Khokhlova and Vainshtein, 2017).

A significant delay in the appearance of first symptoms of geminivirus (7–9 days) and early blight (7–10 days) and a reduced infection rate (43%–55.3%) of early blight were found in the tomato plants grown from seeds exposed to increased MFs of 100 mT for 10 min and 170 mT for 3 min (De Souza et al., 2006). These findings indicate that MF triggers the plant defence response and protects plants against biotic stress. However, the mechanisms by which magnetic treatment protects the plants against the adverse effects of the abiotic and biotic stresses are still not fully understood.

CONCLUSIONS AND PERSPECTIVES

The seeds and plants treated with static and alternating MFs and PEMFs, from 1.5 μT up to 800 mT in the range of extremely low frequencies, showed an increase in seed vigour, plant growth and development, water relations, photosynthesis, accumulation of biomass and concentration of secondary

metabolites and a decrease in free radicals as well as triggering the plant defence responses and antioxidant defence system under abiotic and biotic stress as well as non-stress conditions. This indicates that MF treatment improves tolerance or resistance to abiotic and biotic stresses. Therefore, an approach is revealed for ways to face the environmental stresses being generated by global warming and other causes that disturb agricultural efficiency. The MF treatment of seeds and plants may allow us to design more complex experiments to study the interaction between two or three different types of stress in order to better understand the net impact of stress combinations on plants.

The technology required to treat seeds and plants with MFs is a type of magnetic treatment in the range from 80 to 200 mT for several exposure times (1–10 min; De Souza et al., 2006, 2010, 2014, 2020). This technology is appropriate and inexpensive for the small farmer with diverse crops; however, its application is limited at a larger scale and more research is therefore required to find ways to scale up the procedure.

ACKNOWLEDGEMENTS

The author wishes to thank Prof. Ben Greenebaum, University of Wisconsin-Parkside, for his valuable comments and suggestions on this chapter.

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10 Practical Uses of the Method of Epigenetic Regulation of Protein Synthesis in the Agricultural Field

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CONTENTS

INTRODUCTION: THE GENODIC METHOD

Genodics is a discipline introduced by the physicist Joël Sternheimer that aims to describe interactions of an undulatory, wave-like nature (de Broglie waves; de Broglie, 1924) that are involved in the regulation of the biosynthesis of macromolecules associated with gene expression. The application of this discipline has resulted in a method for the epigenetic regulation of the biosynthesis of specific proteins in living organisms, by means of sound diffusions called *proteodies*, which reproduce certain characteristics of the targeted proteins through a succession of audible frequencies forming a structured melody. The process was discovered and patented by Sternheimer based on his work in theoretical physics that subsequently found applications in biology (Sternheimer, 1992).

All proteins are chains of molecules called amino acids, in a specific order. To transpose them into modulated sound waves or protein melodies (proteodies), each amino acid is allocated a sound wave frequency calculated with the matter-wave equation of de Broglie and transposed into the audible range according to the rules of harmonics. The resulting series of sound are interpreted by choosing a type of voice and a tempo and modulating the duration of each note, in order to get an actual musical score. On small samples, such as in a laboratory, the broadcast equipment can be a simple mp3 reader, combined with a time programmer. In greenhouses or outside, bigger broadcast devices are used that are autonomous (with solar panel and battery), water-resistant and programmable via Global System for Mobile Communications (GSM). More powerful than small mp3 readers, with 4 loudspeakers and 2 amplifiers, each proteody box or P-Box can cover up to 15 ha. Broadcasted programmes are short, from 5 to 10 minutes, but can be repeated from 1 to 5 times daily, according to the needs of plants. Each broadcast programme includes several relevant

DOI: 10.1201/9780429440939-12

proteodies and corresponds to a specific metabolism to regulate or to a plant disease to reduce. On polycultures, the broadcast programmes are modified more often than on monocultures, in order to respond day after day to the needs of each type of plant, as observed by the farmer.

Genodics is also the name of a biotechnology company, created to develop applications for this process and to provide market proof of the concept. To date, the company has established 280 treatment installations, spread over 2,500 ha of crops (vines, market gardening and arboriculture) and 180 farms. The company's activities address many different agricultural issues.

THE FOUR PROJECT CASES

In this chapter, we present four projects conducted by Genodics, the results of which show a significant number of effects that hold potential for the expansion of the process and the development of new applications. The projects are outlined below.

Case 1a, b and c: The prevention and reduction of the effects of Esca on vines between 2008 and 2019. Esca is a cryptogamic (spore-based), vascular wilt disease involving a large number of anaerobic fungi, which develop inside the woody parts of the vine and can lead to the sudden death of the vine stock by blocking the rise of sap (apoplexy). This project was carried out throughout France following the ban on the use of sodium arsenite in 2002 (Ferrandiz et al., 2018; Bargoin et al., 2004).

Case 2: The prevention and reduction of the impact of Grape Powdery Mildew on a 7-ha vineyard. This mildew is caused by the fungus *Plasmopara viticola*. It affects the leaves and berries and can substantially weaken the vigour of the vines, as well as the volume of the harvest and the quality of the wine.

Case 3: The prevention and reduction of the impact of Erwinia on endives. Erwinia is a bacterial disease causing brown rot in endive, which has a strong impact on their quality and the marketable quantity.

Case 4: The reduction of the impact of mosaic viruses on courgettes. Zucchini Yellow Mosaic Virus (ZYMV) and Watermelon Mosaic Virus (WMV2) affect cucurbit crops. These viruses can cause extremely severe damage, resulting in significant crop losses.

The data used in this study come directly from the farms using the genodic process. The data were collected either by the farmer and his/her teams or by the Genodics team with verification and validation by the farmer. All measurements were based on the actual production of the farms under normal conditions, and therefore reflect the actual impact, in real terms, of the use of the process.

In general, the acoustic sequences produced from the protein structures of the plants concerned aim to stimulate their defence metabolisms, and those corresponding to pathogens aim to reduce their activities. The process thus tends to inhibit the pathogen and limit its impact on the host (Sternheimer, 2006).

MATERIALS AND METHODS FOR THE FOUR CASES

In the cases presented, the following evaluation methods were used, as shown in Table 10.1.

These cases are representative of the spectrum of action of the process on different kingdoms of living organisms, whether vegetal (vine, endive, courgette), bacterial (Erwinia), fungal (Esca and Mildew) or viral (Mosaics).

The installation of the acoustic diffusion system required is adapted to the agricultural context and the evaluation method chosen. In general, a stand-alone sequence diffusion box is installed to cover a maximum surface area, with additional diffusion boxes on larger surfaces. In order to highlight a diffusion gradient (in the cases of Grape Powdery Mildew and courgette Mosaic), part of the production is deliberately left out of reach of the diffuser in order to be able to compare the

TABLE 10.1
Evaluation Methods Used for Each of the Four Cases

Case	Evaluation Method
All cases (general)	Counting (exhaustive or statistically significant sampling) of symptoms and mortality related to the presence of a pathogen in the study population
Esca without control	Comparison with historical data from the same plots
Esca with control	Comparison with data from a control group with the same characteristics and growing conditions
Mildew and Mosaic viruses	Predicting and verifying the presence of an effect gradient related to the duration of the broadcast and the power of the sound (the acoustic scattering mode)
Erwinia	Prediction and verification of an effect related to the duration of exposure to sound sequences

development of the crop as well as the presence of the fungus or viruses at different distances from the diffusion device.

Case 1a and b: Prevention and reduction of the effects of Esca on vines.

A count of vines showing symptoms of Esca was carried out each year over 1–6 years around the harvest period on 91 plots of productive vineyards in France, covering a total of 260 ha, and compared with counts undertaken on the same plots during 1–3 years before the broadcast of sequences, in order to accurately estimate the pressure linked to the presence of the pathogen on the plots as well as the mortality associated with it. Mortality by vine apoplexy was the most reliable indicator for assessing the impact of Esca on both production and the condition of the plot. This parameter was therefore used as a reference for the comparison of the impact of Esca with and without the use of the genodic process. Case study 1a groups the plots for which historical data on Esca-related mortality could be retrieved from vine growers (chefs de culture des vignes) who are in the habit of counting and replacing dead strains every year. With these data, a chronology of the mortality rate before and after the implementation of the genodic process was carried out, in order to report on the comparative evolution of each plot exposed to the acoustic sequences. The reference value of the mortality rate used in Case 1b corresponds to the average of the mortality rates of the previous years, before the genodic process was set up, as evaluated by the vine growers when replacing the dead strains, a task that they carry out every 2 or 3 years. In both cases, an evaluation of Esca-related mortality was carried out at the end of the first year of application of the process, by the Genodics team accompanied by the vine grower, and was repeated in subsequent years.

Case 1c: Prevention and reduction of the impact of Esca on the vine, with a control plot.

Study carried out at the Château Gaudrelle in Vouvray, from 2014 to 2019, on two plots about 500 m apart, planted in the same year (1986) with the same grape variety and in the same *terroir*. The counting of vines showing symptoms of Esca has been carried out every year since the genodic process was implemented, and systematically validated with the vine grower, on the same day for both plots (3,972 individual plant locations for the control plot and 6,050 locations for the tested plot).

Case 2: Prevention and reduction of the impact of Mildew on a 7-ha vineyard.

At the Château Fayau in Cadillac, in 2016, a 7-ha vineyard received the usual anti-mildew fungicidal treatment applied by the vine grower. The diffuser was placed at one end of the vineyard, and diffusions were perceptible up to 150 m from this spot. Eighty-five plots comprising five vines each were selected, regularly spaced to cover the entire vineyard. At the beginning of July 2016, the number of mildew blotches on grapes (visible mark of the disease) on each plot was recorded.

Case 3: Prevention and reduction of the impact of Erwinia on endives.

Study carried out at the market garden Delahaye in Touraine, during the growing season 2011–2012 from mid-October 2011 to the end of March 2012. This experiment was carried out

during the endives' forcing phase, inside a thermo-regulated room with ambient humidity saturation. For each batch of endives, placed in containers, the cultivation period (forcing) lasted about 20 days, during which time the roots were permanently bathed in a nutrient solution. On maturity, the containers were removed from the forcing room and the endives harvested. New containers were immediately put in place for the next crop. During the 25 weeks of the season, acoustic diffusions were made for periods of 21 days, followed by 21 days without diffusion, alternating. Thus, depending on their date of entry into the forcing room, the endives in each container received between 1 and 20 days of these sound broadcasts, during which the sequences were broadcast daily for 24 minutes at the beginning of season and 34 minutes at the end of season.

In this way, a diffusion gradient over time was realised in order to compare the batches, with some receiving 500+ minutes at the beginning of the season and others 700+ minutes at the end. The loudspeakers of the diffusion system were installed inside the thermo-regulated room, while the amplifier and programmer were placed outside the room. For each batch, in addition to its exit date from the forcing room (i.e. the date of harvest), the following characteristics were recorded:

- Quantity of endive produced, in kilograms;
- Duration of the broadcast on the batch, from 0 to the total number of days spent in the room (up to 21 days);
- Percentage of 'second-grade' endive (based on the exterior appearance such as shape, size and quality) in relation to the total produced;
- Production yield, in number of endives and in kilograms per container (based on kg per container×no. containers per batch).

A total of 541 tonnes of endives produced under these conditions, grouped by batch, were analysed.

Case 4: Reduction of the impact of Mosaic Virus on courgettes.

This experiment was carried out on the market garden of l'Oustalet, Bouches-du-Rhône, in 2009, in 7 polytunnels on a sample of 100 courgette plants per tunnel (over 400 ft of plants in total, of the Satellite variety). The tunnels were 7 m wide, 80 m long and 3 m apart. The tunnel closest to the diffusion device was 20 m from the device, and the furthest tunnel was between 87 and 94 m from the device. The tunnels were installed perpendicular to the direction of the Mistral wind, and the sound was emitted in the opposite direction to the Mistral. The sequences, aimed at reducing the proliferation of viruses and stimulating the resistance of the courgettes, were broadcast once a day for 6 minutes throughout the production phase from 30 July (planted on 6 July, first harvest on 6 August). For each selected courgette plant in each tunnel, the following criteria were recorded:

- healthy plants;
- plants showing virus-related symptoms (filiform or mottled leaves);
- dead plants.

In this way, the degree of impact of the virus could be assessed in a gradient from the loudspeaker to the furthest tunnels.

RESULTS

Case 1a: Prevention and reduction of the effects of Esca on the vine, with historical data.

The historical values of the Esca mortality rate are plotted in Figure 10.1a and b, together with mortality rates collected year by year from the start of the genodic process (year 1). Prior to year 1, the mortality rate averaged between 1.8% and 5.5%. From year 1 onwards, there is a progressive decrease in the mortality rate, around 1.5% in year 1 (start of the diffusion process) and then between 1% and 2% mortality in the following years. The difference between before and after

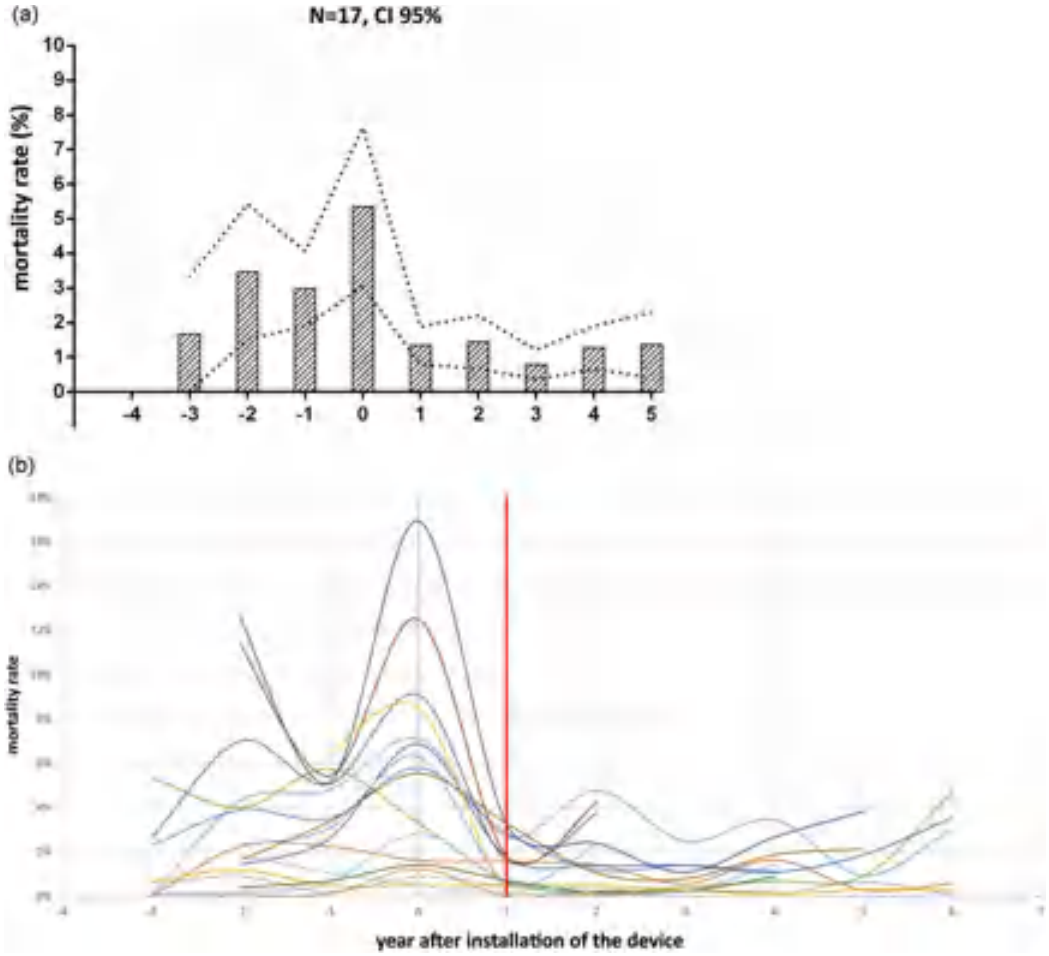

FIGURE 10.1 (a) Evolution of Esca-related mortality rate before and after genodic use. (b) Esca-related mortality rate before and after genodic use.

implementation of the process is significant with a 95% confidence interval. These results cover data from 17 plots, for a total area of 43 ha (about 200,000 vine stocks).

Case 1b: Prevention and reduction of the impact of Esca on vines, with historical averages.

Mortality data related to Esca collected year after year were used to calculate the evolution of this mortality based on the historical average of each plot. The historical average was the percentage loss per year before the beginning of the experiment, based on 3–5 years of available data. The colour curves in Figure 10.2 show the evolution of mortality rates on the 91 plots, each compared with the local average mortality rate; the black line shows the annual means; and the vertical bars show the confidence intervals for each year's data, with a chosen confidence index (CI) of 99%. There is an average decrease in the mortality rate of 57% from the first year of use, then a stabilisation in the following years to between 50% and 65% of the initial mortality rate. The yearly variations are mainly related to differences of climatic conditions in the areas of these plots.

Figure 10.2 also shows the raw data used to calculate the average data, represented by the curve described above. It is interesting to note that the variations in the mortality rate have a large amplitude depending on the plots. The dispersion of these results reflects a statistical effect of the process, spread over all the treated plots, with a central value of between 50% and 70% reduction in Esca-related mortality.

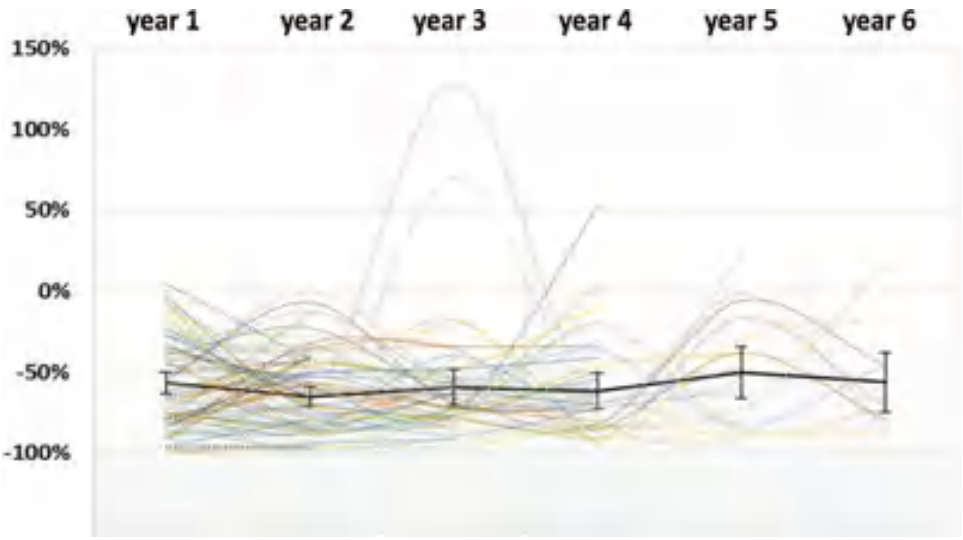

FIGURE 10.2 Evolution of the Esca mortality rate compared to the average historical mortality rate ($N=91$ plots), 1,209,020 vine stocks on 260 ha total, CI 99%.

Case 1c: Prevention and treatment of Esca on vine, with control plot.

By comparing the results obtained for the control plot and the genodic plot, it can be noted that for both symptoms and mortality rate, Esca expression varies in the same way depending on the year on both plots. This corroborates the similarity of the plots and the context in which they evolve (climate, pathogens, exposure, etc.). Concerning symptoms such as mortality, a systematically lower rate is observed on the genodic plot that received the acoustic sequences (Figure 10.3a and b). These differences are between 38% and 80% less for total Esca expression (symptom + mortality) in the plot that received the sequences (Figure 10.3e). When observing the distribution of results in graphs in Figure 10.3c and d, it appears that the dispersion of values is greater for the control plot, which is more marked for the symptoms (value between 0% and 4% for the 'genodic' plot and between 0.5% and 11% for the 'control' plot). All these results indicate a difference in the development of Esca on these two plots with otherwise identical characteristics. The annual seasonal patterns that condition the natural development of the Esca are well distributed from plot to plot each year, but appear to be markedly reduced, between 38% and 80%, in the plot that was exposed to the genodic sequences.

Case 2: Prevention and reduction of the impact of Mildew on a 7-ha vineyard.

The number of blotches on bunches of grapes relating to the presence of mildew was counted by plots of five vines ($n=83$ plots). These values were represented according to the distance of each group from the scattering device. Figure 10.4 shows an increase in the number of mildew blotches as a function of distance, particularly at distances of 150–200 m. The linear regression of the data on the graph (curving upwards) shows a strong decrease at this distance, which corresponds to the acoustic diffusion range limit of the installed equipment. Between 0 and 150 m, the number of blotches by plot ranges from 0 to 1, and then, it varies from 1 to 7 blotches by plot between 150 and 250 m. The correlation between proximity to the device and the number of blotches is represented by the linear regression curve, within the 99% confidence interval shown as a dotted line on the graph. These results show an increase in the impact of mildew on grape clusters as one moves away from the genodic sequence diffuser, with a noticeable increase more than 150 m from the diffuser.

Case 3: Prevention and reduction of the impact of Erwinia on endives.

Batches of endives were grouped according to the duration of their stay in the forcing chamber. Figure 10.5a shows the change in the percentage of second-grade endives as a function of the duration of exposure, showing a clear decrease in the rate of second-grade endives with increasing exposure

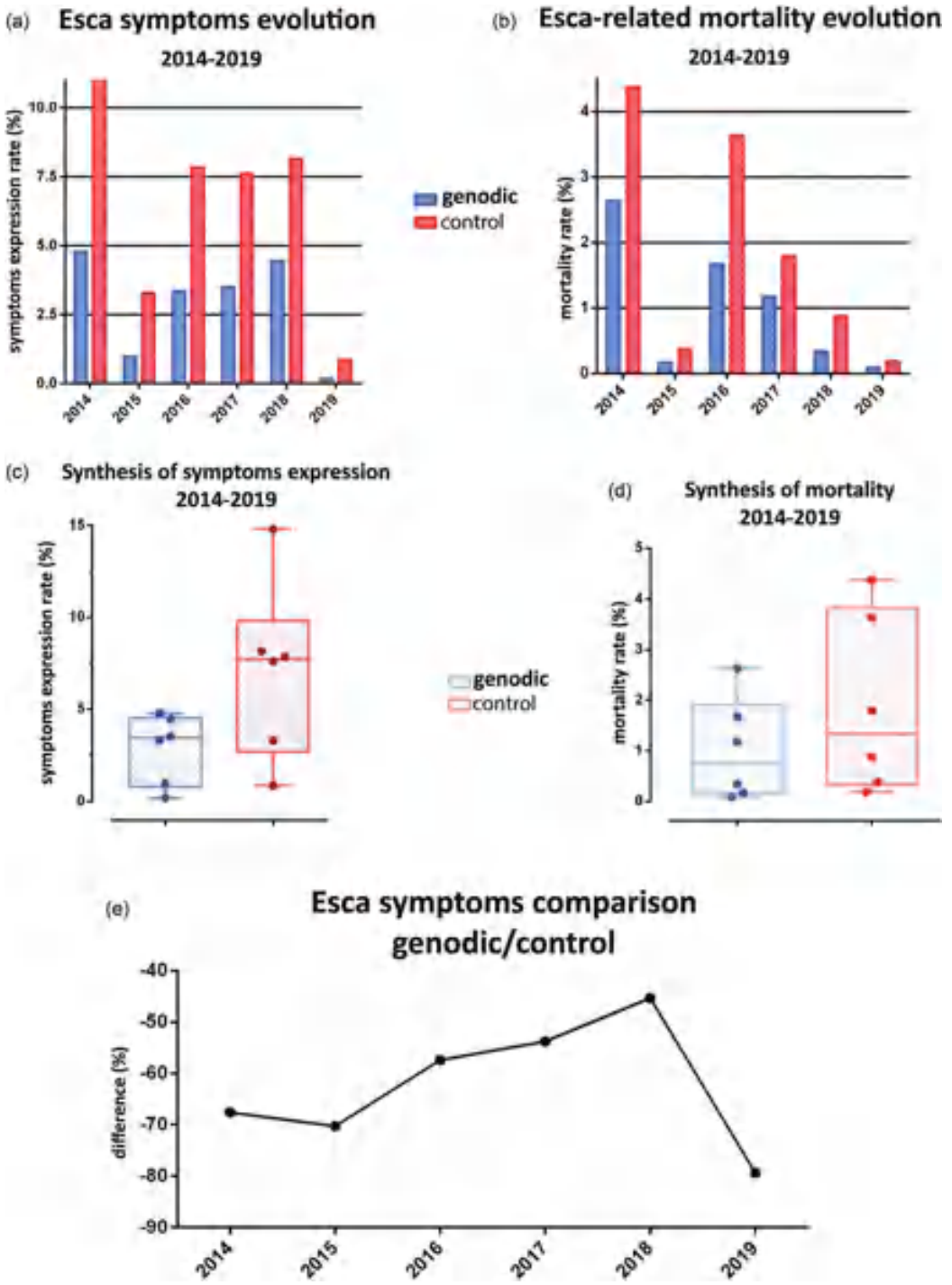

FIGURE 10.3 (a–e) Comparison of the evolution of Esca with and without genodic treatment.

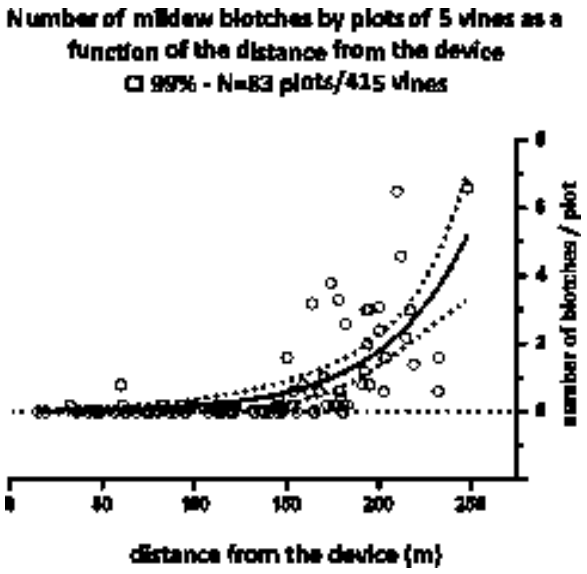

FIGURE 10.4 Number of mildew blotches on grapes, on each plot of five vines, as a function of the distance from the broadcasting device.

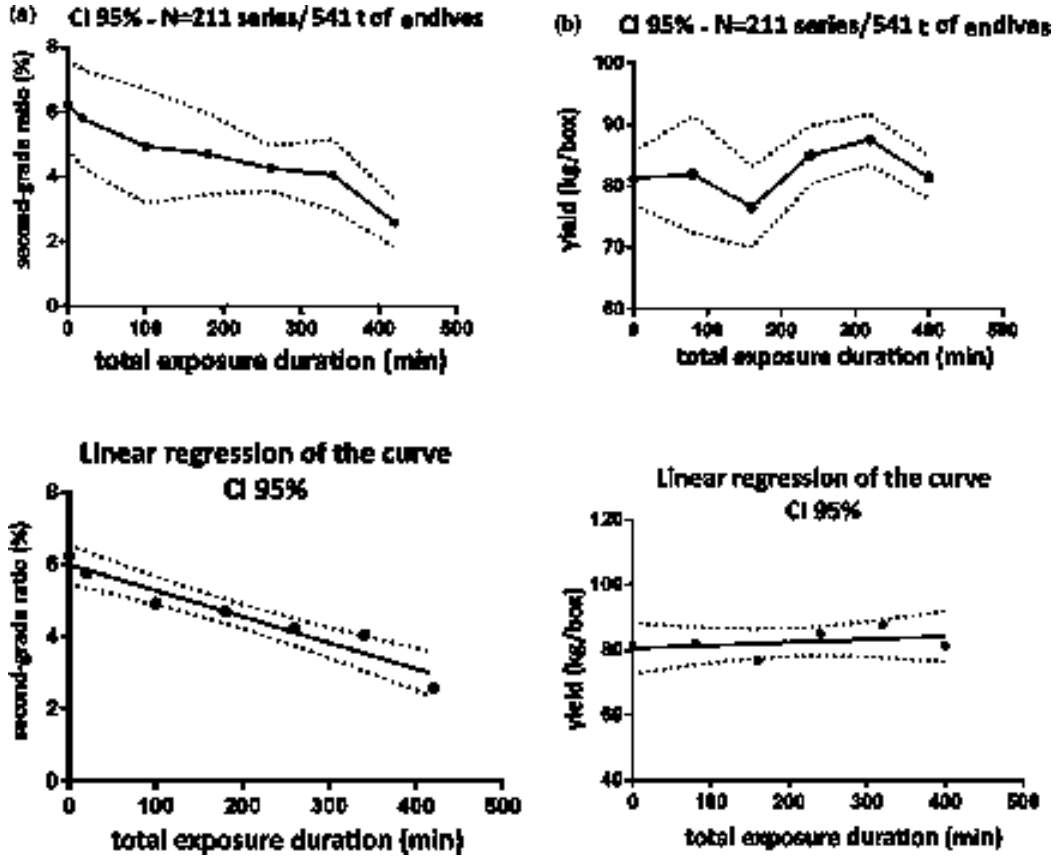

FIGURE 10.5 (a) Change in percentage of second-grade endives as a function of duration of exposure. (b) Evolution of endive yield as a function of exposure time.

to the genodic sequences. Batches that received no diffusion had a rate of second grade of around 6% (±1.5%); then, this rate decreases with diffusion time until it reaches the minimum value around of 2.5% (±0.5%) for a maximum diffusion time of 400 minutes spread over the duration of the forcing (20 minutes each day). The linear regression of these points shows a reduction by a factor of 2, between no diffusion (6%) and 400 minutes of diffusion (3%). In Figure 10.5b, there is an insignificant increase in performance as a function of the duration of exposure to the sequences. The high variability for the production of each batch results in a large confidence interval (between ±5 and ±10 kg/container, although a (insignificant) trend towards increased yield can be observed by linear regression of the data.

Case 4: Reduction of the impact of Mosaic Virus on courgettes.

(Actual distances from the tunnels on the device are as follows: 20, 30, …, 80 m.)

In each tunnel, the values for the number of healthy, diseased or dead plants (as a result of Mosaic Virus) were plotted as a function of the distance from the tunnel to the sequence delivery device. The number of diseased plants increased sharply 30 m away from the diffusion apparatus (tunnel number 3), and then increased more gradually up to plants between 80 and 100 m. The number of symptomatic plants at 30 m appears to be an exception in the linear progression of the number of unhealthy plants, as observed in the linear regression of values (Figure 10.6). The number of healthy

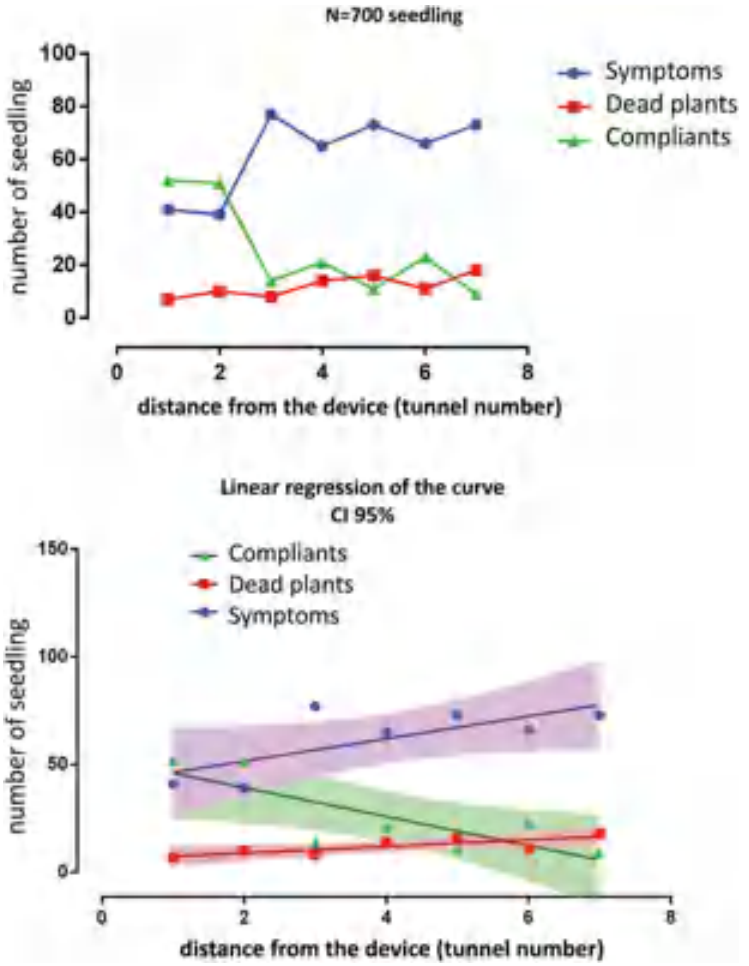

FIGURE 10.6 Virus expression as a function of distance from the delivery device (where compliant signifies healthy).

plants follows the same progression in reverse, decreasing with the distance from the scattering device, from 50% at 20 m to 0% at 80 m. Mortality increased linearly with distance, from 5% at 20 m to 20% at 80 m. The most reliable parameter here is the evolution of mortality, which had a narrower confidence interval and showed a more significant trend. However, the tendency for symptoms to decrease with distance from the device is clearly identifiable, particularly through linear regression of the data.

CONCLUSION

Through these case studies, we have observed the effects of the diffusion of the sound sequences designed by Genodics on plant production results as the following:

- a significant decrease in mortality linked to the vine fungus Esca (between 50% and 70%);
- a reduction in the proliferation of Mildew on grapes by a factor of 6;
- a reduction in virulence in the case of Mosaics on courgettes;
- a significant reduction in the number of second-grade endives, by a factor of 2, through the prevention of Erwinia.

Our experiments demonstrated that within a certain range, the effect of proteodies on plants is proportional to the duration of the broadcast and the power of the sound. This second factor diminishes with the distance from the loudspeaker, resulting in an effect gradient which can be measured.

In the case of Mildew on grapes and Mosaic on courgettes, a spatial gradient of the effect of genodic sequences was noted, while in the case of endives, there was a temporal gradient. This corroborates observations made elsewhere in the field with regard to distance from the diffusion apparatus and diffusion duration. The results are consistent with the characterisation of the effects obtained with this process, over a large number of repeated measurements and several models. These results, in addition to those obtained during the validation of Sternheimer's patent,[1] provide elements that validate the concept developed by Sternheimer and the applications that have followed on since.

This observation is further supported by recent experiments conducted on human cancer cell cultures, published in 2018, during which the assay of the protein specifically targeted by the acoustic sequences was carried out (Orhan & Gulbahar, 2016). Further, plant culture and target protein assays under the conditions of application of the genodic process have recently been implemented in the ERRMECe laboratory at the University of Cergy-Pontoise, Paris (CERGY, 2017). These results, which largely concur with those of this study, were published in September 2020 (Prevost et al., 2020).

The cases presented here represent only a portion of the applications developed by Genodics. The other applications have not benefited from as exhaustive and precise monitoring as the studies cited here, and some applications did not succeed, either because their results were inadequate to be economically interesting or for reasons independent of Genodics' activity. This study demonstrates the effectiveness of chemical-input-free methods for crop protection and support.

Disclaimer: The information contained in this chapter is the property of Genodics SAS. The implementation of the proteodies is protected by copyright.

ACKNOWLEDGEMENTS

We would like to thank all those who participated in the development of this work in biology, in particular Marie-Claude Lang, Vincent Bargouin and Michel Cressy, as well as Jacques-Joël Houziel,

[1] METHOD FOR THE EPIGENETIC REGULATION OF PROTEIN BIOSYNTHESIS BY SCALE RESONANCE, https://worldwide.espacenet.com/publicationDetails/originalDocument?FT=D&date=20070829&DB=EPODOC&locale=fr_EP&CC=EP&NR=0648275B1&KC=B1 (accessed 23 September 2020).

Jean-Marie Pelt and Christian Loizeau. We would also like to thank the vine growers, market gardeners and arboriculturists who have placed their trust in us and who have contributed to these and other research projects. We would also like to thank all Genodics shareholders and all those who have supported and accompanied the company since its inception.

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11 Astronomical Rhythms in Biodynamic Agriculture

A Brazilian Case Study on the Yield and Quality of Daucus carota *L. under Biodynamic Management*

Pedro Jovchelevich
Brazilian Association of Biodynamic Agriculture

CONTENTS

INTRODUCTION

The history of the great civilisations of the past (such as the Egyptians, Babylonians, Greeks, Incas and Aztecs) shows the importance they gave to astronomical rhythms, not only for agriculture, but for all daily activities (ethno-astronomy). Today in Brazil and elsewhere, indigenous populations still apply this knowledge in agriculture. In the 1920s, Rudolf Steiner reconsidered this popular knowledge and extended it, incorporating other rhythms of the Moon and the movement of the planets and the Sun into the planning of agricultural activities. In the international biodynamic movement, the best known astronomical/agricultural calendar is the one created by the farmer Maria Thun (Thun, 1986), which is translated into several languages for worldwide use, and updated every year. Some biodynamic researchers, such as Spiess (1994) and Goldstein (2000), have studied this theme of chronobiology or biological rhythms in cultivated plants. This chapter aims, first of all, to provide some examples of the use of ethno-astronomy in the South, mainly in Brazil, and then reviews selected scientific research on the influence of the Moon on plants and animals, and in biodynamic agriculture. It concludes by reporting the results of some of the author's own field trials on chronobiology.

THE IMPORTANCE OF ETHNO-ASTRONOMY, PAST AND PRESENT

Various ethnological studies document the relationship between the farming practices of indigenous peoples and their knowledge of astronomical phenomena. This knowledge is disappearing, but it can still be observed in traditional populations and especially the use of Moon phases in agriculture and forestry management (Restrepo-Rivera, 2004). Miller (2004) reports the discovery in 1993

DOI: 10.1201/9780429440939-13

of the oldest known celestial disc. It dates from 1600 BC and was found on Mittelberg Hill in Germany. This copper disc, with gold astronomical indications, has been studied by astronomers. It was found to indicate the movement of the Sun between the summer and winter solstices, showing the time when the frosts ended in the region by the position of the sunrise on a certain hill, as seen on the horizon. This information indicated the time when sowing should begin.

Jovchelevich and Vilela (2006), studying the common knowledge of the elderly population in the rural area of Roseira District in Botucatu, SP, Brazil, found that consideration of the lunar phases was a tradition that still persisted, with people having acquired this knowledge from their parents. The use of the waning Moon predominated in their diverse agricultural activities, in particular for chopping wood, but also in the planting and harvesting of grains. The knowledge of the traditional population at the Juréia-Itatins Ecological Station in São Paulo, Brazil, was investigated by Sanches (1997) who observed that the cutting of wood and vines depended on the phases of the Moon, the ideal time for this activity being 3 days before the waning Moon and up until 3 days afterwards.

The astronomical knowledge of the Bororo indigenous people in the state of Mato Grosso (Brazil) was studied by Fabian (2006) who observed their use of the synodic rhythm (the period of time that it takes for the Moon to compete a full cycle), or 'Ari' in their language, for the collection of palm shoots for handicrafts and the planting of specific types of seeds. They also considered the position of the Pleiades star cluster in the Taurus constellation as a seasonal indicator for agricultural activities. Interestingly, Afonso (2006a), who studied ethno-astronomy in sub-Saharan Africa, also cites the use of the star cluster of Pleiades by the Bantu indigenous people. They saw these stars as the shape of a plough, and when this cluster appeared on the horizon after sunset, they knew that the time had come to cultivate the land for planting. He found that the Tupi-Guarani indigenous people in Brazil also knew about and used the Moon phases for hunting, planting and cutting wood (Afonso, 2006b).

Recognition of Moon phases and their use in farming practice plays an important role in 'Quilombola' agricultural management. Quilombos are the descendants of enslaved peoples brought to Brazil, who live in rural communities characterised by subsistence agriculture and by cultural repertoires that have a strong link with their African heritage. They place special emphasis on the waning Moon phase which is when they sow and plant rice, beans, cassava and corn (although for cassava, some farmers prefer the new moon). The waning Moon phase begins 3 days after the full Moon and lasts up to 3 days before the new moon (Jovchelevich et al., 2016).

INFLUENCE OF THE MOON ON PLANTS AND ANIMALS

There is now a growing body of evidence worldwide indicating a relationship between lunar cycles and plant development and growth. Yet when dealing with complex systems, the direct and consistent causal relationship that science seeks is not always detectable. As early as 1953, Simão (1953) undertook doctoral research on the influence of Moon phases on vegetable productivity, using only the Moon phase change day. He concluded that there was no Moon influence, and attributed the changes he found to probable temperature variations and photoperiodism.

Palmer (1974), citing the work of Brown and Chow from 1973, discusses an experiment with beans (*Phaseolus vulgaris*), in which the dried seeds were stored in a cold chamber and then immersed in water for 4 hours every day, from noon, for 8 months over 1 year. A total of 158,000 seeds were used, and their daily weight gain was evaluated. A relationship between the proportions of water in the seeds with the synodic[1] rhythm of the Moon was identified, the weight gain being greatest 1 day before the full Moon.

Endres and Schad (2002:161) describe the work of Maw who in 1967 studied the influence of ionised air on the growth of *Lepidium sativum* L. (garden cress), and noted that growth around the

[1] In the case of the moon's orbit around the Earth, this synodic period corresponds to observations of the moon's phases. The moon has a synodic period of 29.5 days.

full Moon was poor, while growth around the new moon was vigorous. The same authors discuss the research of Rounds (1982) who explored the influence on the activity of leaf extracts from the following plants: *Coleus blumei, Phaseolus vulgaris, Philodendron sagittifolium, Forsythia* sp., *Lilium tigrinum, Ulmus americana* and *Geranium* sp. Rounds found that the stimulating effect was less in extracts made from leaves harvested just before the full and new moons.

In Germany, Spiess (1994) studied the influence of the Moon on several plants (radish, rye, carrot, beans and potatoes) for 6 years and noted the influence of various rhythms on the yields of these species. Potato planted before the full Moon had lower yields, and higher yields were achieved by planting near the lunar perigee (the point of the Moon's orbit closest to Earth). Radish productivity depended on the anomalistic[2] and tropical[3] rhythms of the Moon. In rye, the major Moon phases influenced the germination of the seeds, while the tropical rhythm of the Moon influenced the beans. Carrots sown approximately 3 days before the full Moon and in the Virgo constellation had a higher productivity than when sown in any other zodiac[4] constellation, reaching up to 22% higher productivity, adjusted by a seasonal index. The Moon in Sagittarius gave the lowest productivity for carrots, and carrot cultures were influenced by synodic, sidereal[5] and tropical rhythms.

In the USA, Goldstein (2000) experimented with the influence of the Moon phases on carrot yield. He observed the most positive effect when planting took place the day before the full Moon, causing a 15% increase in productivity (to 11.5 t/ha). This percentage increase was statistically significant at $p = 1\%$. Planting during the new moon appeared to reduce productivity by 12% (10.9 t/ha), with a significance level of $p = 11\%$. Planting during the waning Moon reduced productivity even further, by 17% (9.7 t/ha), and this contrast was significant at $p = 2\%$.

Zürcher et al. (2012) studied the variability of several properties of wood, by analysing measurable parameters. The material stemmed from four different sites in Switzerland, representative of central European conditions. The study involved 576 trees – Norway spruce (*Picea abies* Karst.) and sweet chestnut (*Castanea sativa* Mill.) – felled on 48 dates throughout the autumn and spring of 2003–2004. The wood properties analysed were water loss, shrinkage under controlled drying, and air- and oven-drying density. The statistical analysis of the complete data series revealed (in addition to a seasonal trend) a generally weak but significant role of the synodic and sidereal Moon cycles and, to a lesser extent, the tropical cycle. The lunar-related differences were more marked for the middle months of the trial. The most obvious variation in spruce occurred between samples of trees felled immediately before and after the full Moon.

Deep and Mittal (2014) in India studied the effects of the lunar activity on the sprouting of mung beans and observed a rhythmic character to their potassium content and sprout length that coincided with lunar phases. Statistical analysis of these variations ruled out randomness, with potassium content being highest when they are sown near the new moon, in its first quarter and just after the full Moon (supermoon).

Turning to animals, Elliott (2004) enumerated several scientific studies, showing the relation of the phases of the Moon with the behaviour of mainly aquatic animals. He found that North American crabs mated in the new and full Moons in May and June, grunion fish (*Leuresthes tenuis*) in California migrated to the beach to reproduce a few nights after the full or new moons between February and September, and coral polyps on the Great Barrier Reef reproduced after the full Moon in October and November.

Lobreiro (2002) analysed the relation between date of artificial insemination and the sex of dairy cattle with the anomalistic rhythm. Drawing from 7 years of recorded information from a dairy farm in Mato Grosso do Sul State, Brazil, and data on the occurrence of the lunar perigees

[2] In one anomalistic month, the moon describes its orbit from perigee to perigee, the point at which it is nearest to Earth.

[3] The ascending and descending moon periods, whereby the moon passes through six constellations approximately every 14 days, completing one cycle in about a month.

[4] The set of constellations traversed by path of the Sun across the celestial sphere over the course of the year. The moon and all the planets also traverse these constellations, but at different times.

[5] Timekeeping of the moon's movement through the 12 regions of the zodiac. The moon has a sidereal period of 27.3 days.

and apogees (the point of the Moon's orbit furthest from to Earth), he noticed a greater tendency for male births close to the apogee and females close to the perigee, and more so when insemination occurred within a day of either.

THE USE OF ASTRONOMICAL RHYTHMS IN BIODYNAMIC AGRICULTURE

In modern biology, chronobiology is the sub-discipline that studies the rhythms of life. It includes not only lunar rhythms, but also the rhythms of the day and the Sun (Endres and Schad, 2002). The conceptual basis of biodynamic agriculture embraces the concept of such unseen forces. The farm property is seen as an individuality, an organism with its different components (including soil, plants, animals and humans). Within this, the biodynamic method considers three basic factors: (1) the cycles of substances and forces (forms of activity), (2) the interrelations between the components and the locality and (3) the organisation of the agricultural enterprise. The main goal is the fertilisation of soils in a lasting way through the activation of biological activity to modify the physical and chemical properties of the soil. To this biological aspect is added the dynamic aspect, which consists of the use of biodynamic preparations, using organic and mineral substances in a very diluted (homeopathic) form, and of research-based calendars on the influence of astronomical cycles on land and plants. Thus, biodynamic agriculture has its foundation not only in the practices that it shares with organic agriculture, but also in the recognition that the health of the soil, plants, animals and human beings depends on a broader relationship with forces that stimulate natural processes (Koepf et al., 1983).

Biodynamic agriculture revalues the common knowledge on using the phases of the Moon in agriculture and amplifies it, incorporating other rhythms of the Moon and the movement of planets related to agricultural activities in general. Rudolf Steiner, in the lectures of his agricultural course, addressed this cosmic influence on life here on Earth: the influence of the Moon, the Sun and the various planets and their relationships with soil, plants and animals. According to the first conference of Rudolf Steiner's agricultural course (2001: 34),

> Hence we shall never understand plant life unless we bear in mind that everything which happens on the Earth is but a reflection of what is taking place in the Cosmos.

One of the basic principles of the Maria Thun calendar is related to the movement of the Moon around the Earth in its cycle of 27.3 days, and its passage through the 12 regions of the zodiac (i.e. the sidereal rhythm of the Moon). On each of these days within the cycle, plants receive stimuli that act on the development of their different constituent organs (root, stem, leaf, flower and fruit) (Thun, 2000).

This calendar is also based on the tropical rhythm of ascending and descending Moon periods. These periods should not be confused with the phases of the Moon at different times of the year. Another principle of Thun's calendar is to avoid agricultural activities in so-called unfavourable times. These are periods of eclipses, positions of lunar nodes of the Moon (the draconic rhythm), and perigee (anomalist rhythms) and the negative influence of planets' nodes. (Thun, 2000).

Case Study: Yield and Quality of *Daucus carota* L. under Biodynamic Management, Related to Moon Rhythms

Jovchelevich and Camara (2008) evaluated the influence of Moon rhythms (synodic, sidereal, anomalistic, tropical and draconic) on the yield and quality of carrot (*Daucus carota* L.) roots under biodynamic management sown on different dates. This participatory research was carried out over 2 years on a biodynamic farm in Botucatu, São Paulo State, Brazil. The farmer already held traditional knowledge about sowing carrot on the waning Moon. The influence of rhythms was tested by observing the effects of seeding at different planting dates in spring. In 2005, carrot was sown

every day for 31 days, and in 2006, carrot was sown every other day during the same period as for 2005. The experiment was performed with 4 randomised blocks and 31 treatments (different dates) in 2005 and 14 treatments in 2006. The harvest was undertaken 82 days after the sowing, when carrot roots hold the most desirable qualities for organic and biodynamic consumers. The data for average yields on different days of planting were used to calculate a polynomial equation (as shown in Figure 11.1). This equation produced a line that described the general trend of effects that were due to planting at different times in the spring. The magnitudes of effects associated with planting at a specific lunar position were measured by the deviations from the trend curve (as shown in Figures 11.2 and 11.3). The more deviation up the curve, the better the result. The following characteristics were evaluated: fresh mass of roots and leaves, dry mass, root diameter, root length, the nitrogen, phosphorus and boron contents of the roots, and the perishability of the roots at 30, 60 and 90 days post-harvest. These values were then analysed using a statistical analysis package. Statistical contrasts were used to compare the yields obtained (see Table 11.1).

Dry root mass was the only characteristic in the contrast between averages that showed significant results in both years of the experiment. Dry root mass is a very important characteristic because the roots are where all the nutrients of the plant are stored. Results showed that seeds sown in the new moon phase grew better than those sown in the waxing and waning Moon phases,

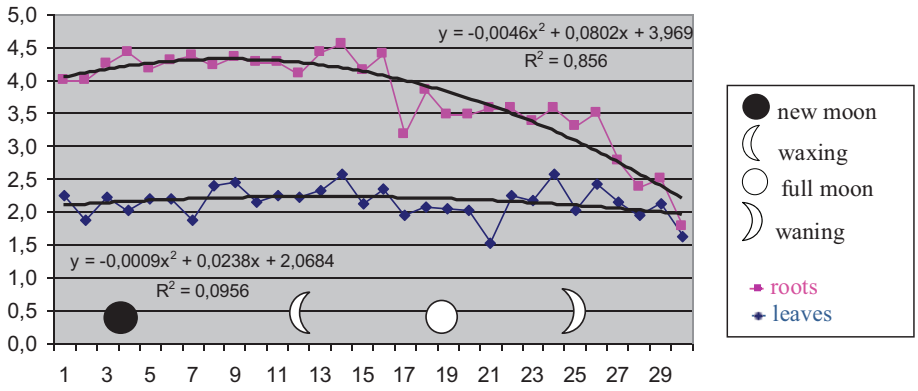

FIGURE 11.1 Fresh mass of roots and leaves (kg, Y-axis) for the different dates of sowing (X-axis) in 2005.

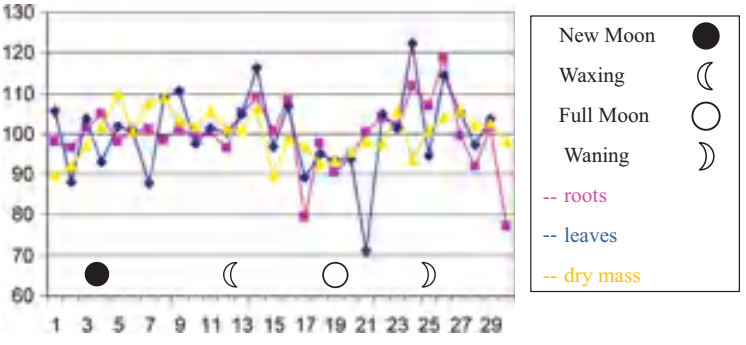

FIGURE 11.2 The per cent deviation from the trend line of the fresh root and leaf mass and dry mass of roots (Y-axis) for the different sowing dates (X-axis) in 2005.

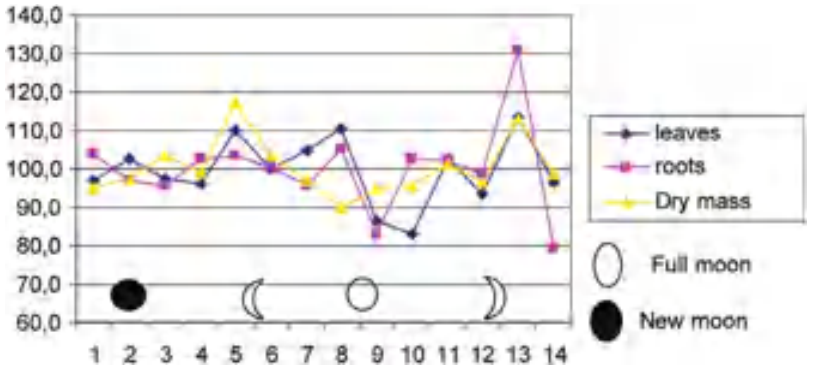

FIGURE 11.3 The per cent deviation from the trend line of the fresh mass of roots and leaves and dry mass of roots (Y-axis) for the different sowing dates (X-axis) in 2006.

TABLE 11.1

Deviations from the Trend Curve (%) of Fresh Mass of Roots (FMR) and Leaves (FML) and Dry Mass of Roots (DMR) of Carrots, According to the Different Lunar Rhythms, in 2005 and 2006

Lunar rhythms	FMR 2005	FMR 2006	FML 2005	FML 2006	DMR 2005	DMR 2006
Synodic						
Before full Moon	95.84	105.37	97.05	110.55	96.06	89.85
Before new moon	98.89	103.81	99.19	96.97	**93.15**	95.04
Sidereal						
Root days	101.43	97.95	102.56	101.58	100.77	100.57
Fruit days	95.41	**94.69**	**91.91**	95.55	99.20	98.76
Flower days	103.15	102.16	103.25	100.00	101.20	95.20
Leaf days	99.89	**105.28**	100.42	101.79	99.39	**105.01**
Tropical						
Descending	101.31	101.22	101.00	98.25	100.18	100.15
Ascending	98.61	98.41	98.28	101.36	100.06	100.21
Anomalistic						
Apogee	99.18	100.40	97.62	99.99	101.78	103.46
Perigee	89.18	**117.36**	**70.91**	**105.23**	98.11	104.10
Draconian						
Ascending node	93.36	**117.36**	**92.72**	**105.23**	97.13	104.10
Descending node	**107.72**	95.80	**106.79**	104.82	98.78	96.77

Source: Botucatu – UNESP (2007).

and grew worse of all in the full Moon phase. In the 2 years of research, the dry mass production of seeds sown at the new moon phase was higher than that of those sown at the full Moon phase ($p < 5\%$). Goldstein (2000) observed better results when carrot seed was sown 1 day before the full Moon, while Spiess (1994) observed better results when the carrot was sown 2 days before the full Moon. While there is little research on this topic, these different results may be because of the

influences of the northern and southern hemispheres, indicating that attempts to compare between different geographic regions may be problematic.

According to Thun's astronomical calendar, carrots should be sown on a 'root day' (when the Moon is passing through Virgo, Taurus or Capricorn), yet I found no evidence that seeds sown on such days were more productive, so further research with longer periods of observation is required here. The evaluation of the sidereal rhythm in 2006 showed that seeds sown on leaf days were more productive than those sown on root days, and both showed better results than those sown on the fruit and flower days (Table 11.1). Spiess (1994) observed that carrots sown when the Moon was in Virgo (a root day) had a higher productivity than those sown when the Moon was in any other constellation.

The negative effect of the nodes and perigees on yields of fresh root matter was statistically significant in 2005, but was not observed in 2006 (Table 11.1). According to Thun's astronomical calendar, both the nodes and perigees are unfavourable for sowing.

On the other hand, the tropical rhythm of the Moon did not present statistically significant results at all: the reason for this could be that Botucatu City is located very close to the tropic of Capricorn and is not strongly influenced by tropical rhythms, whereas Thun's studies occurred at higher latitudes.

Comparing the results of the research with traditional knowledge about the influence of the Moon on crop growth, the empirical results support the traditional practice of sowing carrots between the waning Moon and the new Moon phases.

FINAL CONSIDERATIONS

Various ethnological studies document the relationship between the farming practices of indigenous peoples and their knowledge of astronomical phenomena. Some biodynamic researchers have studied this theme of chronobiology or biological rhythms in cultivated plants. In Brazil, the effect of the Moon's synodic rhythm is highly valued by family farmers and indigenous people and it was precisely this aspect that provided the most consistent statistical results. The results of our field trials support the common wisdom of sowing carrot from the waning Moon to the new moon phase. Our experiment showed that dry mass was the only measured aspect that showed significant positive results in the two periods of the experiment, with the results indicating that the synodic new phase was a superior time to sow compared to the other phases.

Modern agriculture uses costly artificial technologies with little consideration of their environmental or human health impacts. Such technologies are far removed from the ancestral knowledge of past civilisations and current indigenous communities. Biodynamic farming recovers the importance of lunar rhythms to enhance sustainable agricultural management. This research shows the complexity of life and the need to search for a new scientific paradigm, with a more holistic approach for understanding complex systems, and highlights the need for further research on the influence of astronomical rhythms in agriculture.

ACKNOWLEDGEMENTS

I am grateful to farmer Didi Baldini (in memory) for his willingness to share his knowledge and experimental results, and for the support of the Brazilian Association of Biodynamic Agriculture.

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12 Electromagnetic Parameters Related to Plants and Their Microbiomes

Ed Moerman
Koppert Biological Systems

CONTENTS

INTRODUCTION

Few people relate electricity or electromagnetism to plants and plant growth, perhaps because the electrotechnical and plant physiological disciplines seem so different. But there are many electrical and electromagnetic parameters that can be measured in plants and in their environment. This chapter describes a number of these parameters and how they can help us to better understand the plant and may even be used to enhance plant growth. Electrophysiology is the discipline that deals broadly with the flow of ions/electrons in biological tissues and, in particular, to the electrical recording techniques that enable the measurement of this flow. Prof. Volkov has edited various books on this subject, collecting work from scientists from all over the world. The latest work is titled *Plant Electrophysiology*, *Signaling and Responses* (Volkov, 2012: v). Its preface gives a comprehensive description of electrophysiology:

Plant electrophysiology is the study of the electrochemical phenomena associated with biological cells and tissues in plants. It involves measurements of **electrical potentials** and **currents** on a wide variety of scales from single ion channels to tissues to entire plants or trees. Electrical properties of plant cells mostly derive from the electrochemical properties of their membranes. Electrophysiological study of plants includes measurements of the electrical activity of the phloem, xylem, plasmodesmata, stomata and particularly the electrical signal's propagation along the plasma membrane. **Action potentials** are characteristic responses of excitation that can be induced by stimuli such as applied pressure, chemical substances, thermal stimuli, electrical or magnetic and mechanical stimuli, and biotic stressors.

Around 2010, the company I work for started to sell biostimulants to professional growers to improve the resilience of their crops to biotic and abiotic stresses. One of my tasks as knowledge manager was to search for indicators of plants' resilience by asking the following questions: Is there

DOI: 10.1201/9780429440939-14

any method to quantify the condition of the plant and the risk for those stressors causing economic damage? and How can you measure improved resilience after the application of biostimulants? During one of many field visits to greenhouse growers, I experienced a kind of life-changing incident. A top-level Dutch gerbera grower I was visiting had been facing serious problems with his crop from the moment he had installed a combined heat and power (CHP) system in a room next to his new greenhouse. Yearly production figures gradually dropped from 300 to 200 flowers/m^2, and in addition to that, chemical pesticides showed sub-optimal performance. This had already been going on for more than a year, and no one was able to discover the reason for these problems. While brainstorming during a stroll through the greenhouse, a seemingly simple remark of the grower drew my attention. He said that the irrigation water pipe from the borehole to the greenhouse was installed very close to the CHP's power output cable. This did not feel right, although I could not find any hard evidence against it. Despite this, and desperate to solve the problem, the grower changed the irrigation water supply from borehole to tap water and started using a water vitaliser (a device that improves the molecular structure of water by exposing it to certain vibrations). The result was beyond all expectations: within a week, the grower observed visible change in the plants' appearance, and after some weeks, production returned to the previous high level of 300 flowers/m^2 on a yearly basis. This broadened my perspective, and I started collecting publications about plants, stressors and electric phenomena and undertook some basic measurements myself in ongoing experiments and with practical growers to become more familiar with the topic.

This chapter is a compilation of what I have learned from publications, participating in experiments and talking to people who are already more familiar with this topic. It has been an interesting journey, one which has perhaps only just begun. To begin with, the following section explains the main electrical terms used.

EXPLANATION OF SOME ELECTRICAL TERMS

For a good understanding of the rest of the chapter, here are some short definitions of terms related to electricity. Electricity is the set of physical phenomena associated with the presence and motion of matter that has a property of an electric charge: electrons, as well as protons (H+) and other ions. At the beginning of the nineteenth century, electricity was considered as being unrelated to magnetism. Later on, many experimental results and the development of Maxwell's equations[1] indicated that both electricity and magnetism are from a single phenomenon: **electromagnetism**.

The movement of any moving charged particles through a conductor is known as an electric **current**, measured in (milli)amperes. A simple voltmeter can be used to measure the **voltage (or potential difference)** between two points in a system; often a common reference potential, such as the ground of the system, is used as one of the points. A **voltage** may represent either a source of energy (an electromotive force which can create a **current**) or lost, used or stored energy (**potential drop**). Current can flow through electrical conductors meeting a certain **resistance** (measured in ohms). The resistance is a consequence of the motion of charged particles through a conductor. In metals, for example, resistance is primarily due to collisions between electrons and ions.

Conductivity is expressed in mS/cm and is the inverse parameter of resistance. Liquids show a lower resistance (or higher conductivity) when more ions/electrolytes are dissolved.

Current can be **direct current** (DC) or **alternating current** (AC). DC is a one-directional flow of charge; AC reverses direction repeatedly at a certain frequency (expressed in Hz, fluctuations per second). This is often sinus shaped, but other shapes such as blocks also exist.

The electrical properties of **inductance** and **capacitance** are only observed under AC. **Inductance** describes the tendency of an electrical conductor, such as a coil, to oppose a fluctuation in the electric current going through it. A capacitor is a device which allows electricity to pile up by

[1] Maxwell's equations describe how electric and magnetic fields are generated by charges, currents and changes in the fields.

providing space for it to spread out. A capacitor has a **capacitance**, measured in farads (F), or more often microfarads.

An **electric field** is created by a charged body in the space that surrounds it, and results in a force exerted on any other charges placed within the field. The **electric power** produced by an **electric current** (I) passing through an **electric potential** (V) difference is expressed in watts ($P=I\times V$; work done per unit time).

Many important biological processes involve **redox** reactions. **Oxidation** is the loss of electrons or an increase in oxidation state; **reduction** is the gain of electrons or a **decrease** in oxidation state by a molecule, atom or ion. The **reduction potential** (mostly expressed in millivolts – mV) is a measure of the tendency of the oxidising agent to be reduced.

The **phase angle** is the phase difference between an alternating voltage applied to a conductor or capacitor and the alternating current driven through it. It is expressed in degrees, as shown in Figure 12.1.

Electrical **impedance** is the measure of the opposition or **resistance** that a circuit presents to a **current** when a **voltage** is applied.

ELECTRIC PHENOMENA INSIDE THE PLANT

What drives life is just a little electric current, kept up by the sunshine. All the complexities of intermediary metabolism are but the lacework around this basic fact (Szent-Gyorgyi, 1960).

Photosynthesis is the process that increases the potential energy of electrons as they move from water to sugar. Photosynthesis relies on flows of energy and electrons initiated by light energy, which causes the excitation of electrons in chlorophyll that pushes them out of their orbit. The electrons instantly fall back into place, releasing resonance energy. This energy passes rapidly to the chlorophyll molecules, like the transfer of energy from one billiard ball to another. Photosynthesis thus converts light energy into chemical energy, stored in organic molecules. In terms of redox, reduction takes place (see Table 12.1). Reduction implies an increase of electrons in the plant tissue, enabling the plant to mitigate free radicals and better cope with oxidative stress.

A living plant (or tree) transports electrons from the earth to its top. Electrical engineer Arthur Ramthun (2015) used a digital voltmeter and oscilloscope to measure and record the electric potential between the ground, trunk and branch tips of many different trees. Billions of electrons appear to flow up the trees and outwards to branch tips (e.g. 2.8×10E+11 electrons per second to each Aspen branch tip). His model calculations show that this amount of electrons creates enough repulsive force at the branch tips to direct growth direction and influence plant geometry. This phenomenon he named 'electrotropism'. From measurements on a specially prepared young corn plant, he learned that electrons came from the water, through the roots and to the stem of the plantlet.

Clark et al. (2013) demonstrated that plants create an electric field with negative potential around flowers. Pollinators (such as the bumblebee *Bombus terrestris*) are able to detect and distinguish these electric fields. Pollinators usually possess a positive electric potential, acquired during their

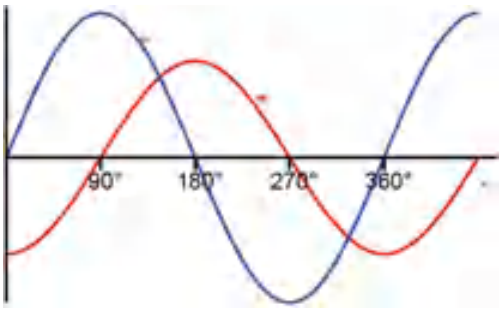

FIGURE 12.1 Phase angle: alternating current (red line) lags 90° behind alternating voltage (blue line).

TABLE 12.1
Reduction and Oxidation in Relation to Plant Growth

	Reduction	Oxidation
Electrons	Gained	Lost
Eh value	Decreases	Increases
Takes place in plant processes	Photosynthesis Proteosynthesis Liposynthesis Synthesis of antioxidants, phenols, etc.	Dissimilation: oxidation (of reduced compounds) avails energy, used for metabolic processes in plants
Energy	Increases chemical potential of molecules	Uses energy stored in molecules
Meaning	Antioxidants important for plant defence	Plant stresses have oxidising effect

flight. The potential difference between pollinator and flower is one of the cues that helps pollinators to find flowers that are ready to be pollinated. It is also a driving force for the transfer and adhesion of pollen during the flower visit. The deposition of pollen and the resulting pollination change the flower's electric potential, so the electric field differs according to the pollination status of the flower. This helps pollinators to focus on the flowers that still need pollination, and not to revisit the pollinated ones.

In 2015, Koppert Biological Systems performed greenhouse trials with tomatoes grown in rockwool substrate with different additions of biostimulants and biochar to stimulate the development of the root microbiome (Moerman, unpublished research, 2015). Orienting measurements of potential differences between the rockwool slabs and the stem base of tomato plants in these greenhouse trials showed a potential difference between 0.5 and 0.6 V, the stems having the lower value. These values, and the polarisation, correspond with what other researchers, Ramthun (2015) and Rajda (2004), found in trees and herbaceous plants.

USING THESE ELECTRICAL PARAMETERS TO BETTER UNDERSTAND AND MONITOR PLANTS' STATUS, DEVELOPMENT AND PROCESSES

In this section, I discuss a range of examples of how various electrical parameters can help to better understand and monitor the plant. The examples given are just a snapshot of the huge amount of work done in this field. They are selected on the basis of their simplicity and potential to provide answers to my search for a method to quantify the condition of the plant and its resilience. The equipment needed to undertake the measurements should be affordable to growers/advisors and simple to operate.

Rajda (2004) measured the electric current flowing between the ground (measured in the soil at some distance from the stem base) and the stem base of hundreds of individual trees. Stems always showed a negative potential compared to the earth. Measurements showed different values for different tree species, positively correlated with stem diameter (and showing a typical seasonal pattern), and lower values for unhealthy trees. With this information, he was able to predict health problems by frequently checking the seasonal current and benchmark this value against the same values of similar trees. Table 12.2 shows the range of values measured in different groups of plants. Frequent measurements of these parameters helped to predict which trees were going to have health problems, before the symptoms were visible.

Vivent,[2] a Swiss-based bio-signal company, is developing an innovative device for exploring and monitoring electrical signals in plants. These devices capture the bio-signals that plants themselves

[2] http://www.phytlsigns.com/.

TABLE 12.2
Range of Currents and Potential between Ground and Stem Base in Different Types of Trees or Plants

Type of Plant/Tree	Maximum Current (μA) Related to Stem Diameter (cm) (μA/cm)	Potential (V)
Deciduous trees	200–500	1.2
Conifers	100	1.0
Vegetables and ornamental plants	8–117	0.4–0.7

Source: Rajda (2004).

are transmitting. The device (PhytlSigns) measures potential differences between the root zone, stem base and leaves. Measured values (voltage) are recorded at very short time intervals. Deep analysis (with the help of artificial intelligence) of the voltage line patterns comparing plants with and without known biotic and abiotic stressors reveals that different types of plant/stressor combinations show a typical pattern. At present, the device is already used by a Swiss research station and had demonstrated that a pesticide spray can put plants 'on hold' for hours to days, depending on the type of pesticide (Personal communication with N. Wallbridge, 2019). The company claims that this device 'can be used to investigate plant responses to diseases, pests, crop protection treatments and environmental conditions'.[3] In time, this device could provide an intelligent monitoring system to detect stressors early on in order to help the grower anticipate potential problems.

The investigation of plant roots is inherently difficult and therefore often neglected. Being out of sight, roots are often out of mind. Nevertheless, roots play a key role in the exchange of mass and energy between soil and the atmosphere, and therefore, it is useful to be able to better monitor root growth and root activity.

The size and activity of the plants' root system are good predictors for plant condition, but difficult to assess. Cseresnyés et al. (2013) did a lot of work on how to use electrical impedance spectroscopy[4] to measure root systems and stressed the usefulness of measuring the phase angle between alternating potential (voltage) between the stem and root zone and resulting AC, for the rapid *in situ* investigation of the root system size and root activity without any intrusion into plant life functions.

Dietrich et al. (2013) report that electrical capacitance, measured (with an LCR meter[5]) between an electrode inserted at the base of a plant and an electrode in the rooting substrate, is often linearly correlated with root mass. Electrical capacitance has often been used as a proxy for root mass and is conventionally interpreted using an electrical model in which roots behave as cylindrical capacitors wired in parallel. However, recent experiments in hydroponics show that this interpretation may not be correct and a newer model has been proposed by Dietrich in his doctoral thesis (2013), in which he revised the existing model of resistance–capacitance circuits in plants and which is tested in solid substrates. The results were consistent with the new physical interpretation of plant capacitance. Substrate capacitance and plant capacitance combine according to standard physical laws. For plants growing in wet substrate, the capacitance measured is largely determined by the tissue between the surface of the substrate and the electrode attached to the plant. While the measured

[3] From the company website https://www.phytlsigns.com/product-solutions (accessed 1 July 2020).

[4] Electrical impedance (EI) and electrical capacitance (EC) measurements in a plant–soil system offer good opportunities of rapid *in situ* investigation of the root system size and root activity. By fixing an electrode at the plant stem and embedding the other one in the soil and connecting them by an LCR instrument, the measured root EI and EC are directly correlated with root mass, root length or root surface area (Chloupek, 1972; Ozier-Lafontaine and Bajazet, 2005; Rajkai et al., 2002).

[5] An LCR meter is an electronic test equipment used to measure the inductance, capacitance and resistance of an electronic component.

capacitance can, in some circumstances, be correlated with root mass, it is not a direct assay of root mass (Figure 12.2).

In 2015, Koppert Biological Systems performed a dedicated propagation trial with cucumbers grown in perlite to validate the findings of Dietrich (2013) and Cseresnyés et al. (2013) in a greenhouse situation (Moerman and Weber, unpublished research, 2015). Measurements of the phase angle and dry root weight of 2 groups of 25 plants taken on 4 and 9 March 2015 confirmed the

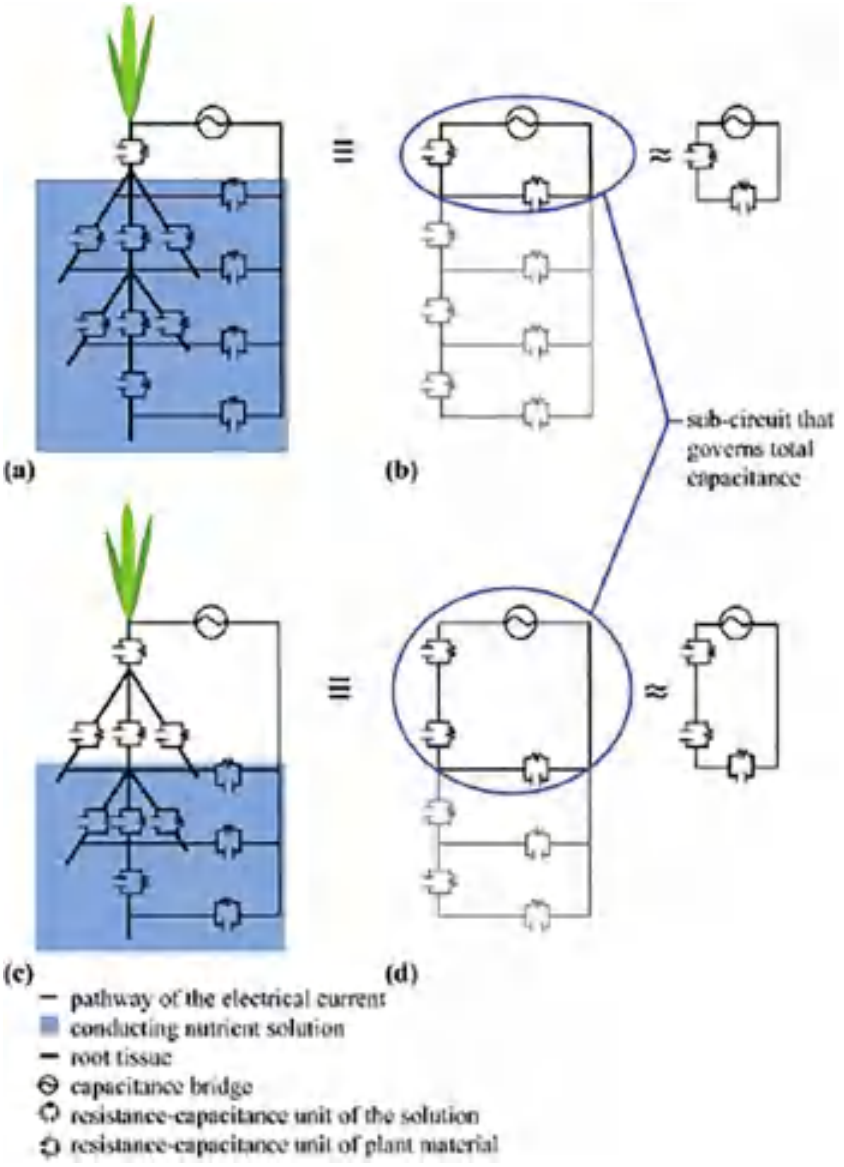

FIGURE 12.2 Resistance–capacitance (RC) circuits according to the revised model: (a,c) diagrams of barley plants with five root tips, (b,d) electrical equivalent networks of the root systems showing the location of the RC components, (a,b) RC circuits for a completely submerged root system and (c,d) RC circuits for a partly submerged root system. The sub-circuit that largely determines the capacitance is ringed to emphasise its importance. Note that the individual RC components can have different values.

correlation between phase angle and dry weight of the root system and showed that a non-destructive measurement of phase angle has the potential to replace the destructive and time-consuming measurement of root dry weight (Figures 12.3 and 12.4).

Postic and Doussan (2016) compared various electrical methods to estimate root mass. The parallel measurement using a clamp as a stem electrode of capacitance and a hand-held LCR meter at an alternating current gave the most reliable results. They found that the frequency of the AC current used plays a role in the accuracy of the outcome.

Benada (2017) described his investigations on variable resistance in wheat plants as a starting point for considering the nature of variable disease resistance of cereals against obligate

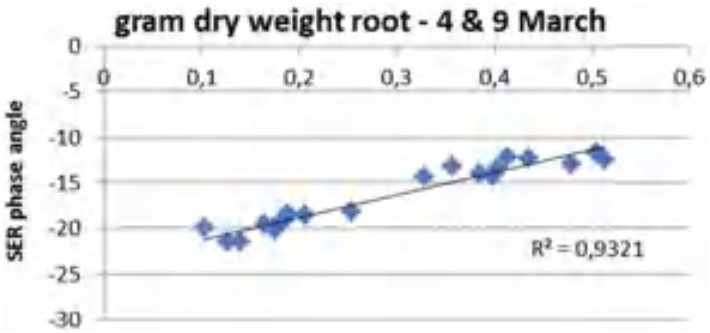

FIGURE 12.3 Correlation between gram dry root weight per plant (X-axis) and phase angle (Y-axis).

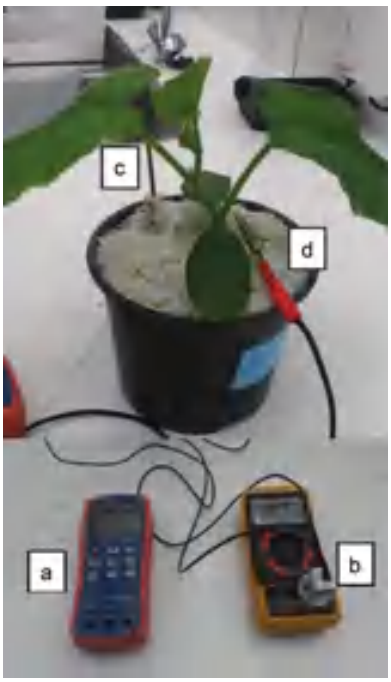

FIGURE 12.4 Simple LCR meter (a) and voltmeter (b) used for measurements of cucumber plants in pots. (c) The grounding probe and (d) a crocodile clamp on a needle inserted into the stem at the plant base.

parasites[6] such as powdery mildew and rust, in which redox potential and pH measurements in leaf sap were the main observations. He developed a simple and quick method for redox measurements in the tissue of detached leaves and formulated a hypothesis for why the biophysical status of a plant plays such an important role in resistance, and plant physiology in general. He found that the principle of resistance lies in the ability of the parasite to gain the energy from the host cell. The parasite uses the terminal oxidase of the host plasmalemma (the plasma membrane of the cell wall) as its energy source.

Plant roots generate electric currents and associated electric fields as a consequence of electrogenic ion transport at the root surface. van West et al. (2002) demonstrated that swimming zoospores of oomycete plant pathogens[7] to plant roots are partly attracted by electrotaxis (the movement of an organism in an electric field) in natural root-generated electric fields. The zones of accumulation of anode- or cathode-seeking zoospores adjacent to intact and wounded root surfaces correlated with their in vitro electrotactic behaviour (either attracted to the anode or the cathode). Manipulation of the root electric field was reflected in changes in the pattern of zoospore accumulation, and imposed focal electric fields were capable of overriding endogenous signals at the root surface. Data suggested that electrical signals from a potential difference (voltage) between root and rhizosphere/rhizoplane can augment or override chemical cues in mediating short-range tactic responses of oomycete zoospores at root surfaces. These findings may help in the future to better assess risks for infection of root-borne diseases.

Akay and Kara (2006) investigated quality parameters that can be measured by different methods. One of them is Vincent's bioelectronic method (BEV). The *P*-value is measured in sap pressed from fruits or vegetables. It is based on three factors: pH (acidity), rH (redox potential) and *R* (resistivity). The *P*-value integrates the three parameters to a parameter of quality and is calculated as $[30\times(rH-2pH)]2/R$ (Hoffmann, 1991), which is expressed in microwatts (μW).

These electrochemical parameters can tell us something about the production conditions and the effects on humans after consumption. Products with low *P*-value are supposed to be health promoting. Good foods give us more power than bad ones and are good for our health. Life processes in plants and animals can be described as chains of electrochemical or redox reactions. The *P*-value is used in the areas of environment, human medicine and food research. Food with low redox values provides many electrons that counteract free radicals (in other words have an anti-oxidising effect) and hence contribute to health. Good examples of these 'curing foods' are beetroot, (organic) carrots and fermented cabbage.

Hoffmann et al. (2007) worked on electrochemical quality assessment, using the redox potential (rH in mV), resistivity (ohm) and pH of a liquified, homogenised sample. In his book, Hoffmann explained the relationship between redox value and entropy: a lower redox potential coincides with lower entropy, which means less chaos or more organised tissue.

Northolt et al. (2004) investigated the usefulness of electrical parameters to assess carrot quality and the development of the inner quality concept and concluded that these measurements can be valuable. Their report presents a comprehensive explanation of the meaning of the different parameters, as provided in Box 12.1.

EFFECTS OF APPLIED, EXTERNAL, ELECTRICAL (ELECTROMAGNETIC) FACTORS ON PLANTS AND THEIR MICROBIOMES

This section explores a number of experiments aiming to influence plant growth to the benefit of the grower/farmer. Although this work started in the beginning of the twentieth century, to the author's

[6] An obligate parasite is a parasitic organism that cannot complete its life cycle without exploiting a suitable host. If an obligate parasite cannot exploit a host, it will fail to reproduce.

[7] Oomycetes, also known as 'water moulds', are a group of several 100 organisms that include some of the most devastating plant pathogens. The diseases they cause include seedling blight, damping-off, root rot, foliar blight and downy mildew.

BOX 12.1 EXPLANATION OF THE USEFULNESS OF DIFFERENT ELECTRICAL PARAMETERS (NORTHOLT ET AL., 2004: 56)

Life processes in plants and animals can be described as chains of electrochemical or redox reactions. Hoffmann (1991) explains how Haas developed a bioelectric theory to derive an electrical energy value for food from measurements of pH, redox potential and electrical resistance. He suggested that food with high reducing power, later expressed as low *P*-value, promotes health. The *P*-value is calculated from the three stated parameters which are affected by the growth conditions of the product. The pH value is the best known electrochemical parameter to measure proton concentration or acidity. The pH is measured by potentiometry using suitable electrodes. The measured mV value is logarithmically transformed to the pH value. The potentiometric equilibrium is at pH 7 and 0 mV. A difference in pH of 1 (at 25°C) equals 59 mV. In plants, proton activity has energy aspects. The redox potential Eh (mV) reflects the gradient of electrons which life processes utilise for their cellular work (Kollath, 1978). The redox potential represents the equilibrium between oxidising and reducing substances. When redox potential is low, plant cells have more energy for their activity. Traditionally, the flow of electrons is considered to be the main form of respiratory energy transport in an organism with oxygen as the terminal electron acceptor. Electrical resistance *R* (ohm) gives an indication of the dissipation of electrolytes in plant cells. High values of electrical resistance indicate that electrolytes are more integrated in membranes and cell organelles. Low values indicate free-moving electrolytes, which might be a sign of deterioration in plant cells and tissues.

knowledge only a few patents have been filed and none of them are as yet applied on a commercial scale. Undoubtedly, there may be many more examples.

Blackman et al. (1923) performed detailed research on the effect of a positively loaded discharge point just above the top of grounded cereal plants, showing it had a lasting effect on the growth rate of barley sheaths. Similar trials in which the direction of the current was reversed did not give the same positive effects, and in some cases results were even negative. So the direction of the current appeared to be important.

Rajda (2004) managed to enhance plant growth by putting a DC voltage on positive and negative electrodes on opposite sides of the substrate in a growing table. However, the mode of action was not explained and could be caused directly by the potential difference or by electrolytic effects on the dissolved nutrients. Wawrecki and Zagorska-Marek (2007) demonstrated that even a weak (1 V/cm) DC electric field with a horizontal direction disturbed the pattern of cell divisions in plant root meristems of maize. This in turn changed the global organisation of the root apical meristem: it influenced the direction of apical root growth. A field of slightly higher strength also damaged root cap initials, terminating their division. This implies that care should be taken when applying this technique and not to apply too high an intensity of treatment. It is not clear if and how this phenomenon could be used to the benefit of growers/farmers. But one could image that stray current[8] could not only affect farm animals but also crops in a way that is not yet understood.

Gasner (2013) demonstrated a positive effect of grounding the root medium of pepper plants grown in pots. Devices were inserted into the plants' growing medium at an angle towards the centre of the pot and connected to earth. Grounded plants grew better and produced more fruits than ungrounded plants. The measure of grounding provided the plants with a continuous stream of electrons from the earth, which could also be measured. The voltage between grounded plants and

[8] Stray current refers to the electricity flow via buildings, ground or equipment due to electrical supply system imbalances or wiring flaws. It refers to an existence of electrical potential that can be found between objects that should not be subjected to voltage.

earth varied between 200 and 300 mV, which is in the same range as in herbaceous plants (Rajda 2004) and also concurs with the author's own (unpublished) trials in 2015 of tomatoes grown in rockwool. Unfortunately, while there are many publications about the positive effects of grounding on human health, this is the only publication showing the positive effects of grounding on plant growth, and the grounding devices for plants that the author has developed may have a commercial potential. There is a patent filed for grounding rods for plants,[9] but it is unclear if this has yet been commercialised.

Olyslaegers (2012) states that electroculture has been investigated for a long time, but with inconsistent results. He defines electroculture as any electrical stimulation of plants. His research focused on the question of whether young tomato plants (*Solanum lycopersicum*) could be electrically stimulated in a manner that would be practically feasible in commercial greenhouses. As well as the attempt to demonstrate the 'proof of principle' and investigate possible mechanisms, attention was paid to the possibilities of this technique with regard to a decrease in the costs and quantities of nutrient usage in intensive greenhouse cultivation. He worked with a low DC voltage (0.1–0.2 V/cm) and two polarities, applied via a piece of felt underneath rockwool blocks. The results were inconsistent.

A recent publication from India (Patil, 2018) describes experiments to study the effect of electricity on germination and growth of radish (*Raphanus sativus*). Here, plants were only briefly exposed to low DC voltage: 3, 6 and 9 V for 10 minutes per day. This helped increase germination rates from 85% in the control sample to 95% in the treated sample.

A very promising method to stimulate plant growth with electricity is described in PJJ van Zyl's thesis (2012) on radio frequency energy for bioelectric stimulation of plants. This principle uses electromagnetism. The study is about utilising low power radio frequency (RF) energy signals from leaky transmission lines for the benefit of plant growth and production in hydroponic systems. The way it works is that plant cell walls are covered with tightly bonded, positively charged calcium ions that affect the inflow of nutrients into the cell. As calcium ions have a mass twice that of the potassium ion, the fundamental harmonic of calcium is equal to the first harmonic of potassium (32 Hz). Thousands (10k:1) fewer positive potassium ions also exist around the cell wall, and when stimulated at their resonance frequency (16 Hz), they will bounce against the bonded calcium ions so that these calcium ions become dislodged from the cell wall. When this happens, more nutrients can enter the cell causing an acceleration in plant growth. However, it is important to control the process, because if too many calcium ions are released it would cause plant stress and a breakdown in the plant structure. The amplitude modulated (block, as opposed to sinus) wave allows sufficient time for the calcium ions to return to the cell walls during the period without externally applied energy. One medium to apply radio energy to a plant is to transmit the energy into two leaky transmission lines to cause standing waves, which can then be absorbed by plants placed between these transmission lines. The energy from the radio waves is then used to create window periods during which the calcium ions are dislodged, allowing additional nutrients to enter the plant cell, enhancing plant growth and production. In the thesis, van Zyl also refers to a US patent from Kertz (1995) where principles of electronic stimulation of plants are described extensively and illustrated with trial results. Van Zyl himself performed some trials to validate the principle. In these trials, treated plants were healthier and produced significantly more biomass and tomato yield than the control plants.

DON'T FORGET THE ROOT MICROBIOME

From what has been described above, plants need electrons to aid all kinds of metabolic processes. This is also the case for microorganisms (which make up the plant microbiome, part of the soil food web). These microbes also need and give electrons for and through everything they do. They need

[9] https://patents.google.com/patent/US20140020294A1/en.

electrons to consume nutrients or spew out methane or expel carbon dioxide, or any other biological process. It is often observed that the microorganisms that make up the root microbiome thrive in the presence of biochar. There had been no clear explanation for this, but scientists from Cornell University (Sun et al., 2017) have now discovered that biochar provides high-definition electron pathways in the soil that allow electrons to travel through the soil farther and more efficiently.

Field trials undertaken by Koppert Biological Systems demonstrated that the addition of a liquified stable carbon source to rockwool enhances Trichoderma (fungal) growth, resulting in at least a 10-fold colonisation of the fungus on the roots in the rockwool slabs that had been treated with liquid carbon. *Trichoderma harzianum* T22 acts as a biological fungicide against *Pythium*, *Fusarium* and *Rhizoctonia* in many crops. It also has plant growth-promoting features. Growers often struggle to get this beneficial fungus established on the plant roots in rockwool substrate. But the addition of a liquid biochar-like carbon gave remarkable improvements. The mode of action has not been investigated. It is unlikely that the Trichoderma fungus uses the carbon as a food source, since it is a very stable form that cannot further be digested. This is confirmed by Sun et al. (2017) who note that the use of biochar as a food source can be discarded because microorganisms cannot consume much of it. So the effect may be explained either in that it provides a more friendly place for Trichoderma to grow than the 'hostile' rockwool substrate or in that high-definition pathways for electrons are created by the carbon.

DISCUSSION AND CONCLUSIONS

The above is a snapshot of the research undertaken to better understand the role of electromagnetic phenomena in plants. The matter has many facets and is quite complicated, and the results are not always consistent. Many methods have been tried. Some look promising, and certainly, the rapid developments in the domain of sensors, artificial intelligence and the Internet of things will help to develop systems that enable growers to better monitor plant growth and have more comprehensive information to support their decision-making. Bioelectric methods could also help with simple and cheap comparisons of fruit and vegetable products and their internal quality.

The same holds true for the methods investigated that promote various types of electromagnetic effects on plant growth. Many approaches have been tried, yet none have really shown a breakthrough so far. The notion that plant growth concerns more than particles at least has started to be accepted in some quarters. There is a need for more in-depth and systematic analysis as to whether – and to what extent – the elements of energy and information connected to electricity can be applied and managed to benefit plant growth.

As a common thread running through all that has been presented above, I am beginning to see a lot of similarities between water and electrons. Both must be able to flow freely from the root zone, upwards through the plant, partly leaving the plant through the leaves and partly stored in the plant tissue. They need electrons to be present in a free and available form, to help flowers to be more visible for pollinators, to facilitate metabolic processes throughout the rhizosphere and the rest of the plant, to store energy in an excited form to help plants cope with oxidative stress and to contribute to the health of those who eat the parts of the plant harvested for food or feed. Similarly, water has to be available in the root zone, be taken up and transported via the root system, carry water-soluble components up and down and be part of many metabolic processes. Water must also be amply available in the leaves for evaporation to regulate leaf temperature, but sufficiently kept in the plant tissue to maintain turgor.

The question arises that if these concepts have been worked on for almost a century, why have there not been more major commercial breakthroughs and uptake? Several factors are at play here. It is curiosity that has driven many researchers and others (including myself) to dive into this topic. For farmers and growers, the combination between the disciplines of electro(magnetism) and (plant) physiology may not be sufficiently attractive. In the area of monitoring, practical people may prefer direct or visible (e.g. morphological or symptomatic) observations above indirect or invisible

(electromagnetic) ones. My own search only started when I wanted to measure plant resilience against stresses, something you cannot see on the outside of a plant. Further, in terms of influencing plants and their microbiomes, the results of experimental electromagnetic interventions are not always as obvious and consistent as chemical and biological interventions, which are also more trusted because they fit with current practices.

At the company where I work[10], we encounter this in terms of growers' and advisors' acceptance of new bioprotection systems: new systems based on beneficial arthropods are more easily accepted than those based on beneficial microbes. Visibility plays a role here: what you see and can manage helps learning and builds trust quicker than something invisible, what you believe or hope to happen.

I hope that this chapter contributes to an improved understanding of plant growth beyond the plant physiological principles that are commonly known and accepted and encourages further research and experimentation in this field.

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13 Homeopathy Applied to Agriculture

Theoretical and Practical Considerations with Examples from Brazil

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INTRODUCTION: HISTORICAL OVERVIEW

Homeopathy, as a science and art of healing, has been used worldwide for more than two centuries. It was proposed by the physician C.F. Samuel Hahnemann (1755–1843) through the publication of his pioneering treatise in 1796 which outlined the axioms for this new area of science, 'Essay on a new principle for ascertaining the curative powers of drugs, with a few glances at those hitherto employed' (Dougeon, 1989). Nowadays and as well as treating humans, the use of homeopathy is successfully applied in agriculture to treat animals, plants and water, as well as the environment as a whole. In order to understand its role in agriculture, we need to consider its historical development.

Early in his career, Hahnemann began to realise that the health care employed at that time was neither safe nor effective. The main therapeutic methods used were blood-letting, leeches,

DOI: 10.1201/9780429440939-15

blistering, intestinal purging, induced vomiting and profuse sweating, and the administering of toxic drugs such as mercury. These techniques were frequently more harmful than the diseases they were intended to cure (Dean, 2001). Disappointed with this practice of medicine, Hahnemann, also a linguist, decided to give up his profession and instead he kept time only to translate medical texts to earn a living (Aversa et al., 2016).

Hahnemann's crucial observation was made whilst translating, from English to German, 'A Treatise of Materia Medica' by William Cullen (1710–1790). Cullen stated that the bark of Cinchona (a flowering plant from South America), that was an accepted medicinal plant to cure for malaria, was effective because it was bitter and worked like a tonic. Disagreeing with Cullen, Hahnemann started taking himself doses of the bark powder from Cinchona and carefully observing its effects upon his own healthy body or organism. Based on his experience, he hypothesised that Cinchona bark cures malaria because, in healthy people, it can provoke similar symptoms to those caused by malaria (e.g. intermittent fever) (Fisher, 2012). Hahnemann subsequently began giving repeated doses of many common substances to healthy volunteers and recorded the symptoms they induced. This technique is known as 'proving' or undertaking a human pathogenic trial, and the descriptions of symptoms, which include physical, emotional and mental, are recorded in compendiums called Homeopathic Materia Medica (Dougeon, 1989).

After his important discovery, Hahnemann began clinical practice again, but now testing the veracity of his new principles of homeopathy, and 6 years later, he came up with the basic premise: *similia similibus curentur* or the like-cures-like principle. In the words of Hahnemann,

> We should imitate nature, which sometimes cures a chronic disease by super-adding another, and employ in the (especially chronic) disease we wish to cure, that medicine which is able to produce another very similar artificial disease, and the former will be cured; similia similibus.
>
> *Dougeon (1989: 265)*

This principle itself was not new; it had already been point it out by others such as Hippocrates and Paracelsus. Hippocrates (460–367 B.C.) observed empirically that through the similar, the disease develops, and through the use of the similar, the disease is healed (Viganò et al., 2015). Theophrastus Bombastus von Hohenheim (1493–1542), better known as Paracelsus, proposed the theory of natural signatures or 'signa naturae', according to which the therapeutic properties of plants or minerals can be deduced from some similarity between their forms or colours and the various parts of the human body (Viganò et al., 2015). Hahnemann may have taken some ideas from Paracelsus, but he did not follow its method. Instead, he emphasised that remedies must reveal their curative properties through proving in healthy human bodies and that a similar set of symptoms in an ill body would then be extinguished. In doing so, Hahnemann was the first to build a medical approach based on a principle that could be confirmed by experience. He was also the first to undertake this systematically, making it a central tenet of his method which is implicit in the name 'Homeopathy' – from Greek *homoios*, meaning similar, and *pathos*, meaning suffering (Walach et al., 2005).

Another important principle of homeopathy concerns the totality of symptoms, a kind of holism, which considers the sick organism as a whole rather than a focus only on the diseased part itself. Hahnemann advocated that remedies should be selected based on the 'total' set of symptoms, from which those more representative of the ill-individual state could be found (Hahnemann, 1810). This meant that two patients with the same clinical diagnoses, for example upper respiratory tract infection, could be treated with different remedies based on their individual characteristic symptoms. Hahnemann also insisted that only one remedy should be used for a given patient at any time considering the totality of symptoms (Hahnemann, 1842).

Throughout his life, Hahnemann continued improving his theory and adding new concepts. One such was the concept of potentisation or dynamisation, which consists of a series of successive dilutions combined with 'succussions' (vigorous shaking) of the homeopathic preparation (Brasil, 2011). At first, Hahnemann only diluted the remedies in order to minimise the side effect of any toxic

ingredients. However, after numerous observations, he noted that the dilutions should be intimately and uniformly mixed (by vigorous shaking) in order to better extract the healing power of the substance (mineral, vegetable, animal or other) (Aversa et al., 2016). Hahnemann became convinced that the healing power could be maintained, by shaking, from the less to the more diluted preparation and did not depend on the physical presence of the original active ingredients but rather on their action, which he called 'spirit-like' (Hahnemann, 1842). Homeopathic remedies are used at a wide range of dilutions (Brazil, 2011). If we take the homeopathic centesimal dilution beyond 12CH,[1] it is statistically unlikely to contain a single molecule of the original active ingredient because this surpasses Avogadro's constant (i.e. the proportionality factor that relates the number of constituent particles in a sample with the amount of substance in that sample).

The fundamental homeopathic textbook is the 'Organon of Rational Art of Healing' (Hahnemann, 1842). Hahnemann published two other important works: 'Materia Medica Pura', a compilation of homeopathic 'proving' reports, and 'Chronic Diseases', where Hahnemann revised and elaborated on his therapeutic approach (Hahnemann, 1846a,b, 1996). His original ideas have been preserved and some adaptations made since, in order to improve its practicality. This has led to the emergence of different schools of homeopathy (Madsen, 2019).

In relation to this, anthroposophical medicine and the biodynamic preparations – as developed by Rudolf Steiner and Ita Wegman in the early part of the last century – are sometimes erroneously classified as being based on homeopathy. Whilst some substances used may be potentised, they do not follow the principle of similarity, nor the same method of diagnosis (Steiner, 2001).

TOWARDS UNDERSTANDING THE MECHANISMS BEHIND THE CONCEPT OF HOMEOPATHY

Hahnemann himself hated speculation. His approach was purely empirical to start with, he would theorise only after numerous observations and he constantly corrected his works, resulting in six editions of the 'Organon'. He believed that the healing process was a secondary effect of a reaction by a 'life force' or dynamism of the sick organism towards health (Hahnemann, 1810).

Through consecutive dilutions and succussions, the remedies tend to the infinitesimal, exceeding Avogadro's constant, as pointed above, at which point the particles cannot be detected. According to dose dependent response, this ought to limit the action of the homeopathic preparation (Silva et al., 2005), and this fuels the argument that a placebo effect is involved. However, scientific evidence shows otherwise. Various fields of study have discussed the nature of high dilutions, ranging from attempts to extrapolate mechanistic rationality through to drawing on complexity theory using nonlinear systems models (Bell et al., 2002; Bonamin et al., 2008). Despite the alleged lack of molecules of the original active ingredients remaining, their biological effect has been systematically and regularly proven in the treatment of plants, animals and humans (Bonfin and Casali, 2012). Double-blind homeopathic trials have also eliminated any subjective (placebo) effect between the patient and the researcher (Betti et al., 2009). Silva et al. (2005) has demonstrated the mode of action of homeopathic remedies through the Quantum theory. The persistence of a biological effect allows us to hypothesise that the curative property of homeopathy may be conserved as an image impregnated in the water/alcohol solvent of the high dilutions (Silva et al., 2005). If this is the case, then the active property of the remedies may be preserved even after consecutive dynamisations, reliably identifiable with the characteristics of the original raw material.

Another approach was reported by Chikramane et al. (2010). They used electron microscopy and emission spectroscopy techniques to confirm the presence of physical entities in the form of nanoparticles, in these extreme dilutions. They suggest that the succussion process causes acoustic cavitation – a mechanism that generates vapour bubbles – and confirm corresponding patterns between the nanoparticles and the starting material. They were also able to measure differences in patterns between different dilutions of remedies when various levels of radiation were applied.

[1] CH dilutions are centesimal (C) dilutions, using Hahnemann's (H) dilution method.

Another way of understanding high dilutions is to consider the concept of vitality or life force, which can have several compositions. Zanco (2016) has shown that biophotonic techniques (the study of light photons) are suitable for detecting subtle effects in the use of high dynamised dilutions by identifying different bioelectric signals among different treatments. Also, Kokornaczyka et al. (2014) using the crystallisation method with droplet evaporation could detect structural differences amongst high dynamic dilutions.

As well as the above, homeopathy has had its theoretical–methodological framework legitimised by scientific peers in several internationally recognised journals working in biological, agrarian and/or agrarian and/or related sciences (Betti et al., 2009; Bonfim and Casali, 2012). Several *compendia* in the form of homeopathic prescriptions have been made available for the treatment of plants and animals and include the practical effects of their application (Bonato, 2007; Kaviraj, 2012; Maute, 2011).

In the following section, we will discuss homeopathy as an integrative therapy, proposed and developed by the group of Homeopathic Studies and Agroecology anchored at the Laboratory of Homeopathy and Plant Health of EPAGRI-Lages,[2] in collaboration with Santa Catarina State University and the University of Planalto Catarinense, in southern Brazil.

APPLYING THE CONCEPT OF INTEGRATIVE HOMEOPATHY

Practices such as homeopathy are embedded in a world view that considers humans as part of ecosystems. Therefore, there is a case for their application to improve not only the health of agricultural ecosystems, but also that of farmers and other humans within the system (Boff, 2009; Casali et al., 2009). Similarly, the interconnectedness of the components within an agricultural system leads us to presuppose that what makes the soil, water, plants or animals sick does the same for humans (Khatounian, 2001).

According to Boff (2009), the most effective way of ensuring the long-term health of the agroecosystem is to redesign it to maximise homeostasis or dynamic equilibrium through its own self-organising life force. This gives rise to resilience (Soule and Piper, 1992). Effective homeopathic preparations need to act on this force in order to treat the agroecosystem, as a whole or in its parts.

Systems theory explains how living organisms are dependent for their life processes on the constant exchange of energy, matter and information with their external environment, at all levels from the quantum to the macro-dimensional (Bertalanffy, 1967). The wave function in the sense of quantum theory was already used by Silva et al. (2005) to understand the mode of action by which homeopathic preparation does resonate in biological systems. A recent paper by Manzalini and Galeazzi (2019) attempts to explain homeopathy through quantum electrodynamics. In it, the authors show how each component has its own macro-wave function with its specific oscillatory pattern that resonates with other specific oscillatory patterns. In order to minimise uncertainty, this process tends towards increasing resonance with other systems around it at multiple levels, which explains how 'organelles, cells, tissues, organs, organ systems, up to a whole organism, are characterized by their own specific wave functions, whose phases are perfectly orchestrated in a multi-level coherence oneness' (Manzalini and Galeazzi, 2019: 4). This may explain how it is possible to use homeopathic remedies not only for humans but also for animals, plants and even the environment. It could be a single apple tree or the whole orchard, a single sheep or the entire herd, the farm or the farmer him/herself (see Figure 13.1). If the apple needs healing, then the orchard needs healing too; if the farmer is ill, then we can assume that the farm is ill too. Treatment may be based on an analogy of symptoms of interest or on the observation of exacerbated effects predominant in the diseased or healthy state of the plant/animal compared to the symptoms as described in the Materia Medica for humans (Casali et al., 2009; de Rezende, 2009).

The effectiveness of homeopathic therapy in agriculture is dependent on its local contextualisation which rests on the practitioner's experience of perceiving the whole sick organism, the relationships

[2] EPAGRI is the Institute of Agricultural Research and Rural Extension of Publica Service of Santa Catarina State, Brazil.

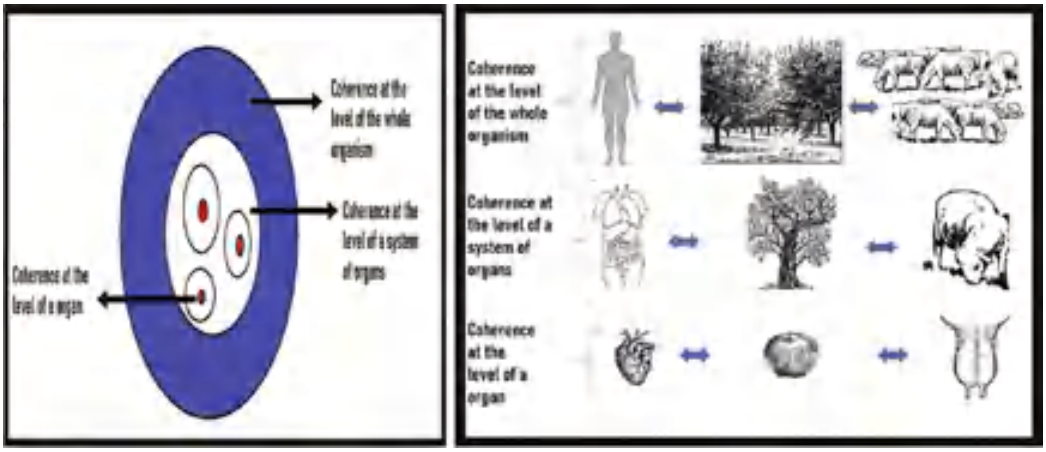

FIGURE 13.1 Levels of coherence/similarities to help select what needs to be healed. (Adapted from Manzalini and Galeazzi, 2019)

between the parts, and the emergent properties rising at different levels of the system (Boff, 2009). Further, before the healing process starts, any obstacles to healing – such as any practices misaligned with agroecological principles – should be identified and removed so that the homeopathic revitalisation of the system as a whole can be fast, smooth and lasting (Hahnemann, 1842).

However, the greatest challenge to the use of homeopathic remedies in plants and animals is applying the homeopathic principle of similarity (Carneiro, 2011). This is due to having to correlate the symptoms described in the Homeopathic Materia Medica – which were developed for and on humans – with those of diseased plants and animals, and has led to the emergence of various alternative approaches. Some practitioners use electronic instruments, electro-acupuncture devices, pendulums or their own intuition to select remedies (Jonas, 2003). Intuition, for example, is appropriate because as well as being a rapid and unconscious process, it does not follow simple, cause-and-effect logic and is able to address, integrate and make sense of multiple, complex pieces of data (Greenhalgh, 2002). Specifically with regard to biodynamic agriculture, the deep knowledge of the farm system and its components has been used to understand the influence of high dynamised dilutions on plants (Kolisko and Kolisko, 1978). Tichavský (2009) has proposed using morphological or physiological symptoms as a guide to search for the best homeopathic remedy for plant treatment. Such a biotype could be understood as the result of the morphic resonance process proposed by Sheldrake (2013) in which the starting point is a memory present in the morphic fields where homeopathy could have some action.

EXAMPLES OF THE USE OF HOMEOPATHY IN AGRICULTURE

Homeopathy has been scientifically recognised for its application in agroecosystems (Betti et al., 2009; Bonfim and Casali, 2012). Whilst researchers, practitioners and companies use different methods to select the homeopathic remedies with crops and livestock, a commonality is its success whether in conventional or in ecological based farming systems. It is important to note that homeopathy remedies can be easily deactivated whenever necessary, which makes it far safer than the use of pharmaceuticals or agrochemicals (Boff, 2009; Moreno, 2017; Savian et al., 2018).

In Brazil, companies producing homeopathic remedies have made inroads into the agricultural sector. Interestingly, the majority of clients are large scale, conventional farms producing commodities such as coffee, soybean, citrus, livestock and dairy. The contribution of homeopathic remedies in re-establishing the vitality of these systems is particularly effective owing to their poor state of health prior to treatment. In terms of diagnosis and treatment, some homeopathic companies undertake their

TABLE 13.1
***Materia Medica* for Some Farm Crops**

Homeopathic Remedy	Symptoms
Arnica Montana	In cases of stress such as when transplanting, thinning, pruning, water deficiency and sudden damage by insects/frosts/harvests
Belladonna	Too many ants (spray remedy on leaves, plants and pathways)
Carbo vegetabilis	When there is general weakness, e.g. after insect attack, defoliation, water deficiency, close spacing, flower loss, death of buds, plants in compacted soils
Staphisagria	Attack of aphids, nematodes or mites, plants in excess shade, grafted plants and artificial insemination in animals, flea infestations
Nux vomica	Plants and soils polluted by pesticides
Sulphur	Excess transpiration, plants with high fertility needs, itches and scabies in animals (the remedy induces detoxification in plants, soils and animals)
Calcarea carbonica	Plants unresponsive to good fertility, chlorosis, seedlings sensitive to cold, delay in new root growth, slow plant development and leaf yellowing, where slow composting is required, e.g. where there is a high C/N ratio

Source: de Rezende (2009).

own diagnoses and prepare remedies using local materials, whilst others use preformulated remedies but focus on advising and training the farmers to be actively engaged in the healing process and to understand the medicines as part of this process. For example, the University of Viçosa, Minas Gerais State, has produced technical guidelines for farmers on the use of homeopathy with plants, as shown in Table 13.1 (de Rezende, 2009).

Much research has explored the use of homeopathy in promoting crop growth. *Arnica montana* 30CH and *Calendula officinalis* 30CH have been shown to promote stronger regrowth and higher fresh mass weight in yerba mate (*Ilex paraguariensis)* forests after drastic pruning, thus contributing to the sustainable management of native forest resources (Domingues et al., 2019). The substitution of pesticides with homeopathic treatments has also been shown to improve the performance of rice plants and to increase grain yield (≥2,000 kg/ha) (Verdi et al., 2020). Faedo et al. (2009) verified higher germination amongst lettuce seeds treated with *Arsenicum album* 7CH: lettuce is one of the most important commercial crops and thus of income for small farmers in Brazil. Verdi et al. (2020) obtained longer branches and higher multiplication success (79%) on the root cuttings of the flowering plant popularly known in Brazil as erva-de-touro (*Poiretia latifolia)* with *Calcarea phosphorica* 20CH. The clean (toxin-free) production of this medicinal plant is commercially very important. Nunes et al. (2019), also working with medicinal plants, used *Kali carbonicum* 12CH to assist in the breakage of dormancy and average germination time of *Hypericum perforatum* (St John's Wort) seeds.

Research has also explored the use of homeopathy in pest management of tomato under field conditions (Mododon et al., 2012). For example, the control of bean weevil has been demonstrated by Deboni et al. (2017). In orchards, insect traps to which *Ac. tannicum* 30CH was added attracted 20% more *Anastrepha fraterculus* (South American fruit fly) than the control. This assisted in the reduction in the numbers of fruit flies, and it is a method that can be used in organic orchards (Brilinger et al., 2018). Giesel et al. (2012), using a high dynamised dilution (nosode) of *Acromyrmex* species (leafcutter ants) and *Belladonna* 30CH, reduced the foraging activity of two species – *A. laticeps* and *A. heyeri* – without causing colony collapse or re-colonisation elsewhere. Portales (2020) observed that when comparing homeopathy with the conventional treatments in dairy farms, homeopathy was more effective at keeping the SCC (somatic cell count per millilitre) below the 250 threshold. Prior to homeopathy treatment, only 22%, 25% and 27% of the samples from each farm had an SCC below 250. Once homeopathy treatment was started, these farms reached 66%, 56% and 46% (respectively) of days with SCC below 250.

Overall, homeopathic remedies appear to be able to harmlessly restore the dynamic equilibrium in agroecosystems. In recent studies, Bonamin (2020) verified the protective role of isotherapy (the treatment of viral and bacterial illnesses by administering dilute dosages of those microorganisms to infected patients) in *Artemia salina* (brine shrimp) exposed to pesticides and heavy metals. The treatment of *Artemia* cysts exposed to glyphosate and lead with the respective isotherapy induced better adaptation of these animals to the harmful medium, reducing problems with egg hatching and the incidence of malformations in the newborn larvae. Bonamin also observed that the treatment of a natural water source with *Phosphorus* 30 CH produced significant changes in dipole moment in water samples harvested from different and distant locales of the same environment.

THE APPROPRIATENESS OF HOMEOPATHY FOR AGROECOLOGY

The ethical and social potential of homeopathy lends itself well to the toolkit of alternative agricultural movements (Kohler and Negrão, 2018), and homeopathy in agriculture is recognised as an effective social technology (Andrade and Casali, 2011). Social technologies need to be simple, cheap, effective and accessible to all farmers without causing dependency on costly inputs. In Brazil, integrative and complementary practices – including homeopathic preparations – have been legislated for public use in the national health system, as well as in organic food production systems (Brasil, 2007).

Homeopathy has been adopted by farmers from the 'Movimento dos Trabalhadores Sem Terra' (the landless workers' movement) in Santa Catarina State. In 2018, in the city of Ponte Alta, 44 families, who cultivate around 200 ha, completed a 6-month training course, organised by the Laboratory of Homeopathy and Plant Health, on the theory and practice of homeopathy, which took place in their own communities. These farmers received homeopathic kits for general use on their farms, with the remedies in these kits being in liquid form which allowed them to make up different potencies for the treatment of livestock, plants and the environment. Through sharing this knowledge in their communities, the farmers were able to empower others and build community resilience, something which the use of purchased agrochemicals is unable to engender.

Because of its holistic nature, homeopathy also holds potential to encourage multidisciplinary collaboration. Over the last decade, the integrative homeopathy course held at the EPAGRI station in Lages and UDESC, Santa Catarina, has trained not only farmers, but also agronomists, veterinarians, holistic therapists, medical doctors, dentists, physiotherapists, psychologists, teachers, undergraduate and postgraduate students, all of whom attend the 150 hour-long course during which they discuss the philosophy of science, vitality, homeopathic science, quantum methodologies and more. Through workshops, case studies and delivering training themselves, they develop a sense of collectiveness as they experience how homeopathy can be applied in different disciplinary situations.

Other research groups, in Brazil and abroad, have also been generating knowledge and delivering extension on homeopathy. Examples are given as following. Within Brazil, there is the work of the Research Group on Biological and Alternative Phytosanitary Controls (COBALFI) and the Popular Homeopathy Group of Western Paraná (CAPA), both based at the State University of Western Paraná (UNIOESTE). Paraná state also has Carlos Bonato's team at the University of Maringa and the Paranaense Agroecology Reference Centre which has been delivering specialised courses in homeopathy for almost 15 years. At Viçosa Federal University, Minas Gerais State, Vicente Casali and his team have, since 1995, been developing participatory research aimed at popularising homeopathy amongst farmers and local communities. Further afield, in France, there is La Groupe International de Recherche sur l'Infinitésimal (International Research Group on Very Low Dose and High Dilution Effects, G.I.R.I.), which was founded in 1986 and consists of more than 100 researchers ranging from physicians, chemists, biologists, pharmacologists, physicists to agronomists, from 22 different countries. In Italy, at Bologna University, Lucietta Betti and her colleagues in the Department of Agricultural and Food Sciences are building evidence on the use of homeopathy in crop production.

FINAL CONSIDERATIONS

Over the last 30 years or so, the theoretical and methodological framework of homeopathy has expanded from the treatment of humans to that of animals, crops and agroecosystems (Bonamin, 2014). The biggest challenge of the homeopathic therapist working in agriculture is to identify the remedies that restore the dynamic equilibrium in such agroecosystems. This exercise of understanding the sick system as a unique and individualised organism, and seeking the medicine that can best remedy it whilst prioritising the most important symptoms, requires the homeopathic therapist to be an integrative healing artist.

Clearly, homeopathy in agriculture is based on a very different scientific rationality from that of Cartesian materialism, which seeks to maximise the factors of production for the continuous increase in productivity. Thus, the medic prescribing pharmaceuticals, the veterinarian prescribing drugs, or the agronomist prescribing agrochemicals is not usually receptive of homeopathy for family farmers, a concept which takes into account the entire interactive environment. Therefore, there is a need in the agricultural arena for both new concepts and new training that embrace such complexity.

Hahnemann believed that homeopathy should help people to reach the highest purpose of their existence which is living in harmony with themselves, and their (social and natural) environments. In particular, homeopathy as a social tool may assist more vulnerable communities to free themselves from the dependencies imposed by the conventional agriculture system. Agroecology is concerned with biomimicry and social issues that relate to, for example, diversity, inclusion, cooperation, complementarity and self-determination. If farmers are provided with knowledge of a theoretical and methodological framework that can deal with such complexities on their farms, and are able to apply low-cost homeopathic solutions, this provides them with a unique opportunity to enhance and work with the connectivity and integrity in the animal, plant, soil, water and human components of the agricultural organism in search of harmony of the dynamic, whole, agroecosystem.

ACKNOWLEDGEMENTS

Many thanks to the Study Group on Homeopathy and Agroecology brought together by the Laboratory of Homeopathy and Plant Health of EPAGRI-Lages that works with postgraduate students and docents and professors from UDESC and UNIPLAC, Santa Catarina State, Brazil. We should also like to thank our colleagues Leyza P. de Oliveira, Marcelo S. Pedroso, Mari I. Carissimi Boff and Amarilys Cesar for their valuable contributions to the manuscript. This study was partially supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), who granted the first author a PQ scholarship as a researcher, and by the Fundação de Amparo a Pesquisa e Inovação do Estado de Santa Catarina (FAPESC) for additional research funding. The second and the third authors were partially funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

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14 Effect of Low-Power Laser Biotechnology Pretreatment on Shooting and Initial Growth of White Mulberry and Sugarcane under Flood Stress

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DOI: 10.1201/9780429440939-16

INTRODUCTION

The problem of soil flooding is global and affects crop yields on all the continents of our planet (Peratae et al., 2011), and it is estimated that 6% of terrestrial land is waterlogged or prone to temporary flooding, due to heavy rainfall and poor soil drainage (De la Cruz et al., 2012; Maltby, 1991). In Latin America, waterlogging affects 11.3% of the cultivated land, while in Cuba, poor drainage affects up to 40.3% of the cultivated agricultural area (CIGEA, 2001).

The term flooding encompasses both excess water accumulation in the soil and submersion. The accumulation of water can involve soil flooding, where only the roots are exposed to these conditions, and immersion, when the plant is partially or fully submerged (Sasidharan and Voesenek, 2015). Flood events have become more frequent, severe and unpredictable and are strongly associated with climate change.

The gas exchanges in the organs of flooded plants lead to the restriction of two vital plant processes, photosynthesis and respiration, which can be attributed to water being an extremely poor medium for the diffusion of gases, mainly oxygen. Most terrestrial plants, including major crops, are extremely sensitive to wet conditions. The adaptation of a plant to flooding includes molecular, physiological, morphological and anatomical changes. Initiating these changes requires an accurate and timely perception by the plant of excess water in order to invoke adaptive responses in the early stages of vegetative growth (Sasidharan and Voesenek, 2015).

In industrial farming, different chemical additives are used to raise the productivity of plants and livestock. Their application can cause the contamination of raw materials for food production with toxins that are dangerous for consumers' health as well the environment. On-farm safety for fresh produce requires the development and implementation of new methods for quality assurance. Through the substitution of chemical ameliorations by physical methods, one can reduce the toxins in the raw materials and thus raise the food safety levels and mitigate environmental concerns (Aladjadjiyan, 2007; Aladjadjiyan and Kakanakova, 2008; Jacubiak and Gdowska, 2013).

Thus, the treatment of seeds from agricultural crops by non-polluting substances and techniques could bring both qualitative and quantitative increases in agricultural production: a possibility that has led to increased interest in applying biophysical techniques in agriculture (Hernández et al., 2010; Mosneaga et al., 2018; Vasilevski, 2003).

Among the biophysical methods used for seed priming are treatments involving magnetic fields (De Souza and Garci, 1999; De Souza et al., 2006), temperature or thermo-priming (Paparella et al., 2015); light amplification by stimulated emissions of radiation or laser (Álvarez et al., 2011); X-rays (Ramírezet al., 2006); ultrasound (Yaldagard et al., 2008); gamma and beta radiation (Mirshekari, 2015); the use of plasma (Volin et al., 2000); and microwave radiation (Banik et al., 2003). All are potential alternatives to reducing the synthetic additives and fertilisers applied to the soil and plants.

Laser treatment involves emitting monochromatic coherent light waves in a controlled fashion (Aladjadjiyan, 2007). The literature concludes that it can be considered a safe technique, as it does not alter the molecular bonds, has no mutagenic effect and does not cause marked morphological changes in the structure of the tissue (Mosneaga et al., 2018). Laser biotechnology has a wide range of applications; it can be used in sustainable environmental engineering and preventive biotechnology to eliminate heavy metal contamination on degraded land, as well as in wastewater treatment bioremediation (Dobrowolski, 2010; Dobrowolski et al., 2012a,b; Mosneaga et al., 2018).

There are many studies about low-power laser biostimulation treatment, applied to plants to stimulate germination, shooting, rooting and plant growth. These include the following:

- improved growth and yield by stimulating morphological change (Hernández et al., 2016; Ivanova, 1998; Perveen et al., 2011; Podlesny and Podlesna, 2004; Podlesny et al., 2012; Ying and Chen, 2010);
- stimulating germination (Abu-Elsaoud, 2013; Hoseini et al., 2013; Jamil et al., 2013; Muthusamy et al., 2012; Podlesna et al., 2015);

- seedling growth (Mosneaga et al., 2018);
- stimulation of cell proliferation through photostimulatory effects in mitochondria (Hu et al., 2007);
- protection against UV-B radiation damage (Abu-Elsaoud and Shahda, 2017; Al-Zhen et al., 2012; Chen and Han, 2014, 2015; Jia and Duan, 2013; Yang et al., 2012);
- stimulated leaf area and parameters of photosynthetic activity (Rybinski and Garczynski, 2004);
- increased nuclease activity of the leaves and roots (Zhang and Han, 2009);
- increased ATP level in cells cultivated under in vitro conditions (Karu et al., 1995); and
- improvements in the chemical composition and structure of lipids in tissue culture (Salyaev et al., 2007).

Laser treatment has been used to increase tolerance to various types of stress, such as the following:

- drought stress (Wu et al., 2007; Metwally et al., 2014; Qiu et al., 2008a,b; Qiu et al., 2017);
- increased drought stress resistance for repairing damage to plants exposed to osmotic stress (Qiu et al., 2008c, 2010) and membrane lipid peroxidation (Wu et al., 2007);
- low temperatures (Chen et al., 2010);
- salinity stress (Ashrafijou et al., 2010; Duan et al., 2010; Gao et al., 2014; Mohammadi et al., 2012; Rasouli et al., 2012; Zare et al., 2014); and
- changes in oxidative stress in response to antioxidant defence (Abu-Elsaoud, 2013; Abu-Elsaoud and Tuleukhanov, 2013; Chen, 2009; Qiu et al., 2013).

In the international scientific literature, most laser treatment research has been conducted with botanical seeds, and less with plant cuttings (Bąbelewski and Szajsner, 2014; Jakubiak and Gdowska, 2013; Rimal et al., 2014; Szajsner and Bąbelewski, 2014).

Plant growth regulators, as well as exogenous plant hormones (bioregulators), are known to be able to increase their tolerance to excess water in the environment. This has been encouraged with the use of paclobutrazol (Lin et al., 2006), putrescine (Yui et al., 2009a), spermine (Yiu et al., 2009b) and ethylene (Wang et al., 2016). Specific attention is drawn to the use of the bioregulator 5-aminolevulinic acid (ALA) in stress pretreatments, as it regulates several key physiological processes; for example, it significantly improves the waterlogging tolerance of fig (*Ficus carica*) and promotes root breathing, leaf photosynthesis and antioxidant capacity (An et al., 2016).

Mulberry (*Morus alba*) and sugarcane (*Saccharum* spp.) are two important species of plants grown commercially in Cuba; the former is increasingly used as a fodder crop and the latter is the main commercial crop for sugar production, but has multiple other uses, such as animal feed and derivatives. Commercially, both crops are propagated by stakes to ensure varietal homogeneity, but varietal characteristics, management factors and environmental conditions may result in low shooting rates and poor early-stage growth that affects crop yields.

The objective of this research was to determine the effect of low-power laser biotechnology pretreatment on the shooting and initial growth of mulberry and sugarcane under normal irrigation conditions and under flood stress.

EFFECTS OF LOW-POWER LASER BIOTECHNOLOGY PRETREATMENT ON THE SHOOTING AND INITIAL GROWTH OF MULBERRY AND SUGARCANE

Materials and Methods

Ninety 1-bud sets of the Acorazonada variety were cut from the mulberry seed bank (*Morus alba*) of the Plant Biotechnology Study Center, University of Granma, Cuba, along with 90 one-bud sets from 10-month-old sugarcane (variety C90-469) and their stalks from the sugarcane seed bank of

the sugar company 'Archimedes Colina', Mabay, Bayamo, Granma, Cuba (using the methodology of the National Institute of Sugarcane Research) (INICA, 2002).

Sixty stalk segments of one-bud sets of each crop were irradiated with laser beams using medical laser or He-Ne, wavelength 660 nm, red light power density of 360 $mW.cm^{-2}$. The laser treatments consisted of two irradiation times to the buds: 10 seconds (30 one-bud sets) and 20 seconds (30 one-bud sets), with a control treatment consisting of 30 one-bud sets that did not receive laser treatment. The buds were placed in nylon containers that are commonly used to market milk or yogurt in Cuba, with a substrate consisting of 50% soil and 50% cow manure. The percentage of vegetative bud break in each species was determined after 15 and 30 days.

In both crops, the variable was checked to see whether it met the criteria for a variance analysis, the normal distribution of data through the Shapiro–Wilk test, using InfoStat 2019 (Di Rienzo et al., 2019), and the homogeneity of variances using the Levene test (Minitab, 2013). The data were found to be distributed normally, and their variances were homogeneous. The data were statistically processed through a fixed-effect simple-classification variance analysis, with a two-factor treatment of 2×2. Factor 1 corresponded to the laser-beam treatment with two exposure times: 10 and 20 seconds; and factor 2 corresponded to the two different times when the evaluations were performed: 15 and 30 days. The multiple comparisons of the mean treatments were made using Tukey's test at 5.0% probability. The mean of each treatment and its standard error were represented in a bar chart (see Figure 14.1).

Results and Discussion

A significant response to the laser applications was found for vegetative bud breaks in mulberry. The best response was found to the laser applications lasting 10 seconds, with 76.7% of vegetative bud break, compared to 63.3% with a laser application lasting 20 seconds, and 60.6% bud break (Figure 14.1a) in the control treatment (with no laser application). No significant differences were found between the two time intervals evaluated (Figure 14.1b), indicating that during this period there were no morphological qualitative changes in the development of new mulberry shoots through the effect of laser beams (Figure14.1).

When the percentages of vegetative bud breaks for the two laser exposure time periods were combined and compared to the control, significant differences in the interactions between these two treatments were found (Figure 14.1c). The higher percentages of budding occurred in buds that received laser treatments for a space of 10 seconds, percentages that increased as the days passed. The lowest percentages were obtained in the control at 15 days, with an increase at 30 days, while with 20 seconds of laser exposure, intermediate results were achieved in both evaluations (after 15 and 30 days)

The same procedure was repeated on the sugarcane (variety C90-469), and produced similar results to the mulberry (Figure 14.2). The highest percentage of vegetative bud break, at 85.6%, was with the application of the laser for 10 seconds, followed by the control treatment with 64.4%, while the lowest bud break was the application of the laser for 20 seconds, with 58.9% (although there was no significant difference between the latter two). As with the mulberry experiment, no significant time factor effects were found.

EFFECTS OF LOW-POWER LASER BIOTECHNOLOGY PRETREATMENT UNDER FLOODING STRESS IN MULBERRY AND SUGARCANE

Materials and Methods

For this experiment, plants from the laser treatment that resulted in the best bud break – exposure for 10 seconds and after 30 days– were used, together with a control. Forty cuttings were prepared (20 of mulberry cuttings and 20 of sugarcane) from the first experiment that were exposed to

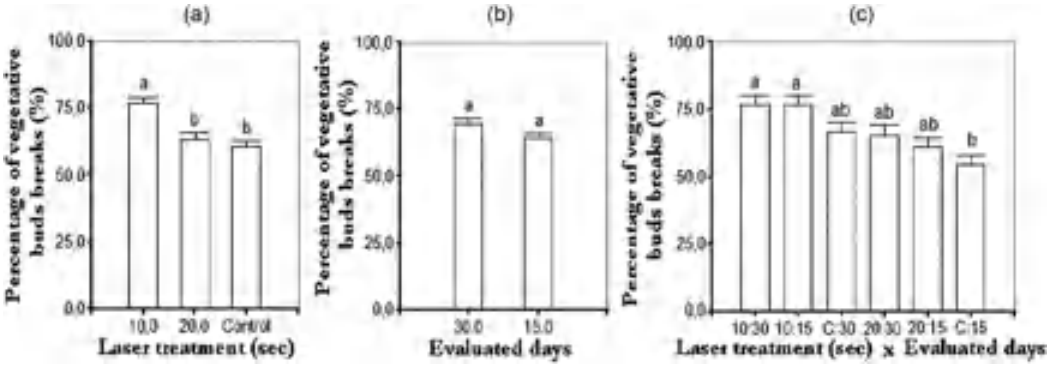

FIGURE 14.1 Percentage of vegetative bud breaks in mulberry, variety Acorazonada, produced by the effect of two laser treatments (10 and 20 seconds) plus the control (graph a), assessed at 15 and 30 days from the initiation of treatments (graph b), and the combination of the two (graph c). Different letters indicate significant differences at $p < 0.05$ using Tukey's test.

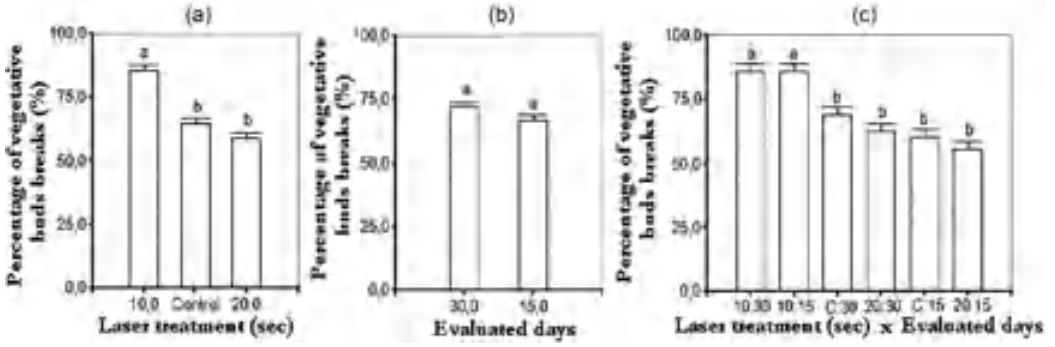

FIGURE 14.2 Percentage of vegetative bud break in sugarcane, variety C90-469, produced by the effect of two laser treatments (10 and 20 seconds) plus the control (graph a), assessed at 15 and 30 days from the initiation of treatments (graph b), and the combination of the two (graph c). Different letters indicate significant differences at $p < 0.05$ using Tukey's test.

this most favourable treatment. Thirty-five days after the treatment, the bud bags (20 stakes with their shoots) were immersed in a pond to a water level that did not completely cover the shoots. They were kept there for 3 days and then held for 4 days out of the water. This weekly process was repeated for 4 weeks (replicating flooding conditions).The remaining 20 cuttings of each crop were applied with water every 3 days (without excess, replicating non-flood conditions). A control treatment was established for both crops at the same age, without the application of laser and without stress due to excess water. At the end of 4 weeks or 63 days in total if counting from the start of the first experiment, the length of the shoots (in cm) and the area of the aerenchyma[1] (in μm^2) were assessed.

For the histological study, samples of first-order branched roots of each crop (which were physiologically active, characterised by light coloration, absence of necrosis and suberisation) of an average diameter of 2 mm and a total length of 5 cm were collected. Three replicates were selected

[1] Aerenchyma is spongy tissue that forms spaces or air channels in the leaves, stems and roots of some plants, which allows exchange of gases between the shoot and the root. There are two types: lysigenous and schizogenous.

from each variety and ten root samples were taken from each replicate. Histological sampling was performed in the area between 1.0 and 1.5 cm from the apex of the root upwards.

The root samples were kept in liquid nitrogen until they were taken to the lab. From there, cross-sections of 0.2 mm thickness were made and analysed under an optical microscope. Digital photos were taken, and the aerenchyma tissue area was calculated using the Motic Images Plus 2.0 program (Motic Instruments Inc., Richmond, Canada) through morphometric methods that gave a magnification of up to 400×.

Prior to the analysis of variance of variations in vegetative bud break in this experiment, it was checked whether the variable met the premises of the analysis of variance, the normal distribution of the data through the Shapiro–Wilk test (Di Rienzo et al., 2019) and the homogeneity of variances using the multiple comparison test (Minitab, 2013). The data were statistically processed through a fixed-effect simple-classification variance analysis, with three treatments for both crops, cuttings with their shoots that received lasers for 10 seconds and a life cycle of 30 days in non-flooding conditions (10´30d NF) and in flooding conditions (10´30d F) and one treatment control (laser-free and stress-free). As the data collected did not follow a normal distribution, the variance analysis of nonparametric form was by the Kruskal–Wallis test. The comparison of treatments was made through the range means (Conover, 1999). For each treatment, the mean of means and their standard error were determined.

Results and Discussion

Table 14.1 shows the differences in leaf shoot length in mulberry, which was significant between the three treatments in general. However, the use of the laser in conditions of stress due to over-wetting was not significantly different from the laser treatment in normal conditions of humidity of the substrate, which suggests that regardless of whether there is excess water, the influence of the laser stimulates the growth of the leaf shoots. The length of the shoot in the control treatment (without the application of laser) was significantly lower than that reached in the treatments where the laser was applied.

For aerenchyma tissue, the three treatments showed significantly different results: a greater growth of this tissue was found on samples that were treated with the laser and placed in conditions of excess water in the substrate, significantly more than those subject to the laser treatment but not to excess water. The lowest growth of the aerenchyma was in the control treatment (in which the laser treatment was not applied and the moisture conditions of the substrate were normal).

Similar results were found when evaluating sugarcane shoots, variety C90-469 (Table 14.2). Both results show that the physical effect of laser beams triggers biochemical and physiological

TABLE 14.1

Mean Values of Foliar Bud Length (cm) and Root Aerenchyma Area (in μm²) in Mulberry Seedlings, Acorazonada Variety, Treated with Laser for 10 Seconds and Evaluated under Flood (F) and Non-Flooded Stress (NF) in the Substrate, and the Control (No Laser Treatment and No Excess Moisture)

Leaf Shoot Length (Mulberry)			Aerenchyma Area (Mulberry)		
Treatments	**Average ± SD**	**Ranges**	**Average ± SD**	**Ranges**
10´30d NF	16.09±0.70	41.40[a]	10739122.9±3056151	30.5[b]
10´30d F	15.86±0.45	37.38[a]	30182546.9±2714263	50.5[a]
Control	14.03±0.97	12.73[b]	186826.1±120669,9	10.5[c]

Different letters indicate significant differences at $p < 0.05$ through the differences between the averages of the ranges.

TABLE 14.2

Mean Values of Foliar Shoot Length (cm) and Root Aerenchyma Area (in μm²) in Sugarcane Seedlings, Variety C90-469, Treated with Laser for 10 Seconds and Evaluated under Flood (F) and Non-Flooded Stress (NF) in the Substrate, and the Control (No Laser Treatment and No Excess Moisture)

Leaf Shoot Length (Sugarcane)		Aerenchyma Area (Sugarcane)		
Treatments	**Average ± SD**	**Ranges**	**Average ± SD**	**Ranges**
10´30d NF F	96.08±5.59	35.15[a]	6437131±2010409	30.5[b]
10´30d F	96.23±5.88	35.25[a]	18046968.8±1406608.9	50.5[a]
Control	91.51±4.64	21.10[b]	108691±72487.7	10.5[c]

Different letters indicate significant differences at $p < 0.05$ through the differences between the averages of the ranges.

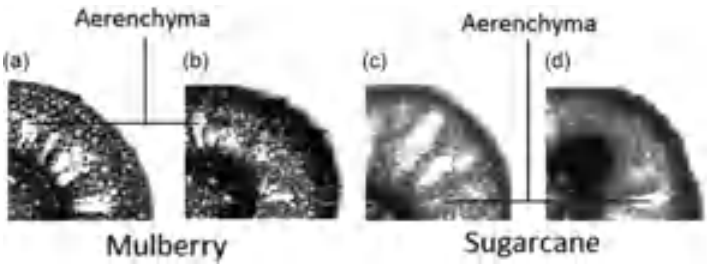

FIGURE 14.3 Histological cross section. (a) Mulberry root, Acorazonada variety, with laser application for 10 seconds in conditions of excess water; (b) mulberry root, Acorazonada variety, with no application of laser rays in conditions of excess water; (c) sugarcane root, variety C90-469, with laser application for 10 seconds in conditions of excess water; and (d) sugarcane root, variety C90-469, with no application of laser rays in conditions of excess water.

mechanisms that produce greater elongation of the main mulberry and sugarcane shoots in a substrate with oxygen restriction, indicating that pretreating the buds of these crops has a robust effect, which allows them a normal early-stage growth and better subsequent development under stress conditions with an oxygen deficit.

The laser-stimulating effect on the leaf shoot length under the effect of oxygen deficiency in relation to the control may be associated with a greater development of the aerenchyma tissue (Tables 14.1 and 14.2 and Figure 14.3) at the roots of mulberry and the sugarcane shoots, which accentuated the formation of aerenchymatic tissue in the substrate with water excess. This suggests that the laser stimulates the synthesis of the ethylene hormone, which under these conditions is responsible for the formation of this tissue by apoptosis or cell death of the genetically programmed parenchymal cells. This in turn promotes the formation of porous spaces or ducts from the roots to the aerial parts of the plant and facilitates the entry of oxygen from the surrounding atmosphere to the roots. As such, it constitutes an important adaptation of certain plant species to live and develop in soils with excess water.

Although ethylene has an inhibitory effect on stem growth for most plant species, it has been found that certain plant species are tolerant of oxygen deficits in the soil. This plant hormone can act as a stimulator of stalk growth due to an increase in the synthesis of the precursor of ethylene, 1-aminocyclopropane-1-carboxylic acid (ACC), under hypoxia conditions (Jackson, 2007; Voesenek et al., 1992; Voesenek et al., 1993), which causes a decrease in the levels of the phytohormone

abscisic acid (ABA) and an increase in the phytohormone gibberellic acid (GA; Azcón-Bieto and Talon, 2008; Voesenek and Van Deer Veen, 1994).

It is important to look at other morphological adaptations. The C90-469 sugarcane variety showed inverse correlations between stoma density and stoma length in the stimulated flood conditions (Rodríguez et al., 2017). In the gas exchange between the plant and the environment, there is a connection between stomata and aerenchyma tissue.

CONCLUSIONS

The growing world population is constantly putting pressure on the need to increase food production, which in turn is affected by the edaphoclimatic phenomena (the influence of soils on plants in relation to climate), such as the frequent extreme events of high and low temperatures, droughts and floods and hurricanes. Flooding is a natural disaster that affects both humans and plants, and man-made driving factors of flooding include deforestation, and intensive agriculture characterised by extensive use of machinery and chemical products, which contaminate water sources, plants, animals and humans as well as being one of the causes of the increase in greenhouse gases that exacerbates climate change due to the increase in the annual average temperature. Agroecological production of food offers a balanced and sustainable alternative, and one more sustainable tool is preconditioning seeds and buds with physical methods. The use of lasers to precondition plant buds such as mulberry and sugarcane in order to increase sprouting and initial growth seems to be a viable method. It has the effect of activation of biochemical, physiological and morphological factors that can increase the tolerance of plants to excess water in the soil, by increasing the aerenchymatic tissue at the root. This apparently stimulates the synthesis of the ethylene hormone within the plant that, under this type of stress, induces shoot growth. This research needs further development although we are confident that the use of low-power biotechnological laser may provide a useful technique for conditioning seeds and vegetative parts in stressful environments at an industrial scale.

ACKNOWLEDGEMENTS

This research is part of the project ‘In vitro plant biotechnology to increase food security in eastern Cuba’, TEAM2017PR438-75644, funded by the Vlaamse Interuniversitaire Raad (VLIR),between the Laboratory of Applied In-Vitro Plant Biotechnology, Department of Applied Biosciences Engineering, University of Ghent, Belgium, and Plant Biotechnology Study Center, Faculty of Agricultural Science, University of Granma, Cuba.

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15 Fluorescence Excitation Spectroscopy (FES) to Evaluate the Farming System's Impact on Food Quality

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Jürgen Strube (in Memoriam)

CONTENTS

INTRODUCTION

Fluorescence Excitation Spectroscopy (FES) was developed by J. Strube in the 1980s and 1990s based on the investigations of F.A. Popp (1984, 2013). Popp used the term 'biophotons' for photons which were emitted by organisms at a very low intensity (ultra-low) and invisible to the human eye. Photons themselves are countable units of light, physically detectable as particles. Popp evaluated the relation between these ultra-low photon emissions – or biophotons – and human health, especially in relation to carcinogenic diseases and the quality of foodstuffs from organic farming. The inspiration for his research was provided by Gurwitsch (e.g. Gurwitsch and Gurwitsch, 1932) who, as a biologist and medical scientist, was interested in growth-stimulating effects. In his experiments on onion roots and yeast cultures, Gurwitsch found that mitosis (cell division giving rise to genetically identical cells) was encouraged by neighbouring root tips. He concluded that growing or living organisms emit light – which he named 'mitogenetic radiation' – which influences other organisms. Nowadays this is named 'ultra-weak photon emission' (UWPE) or 'ultra-low photon emission' (ULPE) and is used to describe a very weak emission of light, in wavelengths of the visible and ultraviolet light. It is now known that coloured light (special wavelengths) stimulates specific metabolic pathways in plants and humans, resulting (in the case of plants) in flowering, growing or ripening (Eichhorn Bilodeau et al., 2019; Monostori et al., 2018), or (in humans) in higher levels of alertness or fatigue (Askaripoor et al., 2018; Bauer et al., 2018; Rahman et al., 2017).

DOI: 10.1201/9780429440939-17

Between the 1960s and 1980s, Popp's thesis made a comeback among some scientists in Germany. Popp argued that high-quality food contains measurable amounts of biophotons and that these could have a nutritive value for humans and may help us to stay healthy. At this time, there was growing scepticism in Europe about the supposed benefits of mineral fertilisers and synthetic pesticides. This raised the question of whether organically grown food might be qualitatively different from that which was industrially grown. In this context, FES was developed, with the aim of determining food quality in a holistic way. Differences between crop samples grown under organic and conventional conditions were explored, as well as the effects of the biodynamic preparations, which at that time were known by some farmers to be potent, but whose mechanistic pathways were not yet understood scientifically.

More recently, scientific research has confirmed the real differences in soil parameters, plant health, product quality and more, between industrial and organic/biodynamic farming (e.g. Geier et al., 2016; Mäder et al., 2006; Mie et al., 2017). Research also shows that the use of biodynamic preparations may[1] result in enhanced product quality, which is measurable through picture-forming methods (Doesburg et al., 2014; Fritz et al., 2017; Bloksma et al., 2001, 2007) as well as by FES (Stolz et al., 2019; Strube and Stolz, 2010). With ongoing developments in analytical capacity, these differences can also be shown by the metabolic pattern (or 'metabolomics'; Shewry et al., 2018; Zörb et al. 2009), by 1H-NMR (nuclear magnetic resonance spectroscopy) (Picone et al., 2016) or by modern gas-chromatographic and mass-spectrometric devices (Bigot et al., 2018).

This chapter describes the general methodology of the FES measurement and provides some relevant results and reflections on the epistemology of the approach. The aim is to encourage the reader not only to think in terms of the dominant mainstream worldview that focuses on material form, but also to consider life processes. Light energy mediates such life processes and is thus also of importance when studying metabolites, and this light- and life-process-related aspect of food quality needs to be taken into consideration when evaluating FES results.

THE METHOD OF FES MEASUREMENTS

The procedure of FES consists of an illumination (excitation) of the sample and a measurement of the subsequent emission of photons (see Figure 15.1). The measurements are conducted in a climate-controlled dark room (at 15±1°C with 40±5% relative humidity). The excitation is done by projecting light in seven different colours (i.e. red, yellow, blue, etc.) one after the other onto the sample, each colour representing a defined range of wavelengths of visible light. Detection after each colour excitation is realised by a photomultiplier which counts the subsequent emitted photons at intervals, and the declining curve over time is documented (Figure 15.2). The data evaluation is performed on the basis of repeated measurements of each sample, and parameters such as the short-time emission (the first data point of the declining curve, Mw1) or the long-term emission (the mean of the last 40 or 80 data points of the declining curve, R40) for each excitation colour are of interest, as well as the relationships between them.

A more detailed description of the method and the devices used is given in Stolz et al. (2019) and Wohlers and Stolz (2019).

EFFECTS OF FARMING SYSTEMS ON FOOD QUALITY, MEASURED BY FES

To date, thousands of such FES measurements have been performed at the research institute KWALIS in Germany, many of which focusing on the impact of farming systems on food quality. To explain the concept of quality evaluation via FES, four examples are provided which show the following:

[1] The term 'may' is used here rather than 'does' because the biodynamic preparations do not work like standard industrial inputs, such as nitrogen fertiliser, and thus should not be compared to or treated as such. The preparations enhance quality in the way that is appropriate for each given situation; they encourage growth and enable other possibilities without forcing the plant.

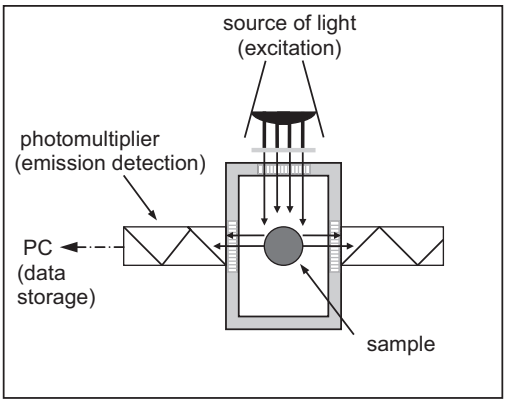

FIGURE 15.1 Schematic overview of the FES measuring apparatus with 90° position between excitation illumination and emission detection by photomultipliers. The time sequence between excitation and emission is regulated by shutters.

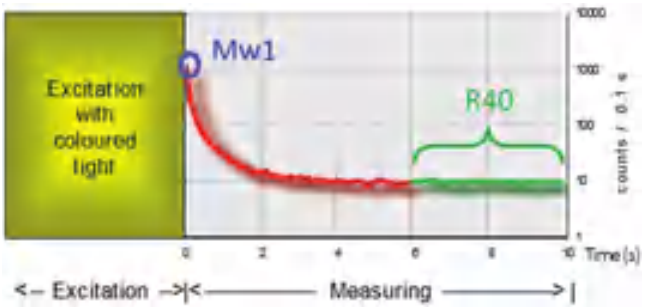

FIGURE 15.2 Schematic illustration of the excitation and measuring interval and a characteristic declining curve of the delayed emission. Mw1 indicates the short-time emission, and R40 indicates the long-term emission.

i) influences of farming systems on the induced emission of food (Nos. 1 and 4),
ii) the variation of induced emission, caused by maturation and growing conditions, and in relation to different parts of the plant (No. 2),
iii) phenomena of induced emission in relation to aspects of holistic quality (No. 3).

1) Wheat from the 'DOC-Trial' Field Experiment

The DOC-trial was established in Switzerland in 1978 to evaluate differences in yield, plant health, crop quality and soil parameters between the biodynamic farming method (represented by D2 in Figure 15.3), organic farming (without biodynamic preparations, O2) and industrial farming systems that use mineral fertilisers, either with (K2) or without (M) the additional use of manure (Mäder et al., 2002, 2006).

Wheat samples from this experiment were measured over several years by FES, and the results were published in Strube and Stolz (2010) and Hermanowski et al. (2013).

Significant ($p<0.05$) differences between the samples were observed. The FES parameter R40yellow/blue (Figure 15.3) showed low yellow-by-blue ratios for the organic and biodynamic

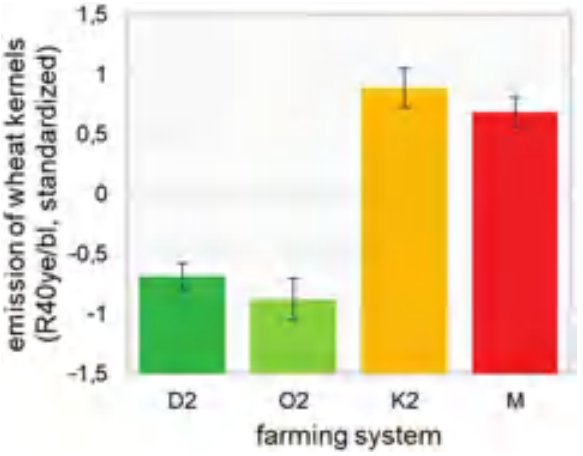

FIGURE 15.3 Differences between the wheat samples collected over 6 (O2 and K2) and 8 years (D2 and M), on the basis of mean values per year and farming system (standardised by year of harvest). Whiskers indicate standard error of the mean. D2=biodynamic; O2=organic; K2=conventional (manure+mineral); M=mineral fertilisation only.

samples in 7 of 8 years. Other parameters, such as Mw1green-by-blue or R40yellow, similarly showed a difference between organic/biodynamic (D2, O2) and industrial farming systems (K2, M). Higher R40yellow/blue values (as observed in the industrial samples) can be interpreted as less maturation in seeds (Strube and Stolz, 2010) and are in accordance with other investigations on bean seeds (Strube and Stolz, 2001c) and calendula seeds (Strube and Stolz, 2001b). This yellow-by-blue parameter was determined as relevant for seeds since those in dormancy have higher biophoton emissions after blue than after yellow excitation, whereas the opposite occurs in germinating and unripe seeds (cf. also No. 2 of this chapter). Fertilisation intensity also changes this parameter to high values, which are characteristic for vegetative states where the seed has not completed the differentiating growth phase (cf. also No. 3 of this chapter).

2) Apple Quality: Maturation and Growing Conditions

An experiment with apple trees was carried out in the year 2000 in the Netherlands by the Louis Bolk Institute, to examine the effects of maturation stages, light intensities and biodynamic preparations on the quality of apples according to the 'Inner Quality Concept'[2] (Bloksma et al., 2003, 2004, 2007). The whole apples as well as the kernels of the apples were measured (full results are published in Bloksma et al. (2001) and Strube and Stolz (2002)).

As the apples matured (Figure 15.4), the values in the R40yellow/blue parameter for the whole apples increased, while the seeds of these apples showed lower values. This divergence in values during seed development can be viewed in relation to the morphologically visible increasing inner differentiation of the apples from their seeds. This was also indicated by increasing amounts of secondary metabolites: the kernels became seed-typical, and the fruits became fruit-typical (cf. No. 3 of this chapter). The highest degree of quality (called 'integration' by Bloksma et al. (2003), or 'product-typical' according to our own terminology) was reached with full maturation, including a specific equilibrium between reduced growth processes (mass production, related to primary

[2] The 'Inner Quality Concept' is a quality concept for food based on the life processes of growth and differentiation. It was developed to show the additional value of carefully grown organic food, to explain properties such as 'vitality' and 'coherence' and to relate to health aspects.

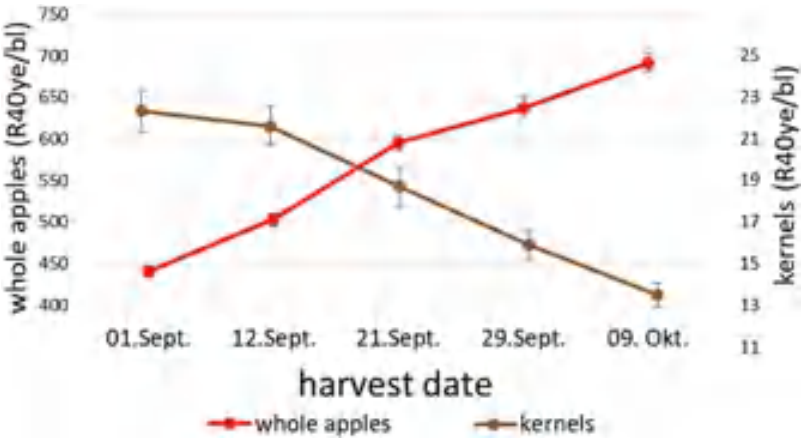

FIGURE 15.4 R40yellow/blue of whole apples and their seeds at different maturation stages. Whiskers indicate standard error of the mean. An increasing divergence of the induced emission of whole apples and their kernels during maturation was observed, these being indicated on the figure by the crossing of the lines.

metabolites) and increased differentiating processes (diversity of tissue structure and integration of small molecules into larger ones relating to secondary metabolites).

Another experiment with factors including light intensity and biodynamic preparations (Figure 15.5) showed that at full light and with biodynamic preparations, an emission with high yellow-by-blue ratios was observed, indicating that under these growing conditions, a fruit developed which was comparable to mature fruits, while shadow resulted in apples which looked as though they were not completely ripened.

Yellow/blue is the most obvious of the colour parameters in terms of excitation and can be found in several other sample sets as relevant to maturation and ripening of seeds. (Single colours are less specific to maturation, and these absolute parameters are more intensively related to, for example, the size of the sample or freshness.) The challenge of this method is that the parameter

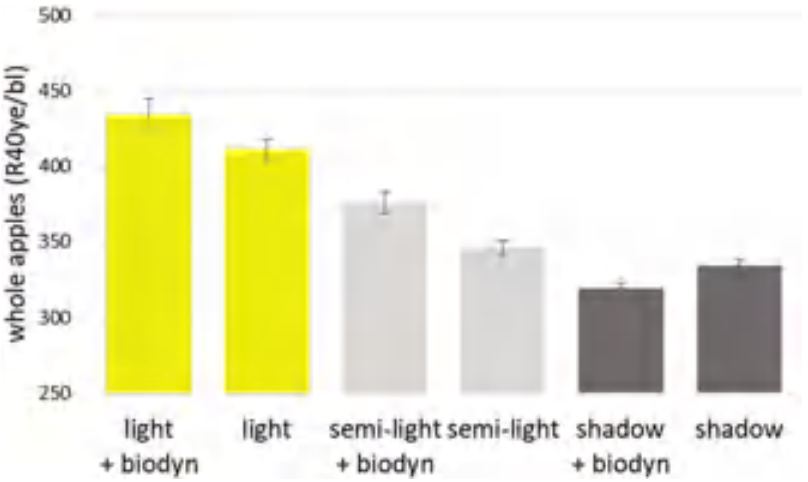

FIGURE 15.5 R40yellow/blue of whole apples from different growing conditions (light intensity and application of biodynamic preparations).

R40yellow/blue is relative and is not a simple value for maturation, such as of the amount of secondary metabolites. It has to be interpreted depending on the sample: the sample type, the plant's organs such as e.g. seed, fruit, leaf have to be considered, and the evaluation scale has to be obtained from the object itself. As the maturation stages of fruits are the plant's steps on its way to its characteristic well-formed, well-shaped, evolved final stage of development before it decays in several stages to death, it can be seen that the different organs differ with progressing maturation, and the FES results represent this. Strube and Stolz (2002) concluded that this development can be interpreted as an increased differentiating, organisational capacity or performance (in German: Organisationsleistung, cf. also Egerer, 2009) and that it was present in the apples grown under full light or in those with biodynamic preparations (Figure 15.5; Strube and Stolz, 2002). In other situations, such as where the crop is intensively fertilised or grown in in vitro cultivation, growth showed less differentiation.

3) Emission Spectrums as Dependent on the Type of Sample and the Sample State

To compare the different characteristics of the spectrally excited emissions of different kinds of samples, measurements have to be performed at the same excitation intensity and the same measuring intervals, which normally have to be set specifically due to different emission intensities of different kinds of samples. It was observed that leaves expressed an intense emission after being subjected to all excitation colours (the most after yellow or red excitation) – and this is named a 'broadband spectra' (cf. Figure 15.6) – whereas a pure chemical substance like citric acid only showed considerable emission after blue excitation – which is a narrowband spectra. Seeds (wheat grains) fell in between these characteristics – they had a low emission when excited with yellow or red light and an intermediate emission after excitation with blue light. These spectra are of importance when evaluating quality in the context of the sample's natural state, that is the whole mass of substances of the sample that are present at the moment of detection (including its life processes and specific composition of substances and physiological processes).

Strube and Stolz (2004) have also observed that when seeds are not totally dried, they may emit more like a leaf, with higher emission intensity after yellow or red excitation – as they are not yet in total dormancy and thus their physiology is more active. Further, when wheat was grown with higher amounts of nitrogen fertiliser, resulting in higher amounts of crude protein in the wheat

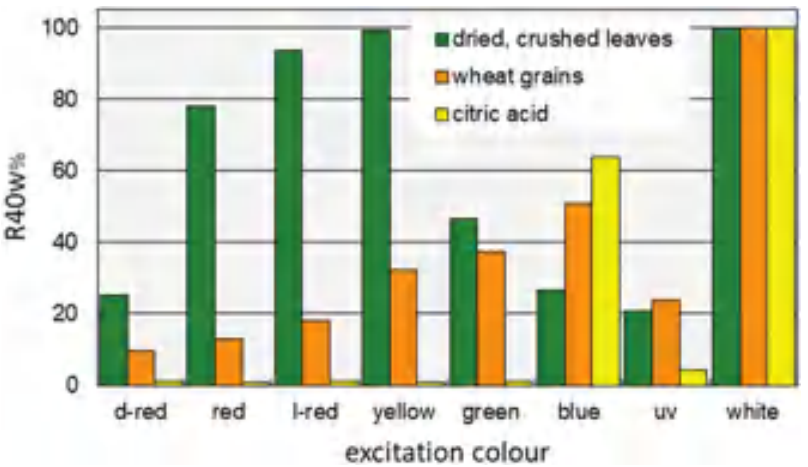

FIGURE 15.6 Fluorescence excitation spectrum of different kinds of samples: emission of leaves (dried crushed nettle leaves), of seeds (whole wheat kernels) and of citric acid. (Derived from Strube and Stolz, 2001a.)

kernels, its emissions were similar to those of a vegetative in-growth state, while the emissions of other samples were more dormant and seed-like. This indicates that the excitation spectroscopy can detect whether growing and ripening were performed and finished by the plant's own characteristic physiology under natural conditions, or whether it was influenced by fertilisers or other physiology-influencing factors.

On the basis of these results, it can be concluded that the biophoton emission after colour excitation can indicate whether the sample is in a more or less characteristic state,

- being more leaf-like, representing vegetative growth-processes,
- being more seed-like, representing generative, mature, dormant situations, where physiological processes are reduced, resulting in conservation and storage of growth-relevant substances,
- or being more like a pure chemical substance, representing minerals which are not actually integrated in life processes.

4) Cocoa Beans Grown in Monocultures or in Agroforestry Systems

A scientifically controlled field trial with cocoa plants was installed in 2009 in Bolivia (Sara Ana, near La Paz), to compare the effects of the farming system on ecological aspects (biodiversity), soil parameters, plant health and product quality. The experimental factors were as follows: (1) monoculture (Mono) vs. agroforestry (AF) farming and (2) conventional (Conv) vs. organic (Org) farming; additionally, a successional agroforestry system (SAFS) was investigated. FES measurements were performed on fermented cocoa beans which were harvested in 2012.

The results are provided in Figure 15.7 for the five farming systems in comparison, and in Figure 15.8, the differences between organic and conventional systems are presented.

The emission of the cocoa beans – although fermented – showed a comparable spectral excitation ability to wheat kernels. Organic and agroforestry (AF) farming systems resulted in lower long-term emission intensities after yellow excitation (Figure 15.7), indicating a more seed-typical quality. The ratio between yellow and blue (R40yellow/blue; Figure 15.8) was higher among the conventional samples than among the organic samples and may indicate a seed with a low degree of specific maturity, again comparable to the conventional wheat samples (K2 and M) from the DOC-trial. The low values of the organic samples may indicate that the seeds reached seed-typical qualities.

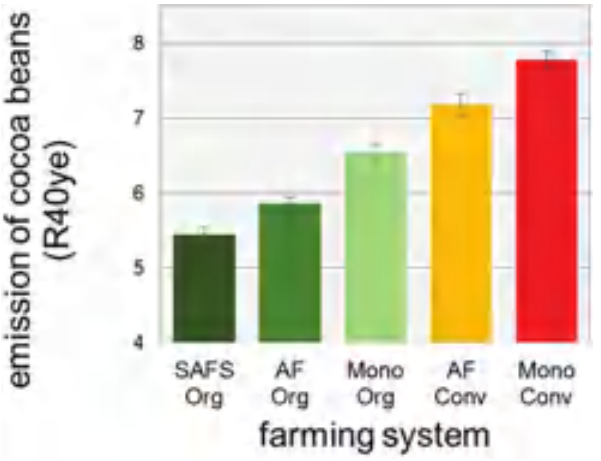

FIGURE 15.7 Emission intensity (R40yellow) of fermented whole cocoa beans from a cultivation trial. Whiskers indicate standard error of the mean.

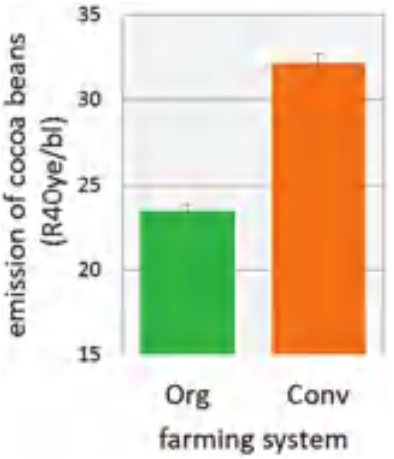

FIGURE 15.8 Differences between conventional and organic farming in cocoa beans in the relative emission intensity of R40yellow/blue.

The SAFS sample had an overall very low emission intensity, characteristic for seeds in dormancy or grown under extensive conditions. Overall, the implications are that more sustainable farming systems are better able to produce or achieve products that are closer to their optimum, naturally predisposed potential.

CONCLUSIONS

The FES has repeatedly been able to show differences between samples originating from different farming systems, and a classification of samples according to their origin has been possible, which was comparable to the classification on the basis of their analytical parameters (Hermanowski et al., 2013). It will be just a question of time before the underlying principles of the induced emission characteristic are better understood. Still, the existing results of the FES measurements are sufficient to support the rationale that the scientific view should be broadened to look not only at the microscopic and analytical world, but also at the phenomena of life and, holistically, at the farming system as a whole that influences the organisms within it and their development, their metabolism and interactions.

A theory common among biologists is that plants seek a balance between growth and differentiation (Bloksma et al., 2003, 2007; Herms and Mattson, 1992; Stamp, 2003). This is based on the evidence that plants may – dependent on the growing conditions – express a more growth-related metabolism with enhanced nitrogen-related primary metabolism, resulting in enhanced yields, or a metabolism which aims at the differentiation of matter by enhancing carbon-related secondary metabolites. The latter is often observed in plants of organic origin, and such plants are observed to suffer less damage from predators or diseases (de Lange et al., 2019). This balance or equilibrium changes with the ongoing development of the plant, from more growth-related to more differentiation-related processes, and each part of the plant and each species has its own characteristic balance.

So when FES results indicate that crop samples of organic, biodynamic or agroforestry origin are ‘more typical’ than conventional/industrial samples, including those from monocultures, the measured emission can be seen as an indication of the growing conditions which were more or less in congruence with the species-specific demands. Under such optimum conditions, plants may express their own individual quality and shape more explicitly than in less optimal conditions. For example, in highly fertilised, conventional or monoculture conditions, where the plants are restricted in their resilience to stay healthy (Döring et al., 2012, 2015), or to exhibit all stages of

development (Bloksma et al., 2007; Lammerts van Bueren and Hospers, 1991), they are forced into a specific growth-related development.

In all investigations with FES, the relative emission after blue excitation and yellow excitation seems to be important in evaluating the sample's quality and metabolic state. Yet it is not just expressing a metabolism which is related either to more differentiation (indicated by secondary metabolites) or to more growth (indicated by primary metabolites). It also has to be interpreted in relation to the type of sample and its biologically predefined physiology. A leaf is most leaf-like when it enhances the carbon metabolism of the plant by photosynthesis, when it expresses life processes. Fruits are most fruit-like when they are ripening and store sugar and polyphenols – also products of life processes. In these cases, high emissions after excitation with red or yellow can be observed, and high ratios of yellow-by-blue are characteristic. The opposite is found for seeds: their emission after red or yellow excitation declines with ripening – so for seeds, a high emission indicates a metabolism which is not seed-like – it is growth-like or life-like, but not dormant, as a seed should be when it is in its typical state. So with FES, the typical expression of a plant's organ may be evaluated in terms of its state of expressing its own, naturally desired condition, its metabolic state, seen as the operating processes of life.

On the basis of this ability of the FES to tell us something about the plant's life processes, it may in the future be used not only to differentiate between farming systems, but also to help farmers or scientists to decide which farming practice is helpful in obtaining the best quality product, or which breeding line offers the most product-typical opportunities.

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16 Picturing Vitality, the Crystallisation Fingerprint Method

Paul Doesburg
Crystal Lab

CONTENTS

INTRODUCTION

Nowadays, food is increasingly being divided into 'good' and 'bad'. This perspective focuses on the nutrients, rather than on the products that we actually eat. This nutrient-oriented framing of food regards food quality as good when it contains few potentially harmful constituents – 'the bads' – and higher levels of health-supporting constituents – 'the goods'. Logical reasoning, right? However, when you take a closer look, this issue is somewhat more complicated, because a living organism is much more complex than a simple chain of cause–effect relations between single ingredients. Lycopene, for instance, is a major antioxidant that is widely distributed in the human body, and is thought to act as a preventive agent against prostate cancer. While isolated lycopene does appear to be effective against single prostate cancer cells grown in a Petri dish, the results from animal and human patient studies are ambiguous. A few studies demonstrated a preventive action from tomato powder (which contains lycopene), but not from isolated lycopene itself (Applegate et al., 2019; Boileau et al., 2003). Even more striking, the daily consumption of carrots by smokers appears to reduce the incidence of lung cancer, a variant on the proverb 'An apple a day keeps the doctor away'. However, when you regularly give smokers beta-carotene tablets – the most important antioxidant in carrots – the risk of developing lung cancer actually increases. Why is that? Doctors aren't completely sure about the difference between the absorption of nutrients through food and their intake as a supplement, but they do acknowledge that the relationship between diet and cancer is far more complex than simply supplementing one's daily nutrition with a few micronutrients (Whitworth, 2006).

Clearly, this cause–effect approach has provided us with a wealth of information concerning the structure and functioning of the inorganic world, but remains inadequate to understand *organic* aspects such as shape, self-regulation and resilience[1]: characteristics of 'the whole plant' or 'the whole animal' from which our food originates. Living organisms permanently protect their integrity

[1] Vitality indicates how the 'self-regulation' of an organism is expressed as 'resilience' – resilience in the sense of 'elasticity', the capacity to cope with challenges. This may be related to the product itself or to the effect of the product on the consumer (Kahl et al., 2012). Self-regulation is the ability of organisms to adjust and maintain various physiological and other biological parameters at comparatively constant levels. Individuality is the characteristic (species-specific) nature of living organisms.

DOI: 10.1201/9780429440939-18

BOX 16.1 THE CRYSTALLISATION METHOD

The crystallisation method was developed in the 1930s by Ehrenfried Pfeiffer (1899–1961), a German scientist, who was strongly connected to the biodynamic agricultural movement. Pfeiffer received an honorary degree of Doctor of Medicine from Hahnemann Medical College in Philadelphia in 1939 for his contribution to the development of the crystallisation method in relation to the detection and localisation of the early onset of cancer via blood samples.

against different environmental influences. Organic agricultural research works from the hypothesis that cultivation measures (fertilisation, tillage, seed variety, etc.) influence the degree to which an organism can maintain its integrity, and this has a strong correlation with the organism's health, whether plant, animal or human (Velimirov et al., 2010). Following this line of thought, a whole food product should not be reduced to a set of chemicals, but should be seen as a dynamic, hierarchically organised unit. Because of this, one could argue that the results of nutritional tests cannot be reduced to the chemical composition of the food. From a systemic biology perspective, it is acknowledged that an organism cannot be regarded as a simple chain of cause–effect relations between its different compounds, but instead as a highly complex coherent whole (Sauer et al., 2007).

THE CRYSTALLISATION METHOD

I encountered the crystallisation method in 2000 at the Dutch Louis Bolk Institute and was overwhelmed. I realised that this method makes it possible to acquire a 'fingerprint' of this extremely complex 'coherence' of our food.[2] Box 16.1 describes the crystallisation method.

The method is based on the generation and subsequent evaluation of dendritic crystallisation patterns (i.e. the 'fingerprints'), which emerge when an aqueous dihydrate cupric chloride solution ($CuCl_2{\cdot}2H_2O$) is crystallised on a glass plate in the presence of a water-soluble additive (the sample; Busscher et al., 2010a; Gallinet and Gauthier-Manuel 1992). Additives can be single molecules as well as complex food matrices. The crystallisation patterns are additive specific (Andersen et al., 1998, 2001; Fritz et al., 2017; Kahl et al., 2014, 2016; Seidel et al., 2015; Shibata et al., 2000; Schweizer et al., 2010; Szulc et al., 2010; Vester, 1960) (see Figure 16.1) and emerge through a self-organisation process of the copper chloride ($CuCl_2$) which is influenced by the physical, chemical and biological properties of the additive (Busscher et al., 2010b, 2014, 2018). A remark by Rudolf Steiner, that 'spirit is never without matter, and matter is never without spirit', helps me to regard the crystallisation images as a 'manifestation' of the spiritual dimension of the organism that the pictures originate from, and the degree to which they're able to maintain their integrity.

The characteristics of the crystallisation patterns can be evaluated by human visual evaluation using defined criteria, developed according to adapted ISO norms for sensory analysis (Huber et al., 2010a; Doesburg et al., 2015), and/or by computer-based image analysis using texture or structure variables (Andersen et al., 1999; Doesburg and Nierop, 2013; Unluturk et al., 2013). This kind of fingerprint analysis has been applied to a broad range of additives, addressing different research

[2] Crystallisation research in the Netherlands took place at the Louis Bolk Institute in Driebergen until 2010. Since 2010, Paul Doesburg maintained an independent laboratory, Crystal Lab (https://www.crystal-lab.nl/), in the former monastery Roepaen in Ottersum (the Netherlands), which is connected to a European consortium of five crystallisation laboratories. Paul is currently rebuilding his crystallisation laboratory at the Hiscia Research Institute in Arlesheim, Switzerland.

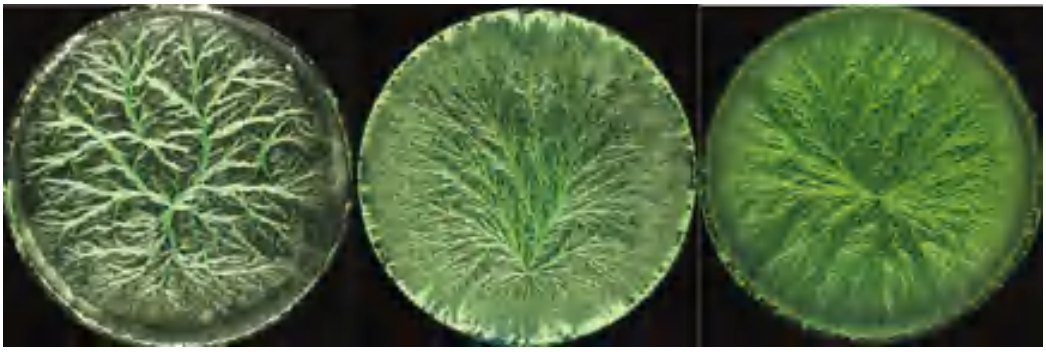

FIGURE 16.1 Product-specific crystallisation patterns of barley (left), tomato (middle) and white cabbage (right).

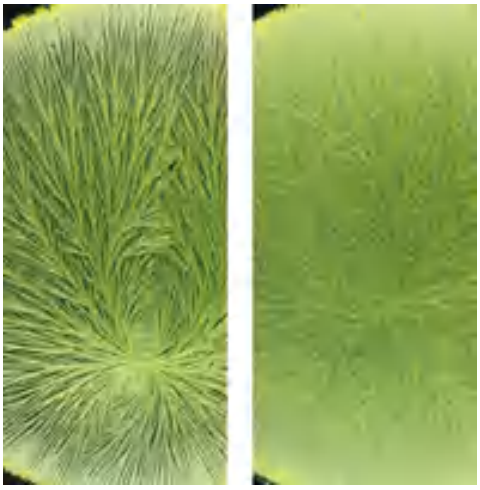

FIGURE 16.2 Crystallisation patterns of the effect of milk processing: raw unprocessed milk (left) and the same sample after homogenisation at 50 bar (right). We can see an enormous conversion of the structure of the crystallisation pattern. During homogenisation (commonly at 200–300 bar, or 200–300 kg pressure/cm2), milk is passed under high pressure through a tiny orifice. The structure and size of the fat globules in the milk are influenced by this. This means that the natural creaming of the milk, which many people find unpleasant, doesn't take place.

questions, such as the effect of innovative processing techniques (Marzaleka et al., 2019), the biological effects of ultramolecular homeopathic preparations (Baumgartner et al., 2012; Doesburg et al., 2019, 2021), the diagnosis of diabetics (Shibata et al., 2000), doping (Shibata et al., 1996), the early onset of cancer (Barth, 1990; Koopmans, 1990) and other pathologies (Piva, 1994) in human blood, but predominantly in food quality analysis. With respect to the latter, the method has been shown to reflect plant physiological processes such as ripening and decomposition (Fritz et al., 2011, 2017, 2018), the effects of processing (see Figure 16.2), feeding regimes and farming systems (Kahl et al., 2009, 2015, 2016; Seidel et al., 2015; Szulc et al., 2010) in a broad range of agricultural products, which demonstrate the method's systemic approach to food quality. The crystallisation method fits seamlessly with the principles of organic farming, in which the focus is on the development of

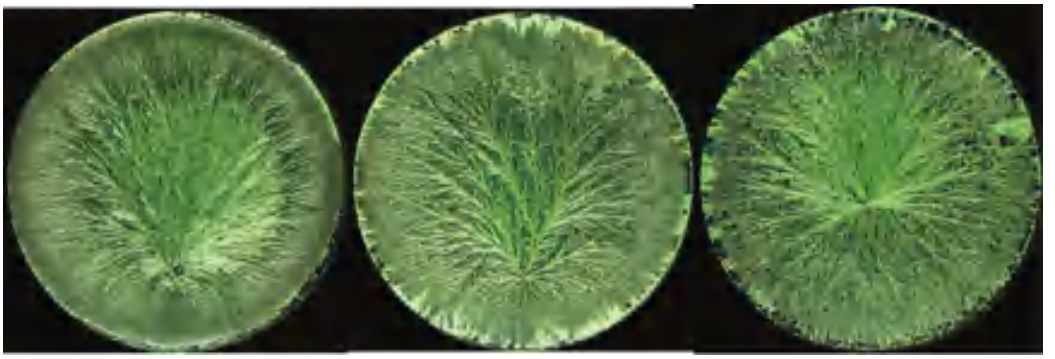

FIGURE 16.3 Crystallisation patterns of different ripening stages of vine tomatoes: unripe, little structure and condensed patterns (left); ripe, structure and cohesion (middle); and overripe, loss of structure and cohesion (right).

robust, resilient soil, crops and animals, hence the use of the crystallisation method for decades in organic and biodynamic food quality analysis.

By means of the crystallisation method, I aim to deduce more about the quality of food than solely the nutrient content. The method allows you to visualise differentiation and ageing statuses in agricultural products (see Figure 16.3). Particularly in ageing experiments (based on sample ageing or processing), it is striking to see how crystallisation patterns fall apart and lose their cohesion. This corresponds perfectly with the image one would generally associate with a loss of structure. Consequently, quality is literally made visible (see Figure 16.4).

The images are evaluated in two different ways: visually and by means of computerised image analysis (Andersen et al., 1999; Doesburg and Nierop, 2013). Depending on the research question, we choose one of the two methods or a combination. Computerised analysis allows us to find significant differences between products or treatments, allows the analysis of large datasets and is regarded as 'objective' which aids communication within the scientific arena. However, this approach misses the nuances of the method which are captured with a visual evaluation. For this, standardised evaluation criteria have been developed and validated within a European collaboration between several crystallisation laboratories according to adapted ISO norms for sensory panels (Huber et al., 2010a). Herewith, the general characteristics – the phenomena of a crystallisation image – can be described. The empirical basis of the visual evaluation of the crystallisation patterns is that the degree of wholeness of a sample is in some way transferred to the microscopic and macroscopic arrangement of the crystal needles. Wholeness in such is the degree to which the sample is capable of forming a hierarchically organised unit.

As reflected in the photos of the ageing carrot juices or the wheat derived from different farming systems (see Figures 16.4 and 16.6), an increasing degree of wholeness generates a better coordinated pattern with a stronger perradiation[3] and a higher degree of regularity in the branching frequency and in the onset and angle of the side needles. Generally, this is observed as a higher degree of harmony in the image.

Currently, I am involved in establishing a scientifically communicable manner to evaluate this wholeness perceived in the images (Doesburg et al,. 2021). For this, we are evaluating the potential of proprioceptive (kinaesthetic) experience, i.e. the perception of one's own position, posture,

[3] Perradiation is the length and perceived tension of the gesture that can be sensed in the main branches that run from the centre towards the peripheral zone, where the movement fades out.

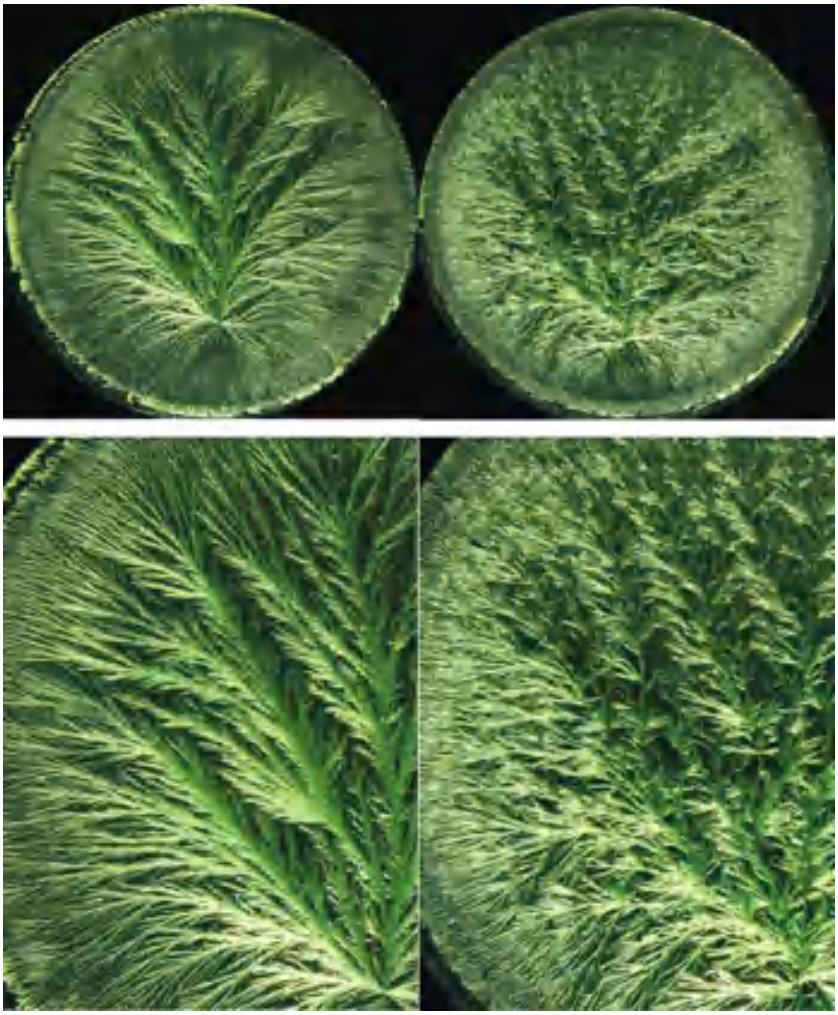

FIGURE 16.4 Crystallisation patterns of fresh (left) and aged carrot juice (right; after 7 days of storage at 4°C). A loss of structure and organisation is apparent in the aged carrot juice.

equilibrium or internal condition applied to sense perception content instead of body self-awareness. It's comparable to the bodily sensation that we are all familiar with when, for example, affected by a dramatic gesture in an artwork. Proprioceptive experience, coupled with the emotional resonance it triggers, is likely to be a crucial component of our aesthetic experience of artworks (Freedberg and Gallese, 2007).

According to the 'growth–differentiation balance hypothesis', an optimal product quality is the result of a harmonious plant development (Bloksma et al., 2007). In the plant's development, two fundamental life processes can be distinguished: growth (mass formation) and ripening (flower and seed formation, flavour and scent). Within this, harmony refers to a balance between these two life processes by mutual influence. It's possible to learn to perceive the patterns by which these life processes express themselves (Doesburg et al., 2015). A harmonious plant development results in an integrated wholeness leading to resilient, crop-specific, tasteful products with a long shelf life (Bloksma et al., 2007).

THE INFLUENCE OF THE AGRICULTURAL METHOD

The method also shows differences between products from conventional, organic and biodynamic origin. Organic/biodynamic agriculture wields a systemic approach which aims towards healthy and resilient plants and animals that have a strong immune system and thus omits the need for pesticides.

One aspect I often see in crystallisation images from products originating from conventional agriculture is that the differentiation phase seems to be missing. This phase, which can be considered the refinement or *finishing touch* of the crop's development, is irreducibly connected to a harmoniously developed product. These conventional products are often fertilised too heavily, causing a one-sided growth. Instead of quietly maturing, degradation trends already start to dominate in the growth phase. To put it more simply, the plants in which growth predominates act like a teenager with ageing symptoms (Figures 16.5 and 16.6). Such a crop is far more susceptible to disease and often does not reach the differentiation phase. It is in this phase that most health-promoting nutrients and aroma substances are formed, which influence taste considerably (Barański et al., 2017).

A justified question is whether harmonious crystallisation images of food samples have health benefits. In 2010, the Dutch government financed a research project 'Is organic more healthy?' (Huber et al., 2010b), to once and for all address the question of whether organic agricultural food products have an increased health benefit.

A feeding trial was performed with three genetically different groups of chickens over two generations. The chickens were fed with identically composed organic or conventional feeds. Although the animals constituting the two feeding groups were all healthy, differences between the groups were apparent. The conventionally fed chickens showed an overall higher weight gain than the organically fed chickens, even though feed intake of the two feeding groups and the metabolisable energy of the feeds were comparable. The animals of the second generation of both groups underwent an immune challenge, causing a significant reduction in growth rate. Yet the organically fed chickens, of all three genetic varieties, showed a stronger immune reactivity, as well as a significantly stronger 'catch-up growth' after the challenge, indicative of an increased resilience, compared to the conventionally fed chickens. Of the feed ingredients analysed with the crystallisation method, only two ingredients (soy and wheat) originated from a standardised field trial (i.e. the same location, seed variety and

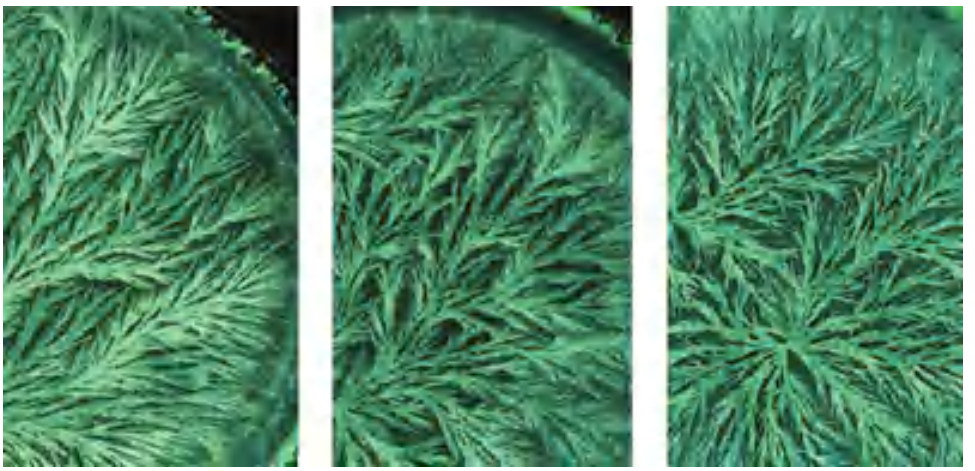

FIGURE 16.5 Enlarged details of crystallisation patterns of a wheat aging series. Left: fresh extract; middle: extract stored for 3 days at 4°C; and right: extract stored for 12 days at 4°C. The photos show a loss of structure and organisation as aging of the wheat extract progresses.

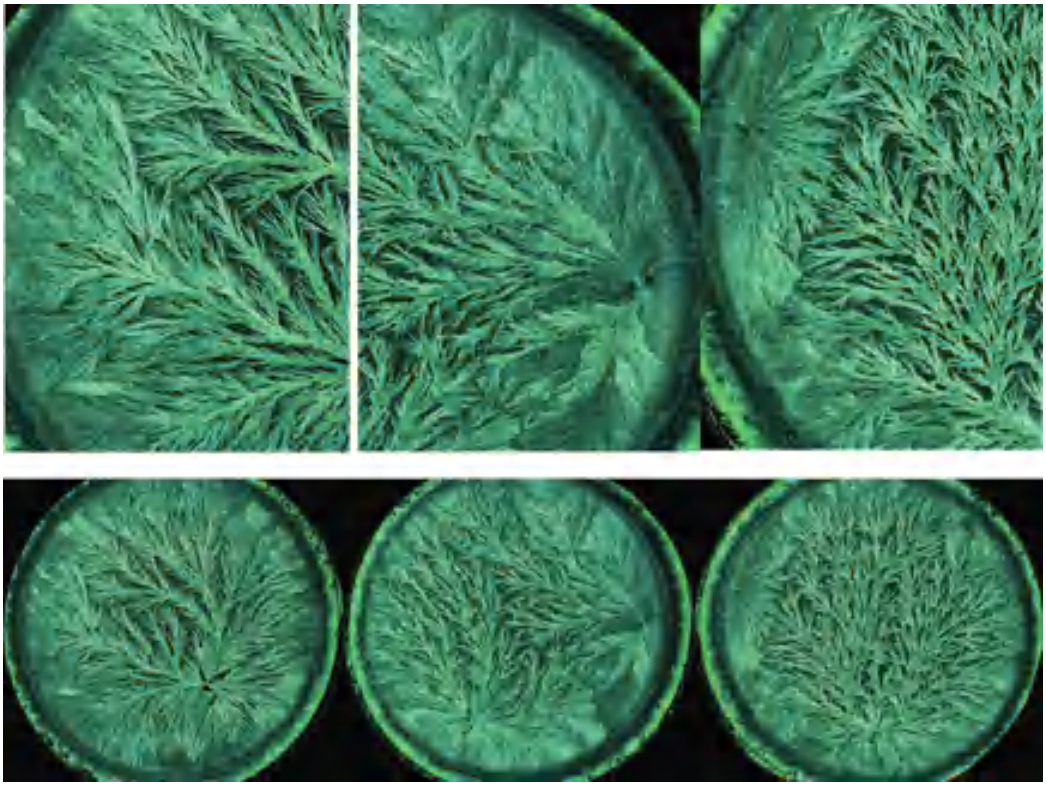

FIGURE 16.6 Crystallisation patterns of 12-day-aged wheat extract originating from a long-term DOC field study (FiBL, CH). Since 1978, wheat has been cultivated according to biodynamic (D), organic (O) and conventional (C) guidelines, in which soil and climate variations are ruled out. Photos bottom: whole images; and top: enlarged details. Biodynamic wheat (left), organic wheat (middle) and conventional wheat (right). The images show an increasing loss of structure and organisation which is minimal in patterns originating from the biodynamic wheat extract and maximal in the patterns from the conventional cultivation (for comparison, also consider the aging series in photo 5). (Images: J. Fritz, Uni Bonn, Germany.)

microclimate), allowing a fair comparison of the effect of the two farming systems on the resulting crystallisation patterns. For both soy and wheat, the visual evaluation clearly pointed to a superior quality of the organic ingredients, which of course is a very interesting find.

A NEW PERSPECTIVE ON FOOD QUALITY

The crystallisation method generates a physical image of the life processes inside an organism. Evaluating the crystallisation images appeals to one's morality when one sees the effect of the agricultural system and/or processing techniques, similar to the frequently applied Röntgen detection technique for the detection of foreign particles (metal, glass and plastics) in food. This opens up an entire field of research. There is a need for new research methods that can visualise or otherwise detect aspects such as vitality, resilience, individuality and self-regulation and make them broadly communicable. These aspects currently are not part of the remit of nutritional science, but the aim of my work is to contribute to broadening this scope, based on the understanding that life is not an ancillary element of chemical and physical processes, but actually expresses itself through these processes. Food is so much more than just a bag of nutrients!

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Section 3

In Search of More Embodied Methodologies