Soil Biology and Biochemistry 159 (2021) 108167

Contents lists available at ScienceDirect

Soil Biology and Biochemistry

journal homepage: http://www.elsevier.com/locate/soilbio

The 'soil health' metaphor: Illuminating or illusory?

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ARTICLE INFO

Keywords:
Health
Metaphor
Ecosystem
Land
Quality

ABSTRACT

'Soil health' has become a dominant, pervasive phrase in soil and environmental sciences. But despite its ubiquity, the concept remains elusively ambiguous, largely because 'health' here is a metaphor, not a literal scientific construct. So we ask: can this imagery nevertheless still advance research toward stewardship of soils globally? To address this question, we here define soil health as: 'the vitality of a soil in sustaining the socio-ecological functions of its enfolding land.' By this definition, soil health reflects not the composition of soil *per se*, rather its capacity to promote the pertinent functions of the *land* in which it is embedded. This means that the term has little meaning for a soil divorced from its ecosystem, and that properties conferring such health depend on place and time. From this view, we consider the metaphor's strengths and pitfalls for stewarding soils, and proffer some ways to elevate its use, mostly to spur conversation. We propose that the point of pursuing the soil health metaphor is not merely to assign a number to the 'goodness' of soil, but to generate understanding of relational mechanisms and thereby lead us to better nurture attributes that catalyze valued functions, now and perpetually. In the end, the continuing usefulness of the soil health metaphor depends, not on whether or not we can finally entrap it numerically, but whether it propels us to greater reverence for soil, deeper insight into its beneficial processes, and wiser ways of managing it. In time, when the health metaphor can no longer carry this prodigious weight, we may seek a worthy successor; a good metaphor produces good science, and good science produces ever better metaphors.

1. Introduction

> *When the human mind deals with any concept too large to be easily visualized, it substitutes some familiar object which seems to have similar properties.* Leopold (1939)

> *Science is built on metaphorical foundations, so metaphors occur in much of the science we hear about each day.* Larson (2011), *p. 4*

Like poets and novelists, scientists rely on metaphor. As concepts become more abstract and stiff academic language falters, we reach instinctively for metaphor, seeking to illumine the opaque with the familiar (Lakoff and Johnson, 1998). Thus, for example, we read of white dwarf stars, RNA editing, genetic blueprints, black holes, and the greenhouse effect (Montgomery, 2003). Such metaphors serve science in several ways. First, they help explain non-intuitive phenomena by augmenting rigid literalism with elastic imagery, drawn from common human experience. Second, they offer connective vocabulary, conveying meanings that transcend disparate disciplines; the 'greenhouse effect', for example, has meaning both for the atmospheric physicist and the marine biologist. Finally, a value easily overlooked, metaphors stimulate creative impulses, drawing out insights not yet fully formed. The crafting of meaningful metaphors forces us to see and think more clearly, more inventively (Johnson, 2006). "*What is mysterious and wonderful,*" writes Brown (2003, p. 196), "*is the power of metaphorical thought to call forth the highest exercise of human intellectual powers*". For these reasons, metaphors make our writing more stimulating for both audience and author.

Ecology, like other scientific disciplines, has its own repertoire of metaphors: food webs, planetary boundaries, carbon footprints, tipping points, to cite a few (Olson et al., 2019). Prominent among them is the imagery of ecosystem 'health'. As with other metaphors (Eisenberg, 1992), its use has provoked some controversy. On the one hand, it offers ecologists an emotive connection to a wider audience, by conjuring imagery of human health, visceral to most people (Ryder, 1990). The fragility of ecosystems, their sensitivity to disturbance, and the

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https://doi.org/10.1016/j.soilbio.2021.108167
Received 6 August 2020; Received in revised form 22 January 2021; Accepted 2 February 2021
Available online 11 February 2021

imperative of avoiding harm are magnified in light of our own vulnerability to illness and injury from inflicted stresses. But what makes the metaphor so appealing and emotionally compelling, also leaves it vague, hard to pin down, almost impossible to quantify in the numerical language of science (Rapport et al., 1997). For this reason, some have argued that the health metaphor has no place in scientific discourse: "Ecological health *is a nebulous concept that should be expunged from the vocabulary*" (Lancaster, 2000).

This, then, is the backdrop for the recent proliferation of the health metaphor in soil science. The term 'soil health' first took root in the scientific literature at the close of the 20th century, and since then, its use has increased exponentially (Karlen et al., 2019; Jian et al., 2020; Liu et al., 2020; Fig. 1). Some reference to soil health now seems almost mandatory in many soil science fora, especially in soil biology. In this context, the health of a soil is a measure of its 'goodness', its functional fitness; and *improving* soil health is assumed implicitly to be the desired aim. A soil of good health is always deemed better than a soil of poor health. But despite this enthusiastic embrace, the metaphor faces ambiguity similar to that of health in wider ecology.

Our purpose, therefore, is to ask: Does the now ubiquitous soil health metaphor advance our science and its overarching mandate of conserving, renewing, and revering our soils? And, if so, how can we hone the metaphor, and our use of it, to invigorate this urgent work? We offer some responses to these questions, not implying we know the answers, but as a way of inciting further debate, perhaps first among soil biologists, often seen as stewards of soil health. In the words of Marsh (1864, p. 10), in a seminal work now mostly forgotten, *"it is [our] aim to stimulate, not to satisfy, curiosity."*

2. What is soil health?

> *"When I use a word," Humpty Dumpty said, in rather a scornful tone, "it means just what I choose it to mean – neither more nor less."*
> *"The question is," said Alice, "whether you can make words mean so many different things."* Lewis Carroll, Through the Looking Glass.

> *Anything that is infinitely defined is, ultimately, undefined and undefinable.* Sojka and Upchurch (1999)

To address the preceding questions we need first to establish what *we* mean by soil health. This is no easy task; *"Metaphor can never be reduced to its literal meanings"* (Ross et al., 1997). Still, definitions abound (e.g., Acton and Gregorich, 1995; Doran and Safley, 1997; Doran and Zeiss, 2000; Kibblewhite et al., 2008; Cardoso et al., 2013; Biswas et al., 2014; Bruns, 2014; Karlen et al., 2017; Lehmann et al., 2020; USDA, 2020). Though diverging in subtleties, most of these have three prominent elements:

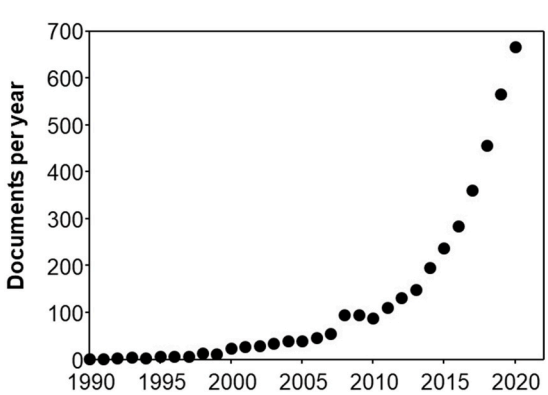


Fig. 1. Number of documents with "soil health" in title, abstract, or keywords, based on Scopus analysis (as on 21 January 2021).

1 Functionality: Health, broadly, can be defined as "*the condition of an organism … in which it performs its vital functions normally or properly*" (Gove, 1964). Thus, soil health has at its core the notion of functionality, the capacity of a soil to promote utility (Pankhurst et al., 1997; Doran and Zeiss, 2000; Arias et al., 2005; Printz et al., 2014; Fine et al., 2017). By 'functions', here, we mean not just 'services', which tend to imply direct human benefit (Fu et al., 2013; Comberti et al., 2015; Danley and Widmark, 2016), but also processes that maintain integrity and stability of the biosphere beyond immediate human demands. If based on function, then, the health of a soil is dynamic, not static; it describes its performance, not its condition, and its behaviour, not its properties. Health, seen through the lens of functions, can be understood or evaluated, not merely by measuring soil composition itself, but by observing how well its ecosystem thrives.

2 Vitality: Another facet implicit in the metaphor of health is 'vitality', which Gove (1964) defines as *"the peculiarity distinguishing the living from the nonliving …. "* Soil is not an organism (Stuart and Jenny, 1984), as the health imagery connotes, but it *is* a living system (Kibblewhite et al., 2008; Lehman et al., 2015). It is not a passive assemblage of inert entities, but a torrent of connective, interwoven processes, many of which are mediated by the numberless, mostly nameless biota in the soil. Biology has always played a prominent role in perceptions of soil 'goodness' (Russell, 1911; Clevenger, 1923), but recently-emerging methods now further amplify this living dimension (Dubey et al., 2019).

3 Sustainability or resilience: A final essential element of purported definitions of health is that of 'sustaining', of continuity (Niccolucci et al., 2010). A healthy soil is one that supports ecosystem functioning into perpetuity – what our forebears termed 'permanence' (Hopkins, 1910; Bracken, 1921). Permeating the concept of health, therefore, is the vexing variable of time. Soil health is not a climactic state, ever fully achieved, but a perpetually moving ideal, reflecting evolving conditions and demands. It can never be documented in a momentary snapshot, but rests in soil's enduring capacity to promote the pertinent functions of its ecosystem, through inevitable disturbances and shifting expectations. It is therefore closely linked to 'resilience' (Holling, 1973; Callicott, 1992; Döring et al., 2015; Hodgson et al., 2015), the capacity of land to maintain, over long unfolding time, its site-specific functions despite ongoing stresses and upheavals.

Based on these three elements, we offer the following wording in an attempt to constrain how *we* use the phrase:

> *"Soil health is the vitality of a soil in sustaining the socio-ecological functions of its enfolding land."*

Although founded on earlier definitions, our rendition offers two slightly distinctive nuances. Firstly, it stipulates that the functions in question are not those of the *soil* itself, but rather those of the *land* in which it is embedded. 'Land', here, is synonymous with ecosystem: the dynamic assemblage of soil, air, water, and all biota (including humans) in their interwoven interactions in a designated place (Tansley, 1935). Soil health, from this perspective, applies to a specific landscape with explicit geographical coordinates. To know if a given soil is healthy, we look to its enveloping ecosystem – a field, a forest, a mountain meadow, an urban garden – and ask: where are we?; who is here?; what is happening here?; and most importantly, what functions can this place support, for nature first, and also for us, both now and indefinitely? Only then, having considered the singular conditions and functions of its ecosystem can we say anything about soil health. This means that soil health will always be context-dependent (Bennett et al., 2010; Bouma and McBratney, 2013; Norris et al., 2020), that properties conferring health will never be the same from place to place (Ng and Zhang, 2019). In short, health has no meaning for a soil divorced from its setting; no

amount of analysis can assess a soil's health without acquaintance with its place.

Secondly, our wording deliberately denotes a broad, inclusive range of both social and ecological functions. Indeed, we propose that it is this expanded spectrum of functions that distinguishes health from its predecessors, 'fertility' and 'quality'. All three concepts – fertility, quality, and health – refer to the capacity of a soil to promote functioning of land. But as we move along that historical succession, the number of functions in play increases (Lehmann et al., 2020; Fig. 2). Fertility primarily emphasizes productivity – the capacity of a soil to furnish high crop yields and economic return. Over time, as soil quality displaced fertility, other functions tied to sustainability of land crept into the definition: maintaining land stability through erosion control, preserving genetic diversity of soil biota, protecting air and water quality by retaining pesticides and nutrients, for example. Soil health, now, envelops even more functions, perhaps especially those related to broader societal aspirations, including human nutrition and well-being, climate regulation, wildlife habitat, biodiversity preservation, and aesthetic appeal (Box 1). To phrase this another way, the domain for each of the three in this series advances from focusing on soil functions within a field to those that influence the broader physical environment to those that encompass the social elements of the biosphere. This trend reflects a gradual evolution of our view of land from 'resource' to 'capital' (Janzen, 1998; Barbier, 2011) to 'socio-ecological system' (Rockström et al., 2017), which Odum (1997) calls 'home.' This shifting, expanding perspective gives health greater relevance and wider appeal, and may help steer research in soil biology toward broader societal goals. Admittedly, including such difficult-to-measure functions complicates measurement of soil health, but that should not deter research; as Meadows (2008, p. 194) implores: "*Pay attention to what is important, not just what is quantifiable.*"

Our wording, we acknowledge, retains a deliberate vagueness, reflecting our collective inability to capture in precise, scientific terminology the meaning of soil health. This, we suggest, is how it must be: "*The great shock of twentieth-century science has been that living systems cannot be understood by analysis*" (Capra and Luisi, 2014, p 66). If 'goodness' of soil could be succinctly conveyed in scientific jargon, there would be no need for metaphor. Indeed, the ambiguity of soil health is what makes it so alluring, and so frustrating for those who insist on trying to pin it down. We know intuitively what the phrase means, but can never quite find the words or numerical constructs to capture it. This is both the weakness and the underlying strength of soil health.

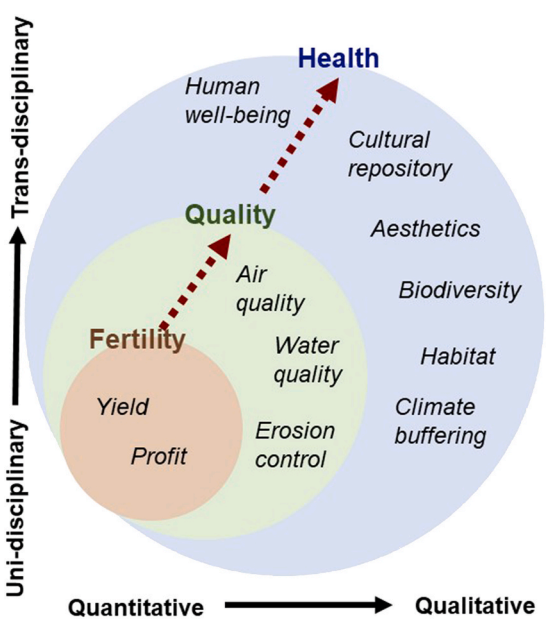


Fig. 2. Conceptual illustration showing the increasing number and range of ecosystem functions considered in the historical succession from soil fertility to soil quality to soil health. The boundaries between the various concepts are not always distinct, accounting for variable interpretations of these terms in the literature; for example, some authors see soil quality and soil health as synonymous. We suggest, however, that a strength of the soil health metaphor is that it enfolds an expanded, more qualitative list of socio-ecological functions, not directly considered in earlier terms. Contemplation of soil health, therefore, requires a deliberate, adventurous transdisciplinary approach.

3. Is the soil health metaphor useful?

Metaphors, writers insist, breathe life into scientific language. But that is the problem, others say. Anonymous (2013).

Metaphors are an indispensable component of science, and should not be appraised as true or false, but rather in terms of how they help or hinder knowledge. Proctor and Larson (2005).

Box 1
Soil health depends on functions expected of the soil in question – the example of aesthetics.

Many crucial ecosystem functions are not easily quantified or assigned a value. One such example is 'aesthetic appeal', which is almost impossible to pin down numerically. And yet it is important. "*The true problem of agriculture, and all other land-use, is to achieve both utility and beauty, and thus permanence*" (Leopold, 1999, p. 225). To illustrate how this influences perception of health, consider a grassland remnant in southern Alberta, Canada, with flora perhaps somewhat similar to the pre-settlement era. An analysis of the soil, using current norms, would likely show that it has low organic matter content, stony texture, alkaline pH, and thin topsoil layer. And yet, on a morning in June, a wanderer there will behold an arresting array of wildflowers. So what is the health of this soil? It depends on the functions that are valued for this land: if the desired function is to grow potato, the soil health is abysmal (and a battery of agronomically-oriented soil health tests might well confirm it so); but if the valued function is to broadly uplift the human spirit, then the soil's health surely is sublime.

Soil science, historically, has been biased justifiably toward yield-producing functions of land; but many critical life-support processes occur on unproductive lands (Odum, 1997), where soils may be of poor health by current yield-oriented guidelines. "*We can all admire a vast Iowa cornfield …, but … we most certainly would not go there for recreation!*" (Odum, 1997, p. 229).

Having framed a definition of soil health, we return to our question: can this metaphor further advance our aim of studying and sustaining soils?

3.1. Merits of the soil health metaphor

As implied by its ubiquity, the health metaphor appeals to soil scientists, perhaps for several reasons.

1 The most obvious strength of the health metaphor, clearly, is its potential to resonate deeply with audiences, in both academic and lay communities (Lackey, 2001; Wood and Litterick, 2017; Dick, 2018; Powlson, 2020). As with all well-chosen metaphors, health evokes in the reader or listener an instinctive intellectual and emotional response that motivates thought and action; it connotes a sense of vulnerability to stress, a desire for renewal, a hope of persistence, all arising from subconscious reflections on our own health. The power of the health metaphor, and likely the root of its widespread appeal, is its ability to incite a meaningful response toward maintaining the 'goodness' of soil, especially among audiences not yet fully aware of soils' mysterious complexity. The words we choose matter; an effective metaphor has power to influence how people think and how they respond (Princen, 2010).

2 Secondly, perhaps less obviously, the health metaphor implies – almost *demands* – an ecological systems perspective. The word 'health' itself "*has etymological roots of wholeness and completeness*" (Mallee, 2017). More than concepts such as fertility or quality, health therefore reflects the interwoven connectedness of soils with other elements of ecosystems: not an entity standing alone, but a dynamic constituent entangled in a complex web of ecological processes. In this way, health invites the input and melding of insights from manifold disciplines, across the boundaries of science and geography (e.g., FAO, 2020). Most scientists, irrespective of discipline, identify with health, so this metaphor provides a focus, a rallying point for integrating disparate perspectives. A biologist studying soil health, for example, will be compelled to consult a chemist and a physicist – and perhaps an anthropologist as well.

3 Finally, the least-recognized benefit: health, like all good metaphors, induces creative impulses (Livingstone and Harrison, 1981; Larson, 2011). Its vagueness baffles the scientist, but that humbling bewilderment inspires fruitful anguish. The very process of debate, of struggling interactively to define what we mean by soil health – if we are willing to engage in it – stimulates new thoughts, novel approaches for studying what makes a soil 'good'. A potent metaphor – "*a word for one sort of thing applied to a different sort of thing*" (McCloskey, 1964) – forces us to think hard about meaning, of exactly what it is we are trying to describe, thereby evincing thoughts and fertile inquiries which might not otherwise arise. A hardened definition, concreted into dogma, suppresses exploration; a shimmery, tantalizing metaphor, the mirage just beyond the reach of grasping intellect, leads our thoughts to insights lurking in places untraveled.

3.2. Potential pitfalls of the soil health metaphor

Soil health, as we have seen, offers potent imagery, in part from the resonance of human health. But the metaphor also has potential limitations:

1 A fundamental constraint is that there can be no universal benchmarks for properties that confer soil health. For humans, a medical practitioner can perform a battery of tests – body temperature, hemoglobin count, blood pressure, for example – and thereby deduce some measure of health by comparing with expected norms. Not so with soils. The cohort of functions expected of ecosystems is not the same from place to place, so desired soil properties vary accordingly (Kellogg, 1941; Letey et al., 2003; Dick, 2018; Norris et al., 2020). A soil deemed healthy for growing grapes may not be ideal for promoting songbird habitat; soil properties favorable for sequestering atmospheric CO_2 may not produce good strawberries. Hans Jenny, when asked *"What made a soil good,"* wisely replied: *"Good for what?"* (Logan, 1995, p. 62). Further, climatic and other conditions vary, so optimal properties even for a single function vary within and among landscapes; ideal properties for a humid soil, for example, may be detrimental in an arid soil. A tempting benchmark, in a given ecosystem, is the composition of that soil under 'natural' conditions, prior to human disturbance (Dick, 2018; Maharjan et al., 2020); for example, a benchmark for a cropland soil might be its condition prior to cultivation. But that raises the thorny question of what is 'natural' and when human disturbance actually began (Callicott, 1992). Moreover, do the properties of a 'natural' soil, tuned to its previous ecosystem functions (e.g., promoting grassland communities), necessarily favor the new functions under human management (e.g., growing irrigated corn)? And will a soil that was 'healthy' in 1850 necessarily be 'healthy' in the novel climate of 2050? Soil properties favorable for conditions and uses in a world long past may no longer serve as reliable benchmark in a different future (Ehrenfeld, 1992). Soil health, therefore, can never be measured using standards that apply universally (Box 2).

Box 2
'Health' depends on who is looking

The attributes of soil conferring health depend on the vantage of the viewer. Consider, for example, a field on a prairie landscape. The expectations an agronomist might have of that land (ecosystem) might not be the same as those of an indigenous Elder. The former might value it for maximizing yield of irrigated corn to produce ethanol; the latter might value it for medicinal and spiritual offerings, or as an opportunity to restore bison onto lands (Wood, 2020). Clearly, the suite of soil attributes that best support these different functions will likely not be the same. This means, then, that there can never be a single set of universally-applicable soil health indicators, let alone a single composite index, for soil in that land. Always, attributes conferring optimum soil health depend on who is asking.

This raises the question then: how do aspirations of different peoples using the land affect the optimal health-conferring properties of soil? This is not a question easily answered by hypothesis-driven scientific inquiry. Nor is soil science necessarily the forum in which to address it. But any serious inquiry into soil health, we propose, must at least be cognizant of such a question, and offer findings that may contribute to a wholesome response. Such questions, for example, may be critical in steering land use toward properties of health that help resolve issues of equity or justice.

2 Secondly, the imagery of soil health is confounded by the vagaries of time. A human lifespan is finite and somewhat predictable, so health assessment is based on a fixed time interval; namely the typical human lifespan. Thus, for example, the physician might say a 60-year-old is healthy, relative to norms for that age. Soils, however, persist indefinitely, so functioning (health) must be viewed across both short and open-ended time periods. A soil producing high corn yields today, for example, may not sustain those yields a half-century from now; indeed, today's high yields may even jeopardise future yields. A soil may be very effective in withdrawing atmospheric CO_2 today, but that function will fade in time as its C stock approaches steady state. Thus a soil's capacity to support each of manifold land functions changes on different time scales, and no single time frame is applicable to all. Soils are not static media – they are unfolding narratives, and our aim in stewarding them is not to attain and preserve some ideal climactic state, but to understand and foster their continuing evolution in harmony with emerging demands, conditions, and perspectives. Time is crucial in understanding soil health, but adds bewildering complexity.

3 Finally, assessing soil health ultimately depends on value judgements (a little like human health, or the currently ubiquitous 'well-being'). Most ecosystems serve multiple functions; for example, a farm field may provide human food, mitigate climate, provide wildlife habit, filter water, preserve soil biodiversity, and offer aesthetic appeal. With so many expectations, trade-offs among functions are almost inevitable (Wiens, 2013; Poppy et al., 2014; Lehmann et al., 2020). Deciding which functions take precedence, therefore, involves value judgement (Ehrenfeld, 1992; Rapport, 1995; Lancaster, 2000; Rapport et al., 2000), extending health assessment beyond the laboratory into the social sphere (Nielsen, 1999). Is songbird habitat more important than maximizing yield? Is reducing nitrate leaching more important than suppressing N_2O emissions? Does the benefit of no-tillage for climate mitigation outweigh potential harm of herbicide residues to human health? Analysis of soils provides meaningful, relevant numerical data, but cannot assign a value to that information, especially in the face of trade-offs. What kind of soil is 'good', in a given place? In Lackey's (2007) words, *"The answer is a value judgment, …"*.

4. Some thoughts on the way forward

It is because metaphors are so crucial to the perception of an idea that scientists need to use them with such care. Pauwels (2013)

A sturdy scientific metaphor will likewise be extended, expanded, explored, and passed from hand to hand Haack (2003)*, p. 210*

There is a difference between using a metaphor and being used by it …. Turbayne (1970)*, p. 22*

The health metaphor has important strengths, but also some pitfalls, accounting for the enduring controversy in its use (Garcia-Álvarez et al., 2003; Mallee, 2017). This brings us back to our original question: Does the soil health metaphor advance our science and our underlying aim of conserving, renewing, and respecting soils?

Our answer, perhaps self-evident by now is: Yes, soil health provides useful imagery for promoting soil inquiry and conservation, but only if used prudently, respecting its limits, exploiting its potency, always aiming for fresh perspective. As seeds for further conversation, we propose the following guidelines:

1 **Remember that soil health is a metaphor.** Health is not an iron-clad, rigorously defined scientific concept, and is unlikely ever to be confined unambiguously in mathematical language. Far from diminishing the health concept, however, this metaphorical lineage amplifies its vigor in advancing soil conservation. The metaphor's shortfalls only arise when we are tempted to describe it as a verifiable, concrete entity, fully decipherable by quantitative analysis and scrutiny. Soil health offers potent, evocative meaning, we contend, but it cannot be squeezed into a single number without subjective, disputable value judgements. Thus, it is proper and helpful to say *"maintaining soil health is crucial for the continued productivity and integrity of agroecosystems"*. But asserting that *"soil health is better under this treatment than under that treatment,"* based on soil analysis alone, strains the limits of the metaphor, and may even be misleading. An ongoing risk, in soil health research, is reification: the fallacy of assuming an analogy is the real thing (Olson et al., 2019).

2 **Be specific about what is meant by soil health.** There is danger, with any compelling metaphor, to use it superficially, relying on its alluring aura without explicitly stating what *we* mean by the phrase. Authors may be tempted, as Ross et al. (1997) write, *"to hide behind the nonliteral language."* In some instances, where we are studying or describing detailed soil attributes or processes, it might be preferable to use terms more specific than soil health. For example, studies focusing solely on soil C fractions are not necessarily studies of soil health; and assessment of pathological microbes in a soil may not describe its health. Unexamined, imprecise, or overly-expansive use of a metaphor can quickly dilute its power.

3 **Relate analyses to land functions.** Soil health itself cannot be measured directly (Elliot, 1997; Garcia-Álvarez et al., 2003; Velmourougane and Blaise, 2017; Baveye, 2021), but this of course does not negate the crucial importance of making ever more meaningful, incisive measurements. Such analyses, in themselves, do not quantify health, but can be illuminating *indicators* (Arias et al., 2005; Congreves et al., 2015). The usefulness of a measure in serving as indicator, however, depends on establishing clearly how that attribute affects desired land functions (Roper et al., 2017; Rinot et al., 2019). For example, C or organic matter concentration is almost universally seen as a premiere indicator of soil health (Lal, 2015; Keesstra et al., 2016; Hatfield et al., 2017). We often tacitly assume that more soil C is better; but is that always true (Janzen et al., 1992; Oldfield et al. 2015, 2020)? And *when* is it true? Tying analyses to land functions may be especially urgent in soil biology (Lehmann et al., 2020); with myriad new techniques now available, we risk compiling a plethora of impressive data without having much to say about how these biotic communities affect functioning in given ecosystems. The critical question is not only: '*who is there?*', but: '*what do they do for the land, in this place, today and a half-century from now?*'.

4 **Enlist the social sciences and humanities in assessing soil health.** As argued earlier, soil health is, in the end, a value judgement. Thus if our analyses are to be useful in promoting health, they will need to be framed in a way that allows societal engagement in assessing values (Fig. 3). Our analytical results will then be projected not only through the lens of ecosystem functions (how do they contribute to expected functions in a specific place?), but also through a societal lens that encourages discussion of values amidst inevitable trade-offs. (For example: if increased organic matter content from applied manure enhances yield, but affects water quality via nitrate leaching, and requires more intensive animal agriculture, is that 'good' or 'bad'?) Soil health can never be established by instrumental analyses alone; it demands also the social wisdom of those outside our laboratories (Rapport, 1992; Bünemann et al., 2018; Sokolov et al., 2020), involving disciplines such as anthropology, philosophy, and human geography. Soil scientists are remarkably adept at measuring soil properties, but not always so clear in saying what they mean. Re-phrasing Clark (1989): *"What kind of [soil] we want is ultimately a question of values …. Science can illuminate these issues but cannot resolve them."* And incautious use of

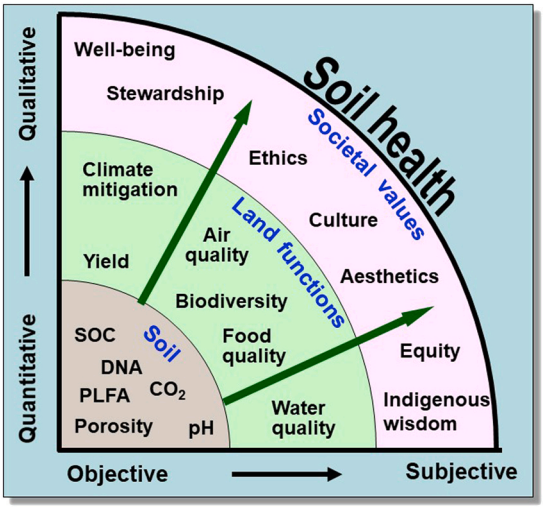


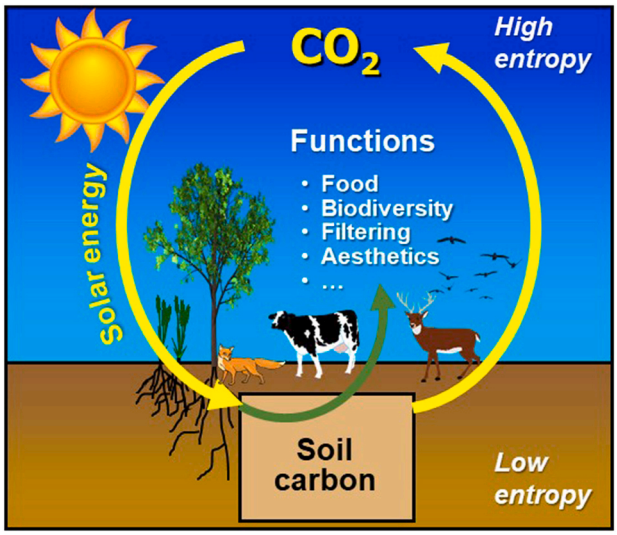
Fig. 3. A diagram illustrating how soil measurements (indicators) need to be projected through lenses of land functions and societal values before arriving at some meaningful perspective on soil health. The diagram is not intended to be comprehensive; functions and values listed are merely examples intended to show the diversity of factors to be considered.

the health metaphor poses a risk of inserting *"personal values under the guise of scientific impartiality"* (Lackey, 2001).

5 **Allow the health metaphor to motivate a transdisciplinary systems view.** Like other fields of inquiry, soil science is ever in danger of tunneling. As understanding grows, and complexity becomes more baffling, we self-congregate instinctively into ever more isolated enclaves, each huddled group burrowing deeper into its own riddles, oblivious of progress elsewhere. Each clan then develops its own distinct dialect, so a soil chemist, for example, may no longer be able to decipher a paper in soil biology. Emergent biology, we said earlier, is crucial in illuminating ecosystem functioning, but elaborate DNA profiles of microbial communities will not help us divine better management strategies without also understanding their habitat (Baveye and Wander, 2019). The health of a soil, like that of a person, reflects the overall functioning of a complex system, enfolding all constituents within their local environment. The metaphor of health, therefore, reminds us of the mutual interdependence of research disciplines, and may motivate us humbly to seek insights from other disciplines and thereby weave our growing understanding into a cohesive, evolving fabric (Costanza, 1992), perhaps seeking unifying threads, such as solar energy flows (Box 3). The challenge may be especially daunting (and compelling) for microbiologists: what do measurements at micrometer scales say about functioning of land, spanning scales of meters to kilometers?

6 **Exploit the imagery of health to reconnect urban audiences to the soils that sustain them, enlisting them in conserving soil.** A crucial aim in the Anthropocene, perhaps as critical as resolving research questions, is to remind people of their dependence on soil and the importance of preserving it (Brevik et al., 2019). In a quickly urbanizing world, we have been "*torn from the bonds to soil*" (Illich, 1990), "*divorced from the soil*" (Kirschenmann, 2010, p. 285). In Leopold's (1938) words, "*The problem, then, is how to bring about a striving for harmony with land among a people many of whom have forgotten there is any such thing as land ….* " In short, fact-making must be complemented by meaning-making. Advances in the latter may arise not from more data or better academic language, but from metaphor (Krulwich, 2008). "*[W]e require metaphors that connect people to both ecological systems and to other people. We cannot rely on stilted scientific language, but instead require resonant metaphors*" (Larson, 2011, p. 125). The imagery of health, so visceral, so evocative, may help us reconnect people to the soil in ways our arcane manuscripts never will. We may even want to enlist more poets and story-tellers in this effort, engaging them to enliven our manuscripts. "*For want of songs and stories,*" writes Berry (2012, p. 317), "*they have dug away the soil, paved over what is left*". If our aim is not just generating soil *data* but also promoting soil *care*, we need exploratory, experimental language to describe the endless human entanglements with soil.

Box 3
Solar energy flows as unifying driver of 'soil health'



Underlying the functions sustained by many terrestrial ecosystems is the capture of solar energy by photosynthesis and its efficient use to propel demands placed on the land. For example, producing human food, sustaining wildlife, enhancing soil biodiversity, furnishing feedstock for bioenergy, and sequestering soil C all depend on maintaining the continued investiture of the sun's energy into biomass, and the subsequent efficient use of that energy for the necessary functions. Soil carbon, in this view, serves as a reserve of stored solar energy, offering resilience to buffer future perturbations. A critical facet, and perhaps a unifying principle, of soil health then, is to progress toward soil properties, tuned to the conditions and expectations of its setting, that maximize this energy capture in a way that allows its sustainable storage and use.

7 **Deliberately invoke the perspective of time (Box 4), thereby forging meaningful narratives.** What molds and motivates human behavior, we are learning, is not information but story (Hendersson and Wamsler, 2020; van der Leeuw, 2020). If we are to preserve and nurture the ongoing 'goodness' of our soils, more data alone will not suffice – we need more compelling, more persuasive narratives that bind our findings into unfolding trajectories and offer us all, scientists and lay people, a way forward through the unfolding environmental upheavals. For example, soils of the Canadian prairies remember and can tell a multi-millennial narrative of organic matter accrual under grasslands grazed by bison, then abrupt depletion of those long-accumulated reserves under disruptive arable farming, and now prospects of slow re-accrual under wiser farming methods. In localized places, now, there are even tantalizing prospects of re-introducing bison on indigenous lands (Wood, 2020). In this long

Box 4
Soil health – historical perspectives

Photo credit: Agriculture and Agri-Food Canada, Lethbridge Research and Development Centre Photo Archives (file P1-69b), (1910)

Now give we place to the genius of soils, the strength of each,
its hue, its native power for bearing.
First then, churlish ground and unkindly hills,
where there is lean clay, and gravel in the thorny fields,
delight in Minerva's grove of the long-lived olive. …
But a rich soil, which rejoices in sweet moisture,
…this land will some day yield you the hardiest of vines, …;
this is fruitful in the grape, …
Land that is black, and rich beneath the share's pressure
and with a crumbly soil …
is, in the main, best for corn;
Vergil (70–19 BC) From Georgics, Book II, transl. by H. R. Fairclough http://pages.pomona.edu/~cmc24747/sources/vergil/georg_2.htm.

[T]he first principle of agriculture is to know good soil from that which is poor. Of the good the best is that which is like old manure, black and crumbling, not muddy, not hardening or cracking, nor given to drying out as sand does; it is a rare thing to find …
The ancients considered that land might be known by the condition of the wild plants which grew on it. Where these are vigorous and compact, closely entwined, it is of good quality. But your judgment should not be hasty – for a soil which cracks will be good for corn even though nothing else loves it, and the pine will flourish in sand when the apple, pear and plum will fail. A Moorish Calendar, The Book of Agriculture of Ibn al-'Awwām, 12th century (Transl. by Philip Lord, Edited by Peter Lord), p. 38.

Even the good soils are vastly different. A good soil for rubber trees is not the same as a good soil for wheat; and one good for clover is quite unlike one good for strawberries. Nature has had to make many right combinations to produce all the various kinds of good soil in the world. Kellogg (1941), p. vii - viii

Exploring and seeking to instill what makes a soil 'good' is as old as agriculture. From early on, students of soil have known that there is no single recipe for such 'goodness' of soil, no universal suite of traits. Each has its own peculiar "genius". 'Good' depends on functions assigned to a given unit of land or, more precisely, to functions it will support. And when we include in health functions beyond just agriculture, encompassing also those related to social and biospheric resilience, 'goodness' becomes even more complex, and the attributes conferring it even more diverse and variable. Thus, as Ibn al-'Awwām implores, our *"judgement should not be hasty"*; understanding health demands wisdom afforded only by patience and time. And, although our definition of health keeps evolving, we should not overlook the wisdom of those who pursued it, perhaps by another name, long ago.

and uncompleted narrative, clearly, any momentary snapshot of soil health may be distorted or even misleading. Our analyses need the context of time – they need to be placed into this narrative, to make them much more compelling, relevant, and scientifically stimulating.

8 **Engage the ambiguity of soil health to unearth new fundamental insights.** The vagueness of the health metaphor, while stymying numerical description, offers a fertile seedbed from which can sprout fresh thoughts from exploratory questions. For example: what exactly makes one soil better ('healthier') than another in a given place?; how do we know when (if) a soil has been improved?; can we ever quantify 'goodness' (and should we try?); over what time span does health apply – a growing season, a generation, a century?; what does soil health mean in a *landscape*, where soil is never the same from one spot to the next? The countless repetitive analyses we perform deliver many manuscripts, but may not always germinate new ways of looking at old questions. Maybe what is needed in our science is more thinking and less measuring; more rigorous debate and less rutted, discipline-based analyses; more provocative, stimulatory narrative, based on metaphor, and less obsession with merely securing statistically-significant differences to appease reviewers. The ambiguity of the soil health metaphor guides us to humility (Jasanoff, 2007), instigating perpetual learning cycles where our studies of soil variables and processes lead us to new and deeper questions, and where societal responses to what we find unearth intriguing mysteries unseen before (Fig. 4). As we learn, what soil health means to us may well evolve, gathering new insights, deeper and from farther afield, into its domain.

9 **Accept that metaphors have a limited lifespan – a best-before-date.** Eco-metaphors "rise and fall" over time (Kloor, 2011). After extended use (or over-use) a once-potent metaphor may gradually harden into stultified dogma. Or worse, it becomes a tedious cliché, so commonplace that we forget it is a metaphor and accept it unthinkingly as literal scientific concept. Soil fertility, for example, was once a potent image, implying fruitfulness and reproductive potential, specifically rooted in biological processes (Russell, 1911; Hall, 1912). But in time, its metaphorical overtones were lost, and today

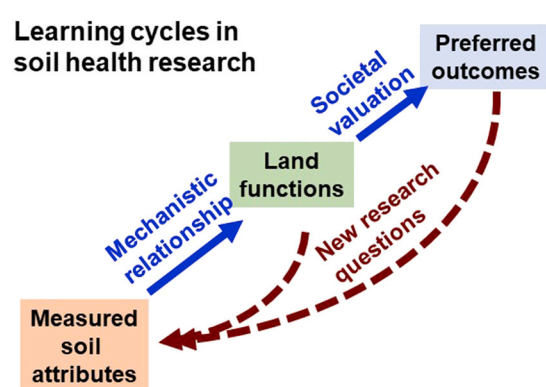


Fig. 4. A conceptual illustration showing how the soil health metaphor can stimulate learning cycles toward finding ways of managing soils that better sustain the manifold social and ecological functions of land. Researchers measure soil attributes ('soil health indicators') and try to establish mechanistic relationships to land functions. This research inevitably generates new questions, which prompt further research. At the same time, the various prospective land functions are continually evaluated by wider society, which, in turn, also feeds new more relevant and pressing questions to researchers, reflecting evolving societal demands and ethics. Consequently, soil health is never fully and finally articulated; the way we define it grows as our learning and societal engagement continues. The continued use of the metaphor depends on whether it still propels these cycles.

we think of fertility largely in terms of nutrient availability, often linked to fertilizers, measured by various 'soil testing' methods. Soil scientists, therefore, should be alert for new language that elevates the importance of soils to human and biospheric aspirations. Always the question to ask of such an emerging metaphor is: how effectively does it motivate better ways of fostering soils to sustain the functions of their lands?

The preceding are tentative directions, merely to elicit debate on an urgent question. The now-prominent metaphor of soil health, once evocative and fecund, is at risk of fading into a limp and lazy phrase, a hazy platitude applied with little thought. To re-amplify its potency, we invite spirited discourse about the meaning of soil health, not to nail down a final, ultimate definition, but to spur and explore new ways of studying and narrating the ways in which soils undergird life on this planet.

Soil biologists are perhaps best placed to lead this effort to resuscitate the metaphor. Health conjures imagery of an organism, and therefore falls directly in biology's domain. The processes that connect ecosystem elements into a cohesive, vibrant whole – the interwoven streams of energy and nutrients – are impelled largely by soil biota. And biologists may have the most to learn from the rehabilitation of the metaphor, because this iterative, ongoing process may force us to place our new findings more cohesively, seamlessly into the context of land, the timeless, evolving ecosystems that enfold our soils. The debate, of course, should engage many disciplines, including also social sciences. Soil biology can perhaps elucidate connective arteries, but not land's entire elaborate, evolving anatomy.

5. Conclusion

Can the soil health metaphor further advance the underlying aim, now so crucial, of restoring, sustaining, and revering soils? Our answer to the question, for now at least, is yes!, soil health does promote soil stewardship, as long as we do not use it too rigidly. And yes!, measuring relevant soil attributes is intensely useful, as long as we recognize that such numerical analyses alone have not yet captured health. To fully ascertain a soil's health, we need also to establish what is 'good' in a given ecosystem, encompassing the unique blend of productive, social, and ecological functions valued in that place.

The point of pursuing the soil health metaphor, then, is not merely to assign a number to the 'goodness' or 'fitness' of soil for given functions, but to illuminate relational mechanisms – What makes a soil 'good' in a given place, and why? – and thereby lead us to nurture more wisely those attributes that sustain the land's pertinent functions. The usefulness of the soil health metaphor rests on how well it promotes respect for soil, insight into its vitality, and wiser ways of managing land to sustain its manifold functions.

We may never finally define soil health, nor need we. The power of the metaphor, after all, is to invite deeper, wider inquiry, scientific as well as social and philosophical. As long as soil health helps unearth better ways of knowing and sustaining land, let us use it, honing and redefining it as we learn. In time, when the metaphor grows stale, when we use it unthinkingly as tired cliché, it will need to be supplanted, like others before it. A good metaphor produces good science, and good science produces ever better metaphors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank countless colleagues whose insights, from interactions over many years, lie embedded in this manuscript. Among these colleagues were three anonymous reviewers whose thoughtful comments already engaged the explorations we proposed. Their discerning, innovative suggestions substantively strengthened this manuscript. Funding for this work was provided by Science & Technology Branch, Agriculture & Agri-Food Canada and by New Frontiers in Research Fund – Exploration (NFRFE-2018-02138: 'Soil as a relational medium').

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