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REVIEW

Concepts of plant health – reviewing and challenging the foundations of plant protection

T. F. Döring[a]*, M. Pautasso[b], M. R. Finckh[c] and M. S. Wolfe[a]

[a]*The Organic Research Centre, Hamstead Marshall, RG20 0HR;* [b]*Department of Life Sciences, Imperial College London, Silwood Park Campus, Ascot, SL5 7PY, UK; and* [c]*Ecological Plant Protection Group, Faculty of Organic Agricultural Sciences, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany*

Plant health is a frequently used but ill-defined term. However, there is an extensive literature on general health definitions and health criteria in human medicine. Taking up ideas from these philosophical debates, concepts of plant health are reviewed and a framework developed to locate these concepts according to their position in several philosophical controversies. In particular, (i) the role of values in defining plant health in a naturalist versus a normativist approach; (ii) negative and positive definitions of plant health; (iii) reductionist versus holistic perspectives; (iv) the focus on functionality versus resilience, i.e. the ability of the plant to perform under stress with or without human interference; (v) materialist versus vitalist approaches; and (vi) biocentric versus anthropocentric views, are surveyed. The ways in which these perspectives relate to mainstream and alternative approaches to plant protection are explored and we suggest how the contradicting views might be reconciled. It is argued that none of these perspectives is without inherent contradictions, but that by combining contrasting approaches it is possible to provide a comprehensive though fuzzy concept. Rather than giving a new definition of plant health, a conceptual framework is developed that suggests what questions may be answered in debates on plant health issues and how such debates could be organized.

Keywords: disease, pathogen, pest, resilience, salutogenesis, symptom

Introduction

'The health of green plants is of vital importance to everyone' (Lucas, 1998). Indeed, numerous examples point to the high profile of 'plant health'. It is a term frequently used in scientific papers; it crops up in a motto of organic farming (Balfour, 1943); divisions of agricultural ministries are called 'Plant Health'; a German plant protection journal is named *Healthy Plants*; and claims appear copiously in pesticide adverts that the product promotes the health of the targeted crop (Döring & Finckh, 2006).

So, what is 'plant health'? How can we know when a plant is healthy? What are the criteria to assess health in plants? Surprisingly, despite its frequent use, the term 'plant health', unlike 'human health', has not been subject to a critical scientific discussion. The conceptual development of plant health has largely remained *terra incognita*. This paper ventures to change this, by mapping out conceptual fault lines, ambiguities and contradictions, and by discussing consequences for plant production practices.

The term 'plant health' has two overlapping uses. In one sense it refers to the scientific and regulatory framework of checking plant imports for the presence of potentially invasive pests and pathogens (Ebbels, 2003; MacLeod *et al.*, 2010). The second use of the term is less specific and touches on all areas of plant protection. This second meaning is explored and discussed here.

The term 'concept' is used to denote a broad set of rules, ideas, attitudes, paradigms or viewpoints (Margolis & Laurence, 2008); these may not necessarily be explicit or conscious, but they show manifestations in actions or texts. One manifestation of a plant health concept is a 'definition', i.e. a short and explicit concept summary. As plant health concepts have not been discussed in a systematic way, but short working definitions have been given, analysing these definitions provides a useful tool to investigate conceptual problems.

This review takes inspiration from other disciplines, especially human medicine, by summarizing ideas of opposing schools in the conceptualization of human

*E-mail: thomas.d@organicresearchcentre.com

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health and transferring these to plant health. Ways to reconcile contradicting views and how the term 'plant health' may be used in the future are proposed.

Human health concepts as a starting point

In the last few decades, advances in medical diagnostics and treatments for human illnesses have literally pushed the boundaries of life (Porter, 2000; but see Exner *et al.*, 2001). However, these developments have come at a cost; areas of concern are, for instance, the effect of life-prolonging measures on quality of life (Coates *et al.*, 1983), or the potential ethical conflicts of gene therapy (Kimmelman, 2008). These dilemmas have started ethical debates about how – and by whom – health and quality of life can and should be defined (Slevin *et al.*, 1988; Gimmler, 2002; Richman, 2004). This paper investigates the ideas put forward in these debates for the exploration of plant health concepts. However, it is clear that human and plant health are in some respects fundamentally different:

1 Although humans can also feel compassion for plants (Wilson, 1986), there is no ethical problem if some plant individuals are unhealthy, as long as the average health level of the *plant population* remains acceptable. Because we tend to attribute a lower value to the individual being of a plant relative to an animal or to a human individual (Gäumann, 1951; Ingensiep, 2001), we can tolerate the ill-health of plant individuals if this is *compensated* by other, more healthy individuals (Spieß *et al.*, 2010). Such compensation is not a current ethical option for human health.

2 While human beings are one species only, plants are many and this diversity influences health concepts. For example, health in one species can be off-set for health in another (Geils *et al.*, 2010).

3 In many cases, humans and animals can be cured by treatment, while plants are rarely cured; instead they are mostly prevented from becoming (more) diseased.

4 When asked if they feel healthy, many humans will respond and produce an intelligible answer. Plants, however, won't. As Agrios (2005) puts it: 'It is not known whether diseased plants feel pain or discomfort'.

Despite these fundamental differences between humans and plants, the extensive literature on the philosophy of human health is still relevant for plant health questions, since there are also some health-related similarities: for example, for both humans and plants, (i) health varies between individuals (e.g. as a result of age differences); (ii) health and disease are dynamic: within individuals, they change over time; (iii) health is subject to geographical patterns in pathogen occurrence; and (iv) pathogens can develop resistance to treatment.

The role of values in defining health: naturalism versus normativism

The debate on human health concepts has been dominated by two opposing views which have been tagged naturalism and normativism (e.g. Gimmler, 2002; Nordenfelt, 2002; Schramme, 2007; Hamilton, 2010). Central to the controversy is the question whether values influence our notion of health.

Naturalists think that health is rooted in nature, independent of human values, and can be determined objectively. They claim that natural sciences are sufficient to analyse health in its entirety. Their approach is a descriptive one: health is viewed as an objective category 'out there' that can be described via various measurements. Health is typically determined by an expert (e.g. a physician or, in the case of plants, a plant pathologist), who makes use of knowledge gathered with tools of the natural sciences. Health is seen as an abstract entity that can be determined in all individuals using in principle the same methods. The most influential naturalist concept of health was proposed by Boorse (1977), who developed a definition of health explicitly as a 'value-free theoretical notion' (see below).

Normativists believe instead that the meaning of health depends on the values held by the human beings who define it. Their approach is a prescriptive one, since at some point in defining and assessing health, human values are used to prescribe what is good or bad. Normativists tend to tolerate a diversity of health concepts, acknowledging that values vary between individuals. In particular, they leave more freedom to the (human) patients to identify what health is for them.

A naturalist approach to defining plant health

Boorse's health concept has had a great impact on the health concepts debate, because of its clarity and operability. He summarizes his concept in four steps:

1 The reference class is a natural class of organisms of uniform functional design; specifically, an age group or a sex of a species.

2 A normal function of a part or process within members of the reference class is a statistically typical contribution by it to their individual survival and reproduction.

3 A disease is a type of internal state which is either an impairment of normal functional ability, i.e. a reduction of one or more functional abilities below typical efficiency or a limitation on functional ability caused by environmental agents.

4 Health is the absence of disease (Boorse, 1977).

There is a problem of reference: with what object is a plant compared in order to assess its health? Here, the first point is to avoid circular referencing. We fall into circularity if we define health by the absence of disease but, when urged to define disease, have nothing to offer but 'inconsistent with health' (Boorse, 1977). Although this circular argumentation would accumulate synonyms that may be useful in a casual conversation about health, it leaves the health definition with a major weakness.

Commenting on plant disease definitions, Lucas (1998) writes that usually reference is made to *normal* plants, but that there is 'no consensus about the exact extent of deviations from this norm'. Boorse solves this problem statistically, by defining the reference group in terms of statistical deviation (but see Ereshefsky, 2009).

Boorse's approach only works if the majority of individuals are not diseased – but there are cases when pathogens spread through an entire plant population. Also, statistical deviations are only meaningful if certain factors, such as age and sex, are accounted for. For example, it should be possible to call a function normal in old plant individuals, even if it makes a poor contribution to reproduction and survival compared to the same function in a middle-aged individual. A fair comparison can only be made within a group of individuals of the same age.

However, there is no reason to stop there. Varietal differences in reproductive potential of plants could be considered as well. For example, the comparison of a high-quality milling wheat variety with low yield potential, versus a high-yielding feed variety would show a reduction of one or more functional abilities in the milling variety that affects its reproductive success. However, it would be unfair to call the milling variety unhealthy just because of that (cf. Lucas, 1998). Other authors have tried to solve this problem by referring to the genetic potential of a plant: 'A plant is healthy, or normal, when it can carry out its physiological functions to the best of its genetic potential' (Agrios, 2005). However, it is unclear how this potential may be determined. The issue of choosing the reference group for defining plant health becomes even more contentious when environmental variation and management are considered:

> Therefore a plant can be regarded as healthy as long as its physiological performance, determined by its genetic potential and *environmental conditions*, is maintained. (Schlösser, 1997; translation from German, as in cases below, by TFD).

Similarly, Nordenfelt (2006) writes:

> a plant P is healthy if, and only if, [...] P has the ability to realize all its vital goals given standard (or reasonable) circumstances.

At first, it seems useful to make environmental conditions a reference criterion. Plants that receive different amounts of fertilizer frequently show different reproductive success, and that should not result in describing the less fertilized plants as unhealthy. However, this criterion entails several ambiguities. How should nutrient deficiencies, frequently considered as signs of ill-health in plants, be dealt with (Barker & Pilbeam, 2006)? How can it be decided when pests or plant pathogens benefit from higher fertilization (van Bruggen, 1995)? And where should the reference criteria stop? The myriad of ecological interactions makes it difficult to draw a line. These questions illustrate that Boorse's naturalist concept, although appearing clear at first, leaves several points undecided that force potentially arbitrary choices to be made.

A second point in Boorse's considerations is the choice of 'survival and reproduction' as the central criteria to determine functional ability. Their status as ultimate aims makes it difficult to see how any other criterion could compete in justifying and defining (plant) health. Because survival and reproduction are such strong criteria, any condition that promotes plant survival or reproduction would not be classified as hampering health.

However, the incidence of plant pathogens is often positively correlated with the host's reproduction. For example, in an organic field experiment leaf lesions caused by *Septoria* spp. were positively correlated with grain yield in wheat (Döring *et al.*, 2010a). Although *Septoria* can in principle decrease yield, in this case the fungus presumably benefited from the same environmental conditions as the plant. However, many would intuitively classify plants with small lesions as healthier than those with large lesions. If reproduction and survival are central criteria to define and measure health, counter-intuitive cases are inevitably created where the incidence of organisms that are in principle pathogenic is linked to better health.

Thus, inspecting the naturalist approach to plant health reveals several dilemmas, showing that it cannot hold its claim to be clear-cut and objective.

Exploring the normativist position

Normativists raise some general arguments against the naturalist health concept. A purely descriptive science cannot generate aims. For the naturalist it is difficult to argue why health should be striven for in the first place. Normativists get around this problem by following an evaluative approach, i.e. placing values on health and disease from the beginning (Schramme, 2007). Also, strong normativists (Khushf, 2007) insist that all measurements of health or disease, including those gained with the methods of natural science, have a cultural dimension, and can therefore never be completely objective; pathology always has a socioeconomic element. So, what is classified as deviation from health is dependent on the cultural background. The classical example in the context of human health is homosexuality, which was judged as a disease in the past but is now seen as a normal phenomenon (Gimmler, 2002).

Cultural values also play a key role in plant protection (Jansen, 2003; Kroma & Flora, 2003; Abrams *et al.*, 2005). Adopting a normativist position, the term 'plant health' appears to be both evolving and strongly influenced by cultural factors outside the remit of natural sciences (McRoberts *et al.*, 2011). In particular, it can be hypothesized that its uses and meanings are affected by concepts of human health.

A strong point of normativism is its ability to reveal the social context of health concepts, thereby enabling us to question the interests that underlie a definition. However, there are also conceptual problems in normativism. At its extreme, normativism results in complete arbitrariness. At this end of the spectrum (held by radical constructivism), health is entirely rooted in cultural values. Measurements provided and treatments suggested by the natural sciences could not be justified to be truer or more valid than the judgement of any lay person. The risk of such relativism is that health ceases to be a concept, but becomes a collection of subjective and potentially contradicting opinions, making it difficult to guide decisions on health issues. It is not necessary to go to this extreme to see that plant health is not entirely determined culturally: plants were challenged by pests and pathogens long before human beings started pondering the values of plants.

Regarding plant health, however, normativists face another difficulty. Whenever they place emphasis on individual patients' views in assessing their own health, they introduce a subjective perspective into health that cannot be transferred to plants. The reason is that plants cannot communicate their individually perceived health status to us – if they perceive it at all. Although plant diseases are often highly visible to humans, humans always have to rely on their interpretation of a plant's health status without the possibility of the plant correcting the human view. This contrasts with the relationship between physician and human patient who, in a dialogue, can (but do not need to) come to a common view of the patient's condition. Plants share this inability to directly communicate their state of health to humans with animals, neonates, or patients in coma. These are precisely the groups for which ethical debates about health and quality of life are most difficult and controversial. The impossibility of gathering direct information on how a plant individual would assess its own health is probably a reason why the predominating view of plant health tends towards naturalism (thereby, however, ignoring other benefits of a normativist position).

Naturalism and normativism in current plant protection debates

Whether a more naturalist or more normativist position is taken is linked to practical and political decisions on plant protection, in particular how these views relate to conventional and alternative approaches to plant protection.

Conventional plant protection relies primarily on chemical control, using synthetic pesticides that aim to kill pathogens and pests. Alternative (or ecological) plant protection relies on interactions in the ecosystem to provide regulation of pathogens and pests, such as predation of pests by natural enemies, as well as a multitude of non-chemical management practices, including resistant varieties, appropriate planting time, intercropping, variety mixtures, and many others (e.g. Zehnder *et al.*, 2006). Proponents of an ecological approach oppose chemical control on the grounds of concerns over the development of resistance to pesticides, environmental pollution and detrimental effects on human and animal health.

Where do normativists and naturalists stand in this debate? While normativists acknowledge a diversity of approaches to plant health, naturalists claim that in a given situation one approach is valid for everyone, determined by experts with the methods of natural sciences. It is therefore easier for normativists to incorporate farmers' views in defining and assessing plant health, thus tending towards a more participatory relationship between scientists and farmers (Watkins, 1990). Conversely, it is easier for naturalists to promote a plant protection product (such as a pesticide) for a large market as a one-fits-all solution. The normativist acknowledges that interests (such as economic or cultural ones) may underlie plant health definitions – a notion that is alien to naturalist reasoning.

These (possibly extreme) examples reveal an affinity between chemical plant protection and a naturalist view of plant health on the one hand, and between ecological plant protection and normativism on the other hand (Table 1). However, this affinity is likely to be imperfect. Also, rather than being ideal dichotomies, naturalism versus normativism, as well as ecological versus chemical control, are better represented as ends of a spectrum.

Pure naturalist or normativist views are rare, both in general health debates and with respect to plant health. This discussion, however, has shown that both schools of thought show inherent inconsistencies.

Negative and positive health concepts

Health can be defined in a positive or negative way. For instance, the World Health Organization (WHO) defines human health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (WHO, 1946). Here, a negative aspect (non-presence of disease) is a necessary but subordinated criterion to define health, while the positive criterion of complete and comprehensive well-being dominates the definition.

Perhaps the most decisive difference between positive and negative health concepts in plants is their focus of attention: while negative concepts focus on the pathogen (and how to get rid of it), positive concepts focus on the plant.

The pathogenic position

Negative health concepts define health as the absence of disease (or of the pathogen causing the disease). Interestingly, when defining disease, Boorse (see above) uses the negation of positive criteria such as survival and reproduction (impairment of normal functional ability), thus defining health through a double negative.

Explicit examples of pathocentric plant health definitions from textbooks are rare. However, in many other contexts plant health is indirectly conceptualized as the absence of disease. Pesticide adverts frequently describe a plant treated with the promoted product as healthy (Döring & Finckh, 2006). As the pesticide targets a specific pathogen, this use of the term healthy implies that the plant is healthy if it is free from the particular pathogen against which it is treated.

Table 1 Opposing views on plant health

Criterion	Thesis	Antithesis
Values	Naturalist: be objective	Normativist: apply values
Discipline	Chemical: use molecules	Ecological: employ ecological interactions
Focus	Negative: kill the pathogen	Positive: strengthen the plant
Method	Reductionist: find rules	Holist: integrate
Interference	Functional: deliver	Resilient: be self-sufficient
Nature	Materialist: find the mechanism	Vitalist: feel the force
Ethics	Anthropocentric: fill the basket	Biocentric: support the plant
Definition	Definitive: be concise	Fuzzy: embrace complexity
Change	Conventional: maintain the status quo	Alternative: promote change
Mindset	Industrial: maximize production	Traditional: maintain multiple benefits

Each row can be viewed as an axis or dimension on which the thesis and antithesis positions correspond to the plus and minus side, respectively. Any use or definition of plant health can then be mapped in the resulting multidimensional space. Note that although within each column positions may have mutual affinity, there is no strict correlation between them (see text).

Many scientific papers apply the term 'health' in a similar way, often using 'healthy' for non-inoculated plant individuals in laboratory experiments. For example, Tang *et al.* (2005) write 'To inoculate plants, diseased plants were used to brush healthy 4- to 6-week-old plants to pass asexual spores (conidia) onto the new plants'. Here, 'healthy' is just used as a short form for 'not infected with the particular plant pathogen in question'. Whether any other plant pathogens or abiotic disorders were present and caused disease is not reported, but most readers would presumably expect the plants to be free from other pathogens or disorders. More importantly, however, the short-cut use of 'healthy' as 'disease-free' reiterates a negative perspective on health, thereby obliterating any alternative views *en passant*.

In the context of human health, negative concepts have been repeatedly criticized. First, negative health definitions force the definition of disease – and this has often resulted in circular reasoning. Also, it may appear too restrictive to define health only by the absence of disease, i.e. negative health definitions do not capture the complexity that many people feel is ingrained in the term 'health'. Furthermore, although the absence of disease is a necessary criterion for health, it is not sufficient, i.e. 'health' and 'disease' are not symmetrical terms (Wulff, 2002). By concentrating on disease, negative health definitions do not include absence of injury or damage caused by pests or abiotic causes, although plants attacked by pests or otherwise damaged would also not be called healthy. Finally, using a pathocentric concept leads us away from something negative, but does not give us a clear sense of where to move to. So what does the alternative view offer?

Positive health: potential, harmony and balance

Agrios' definition of plant health – the ability of a plant to 'carry out its physiological functions to the best of its genetic potential' – is an example of a positive plant health definition. It does not refer to disease or injury and does not carry any elements of negation. By offering something to strive for, it provides a more constructive aim than do negative definitions. However, it also has some shortcomings – it is unclear how and under what conditions (e.g. regarding environment or agricultural management) it could be determined whether the plant's potential has been achieved.

Agrios' attempt to define plant health is firmly rooted in physiology. Broader positive concepts include terms such as vitality, well-being, balance and harmony. For example Schimitschek (1952) proposes that

> the health of the individual is characterised by all its organs being active without disturbance, co-acting in harmony for the sustenance of the whole individual as well as for ensuring its reproduction.

However, Schimitschek does not provide a definition of harmony. This exemplifies a common problem of many positive plant health definitions: they often lack clarity and do not lead to an unambiguous protocol for assessing health. Bos & Parlevliet (1995) propose 'reduced vitality' as a criterion for disease, but leave vitality undefined. Nordenfelt (2006) employs 'vitality' as an undefined criterion of plant health. Comparable gaps appear in other concepts in which balance, potential, vigour or harmony are used.

How to fill the gap that Schimitschek left? An explanatory definition of harmony could easily be devised (e.g. as a state of a whole in which the parts fit well together). Yet an operational definition detailing how to assess harmony is more difficult. Indeed, many authors have tried to introduce positive elements such as harmony into plant health definitions, but have ultimately failed to translate them into instructions for their assessment.

Positive health: Antonovsky's salutogenic concept

An influential positive health concept revolves around the term 'salutogenesis', introduced by Antonovsky (1996). This approach can be summarized as follows:

1 It rejects the idea that people are either healthy or sick, suggesting instead a continuum between these two poles.
2 Rather than considering specific diseases in isolation, it is interested in the 'overall spectrum of well-being'.
3 It focuses on movement toward health on this continuum.
4 Instead of concentrating on risk factors of diseases, it asks what factors are responsible for moving toward health (salutary factors).
5 It challenges the self image of the 'sick role' and the identification of the person with the disease; instead it searches for new social roles and looks at the person's compensatory abilities.

Although it has been suggested to transfer salutogenetic thinking to plants (H. Spie*ß*, Dottenfelderhof, 61118 Bad Vilbel, Germany, personal communication; Döring & Finckh, 2006; Spieß *et al.*, 2010), it has not yet been specified how to do so. Critically, health needs to be defined before one can see how plants or humans move towards it, and what makes them move in that direction. The hurdle of first defining health is easier to overcome with humans if a patient-centred approach to health is adopted, but this is impossible with plants. However, salutogenesis still offers some inspiration for plant health concepts. Three aspects of how plants can move towards health will now be discussed.

First, while genetically fixed resistance to pathogenic organisms conveys a way for the plant to stay healthy, induced resistance is closer to Antonovsky's idea of moving towards health, because following attack by a specific pathogen strain, the plant's level of resistance increases, including resistance to other strains and even other pathogen and pest species. Induced resistance is currently gaining momentum as a potential plant protection strategy (Walters *et al.*, 2007; Sharma *et al.*, 2010), and it may become an important part of a salutogenic approach to plant protection.

Secondly, a fresh outlook on plant health is also expected from studying compensatory effects of plants' responses to pathogens. For example, wheat responds to adverse growing conditions in one period by compensatory growth in subsequent periods. In many cases, there will also be dilution effects of pests or pathogen – i.e. when the pest or pathogen cannot destroy plant tissue as fast as the plant tissue grows.

Thirdly, the perspective of movement towards health can be extended beyond a single plant generation. An example is the use of composite cross populations. Saving seed of such populations and re-sowing it after harvest, year after year, opens the door for the evolution of the populations (Suneson, 1956). Since populations are genetically more diverse than pure line varieties, they provide the necessary variability upon which natural selection can act (Wolfe *et al.*, 2008). As plants favoured under the specific growing conditions will contribute more seed to the following generation, natural selection will favour plants with higher fitness. This might include a better ability to cope with stress conditions (Döring *et al.*, 2010b). Similarly, increased mortality of individual trees provides a way of promoting the adaptability of a forest community to stress conditions (Kuparinen *et al.*, 2010). Therefore, observing plant populations and their disease and health levels over several generations offers the opportunity to study movement towards health in an extended salutogenic sense.

Positive and negative health concepts in the plant protection controversy

What are the positions of the pathogenic and salutogenic mindsets in the debate between chemical and ecological plant protection? It is not necessarily accurate to suggest that the pathogenic position is married to chemical plant protection, and salutogenesis to the ecological approach. Nonetheless, it is easier from a negative view on plant health to argue for conventional plant protection; getting rid of the disease would deliver health. Similarly, the salutogenic position, focusing on more complex interactions between plants and pathogens, as in induced resistance phenomena and in evolving plant populations, is easier to embrace in ecological plant protection.

Reductionism versus holism

Controversies between reductionists and holists have been fought in two areas with plant health relevance, namely ecology (Wiegert, 1988) and human medicine (Janich, 2002). Central in both debates is the question of how entities made of several parts (systems) should be investigated (Nagel, 1961).

Reductionists consider systems to be made up of components that can be analysed in isolation and that systems can be explained by a relatively limited number of factors. At its best, the reductionist approach is able to predict future behaviour of the investigated systems without the need to study every system individually. Reductionists transfer conclusions from one system to another, similar one. Holists wary of such transfer across systems believe that different systems need to be considered individually, and that 'bodies or things are not entirely resolvable into parts' (Smuts, 1929). Holists look at each system as a whole, not focusing on the analysis of selected components, but trying to understand it at a high level of integration. Emphasis is placed by holists on interactions within and between systems.

Reductionism and plant health

For reductionists, a health definition valid for one individual could be transferred to another individual – thus, reductionism is close to naturalism as described earlier. [Note that the reductionist view is not necessarily negativist (Rudnick, 2002)]. Reductionists consider factors affecting health in isolation. Criteria of health would be relatively few and would be rooted in single, specialist disciplines. Reductionists typically place the natural sciences in a clear ascending order, with physics as the most basic science, moving up to chemistry and biology (Janich, 2002); they propose that all phenomena are ultimately explicable by and reducible to physical laws. This view links reductionism to a materialist (or more generally, physicalist) position.

Most importantly, the reductionist is content to investigate a small part of the pathosystem, for example just one species of pathogen. Once the particular plant organ or tissue is free from the particular pathogen, the reductionist considers the job completed. However, even early pathologists observed that plants resistant to certain pathogens will often be taken over by others. For instance, when resistance to the obligate rust pathogens was increasingly successful in wheat, weaker pathogens such as *Septoria* and other agents of leaf spots moved in (Stakman, 1947; but see Makepeace *et al.*, 2007).

The reductionist approach is rooted in the increasing specialization of different branches of biology during the last two centuries, particularly in botanical and zoological classification. This tradition led to the creation of subdisciplines within plant protection science, such as plant virology, mycology or entomology. Subdisciplines often focus on just one pathogenic or pest organism, which fits nicely into a taxonomic system, while interactions with other organisms or insights from other branches of biology are at risk of being neglected.

Holistic view of plant health

In relation to plant health, holistic ideas appear on three levels (e.g. Ferretti, 1997). The first level is the consideration of the plant as a whole, as opposed to the separation and isolation of parts of the plant, the second refers to the plant in its (natural) environment, and the third includes the integration of socioeconomic perspectives.

On the first level, some authors refer to the wholeness of the plant as its integrity (Lammerts van Bueren *et al.*, 2003). Here, the plant can only be healthy if it is whole, i.e. if its integrity is not violated; [on a physical level, there is an important caveat regarding the use of integrity as an indicator of health: in contrast to many animals, plants can often compensate for loss of organs; this is critical for many diseases where the loss of an organ (a seedling leaf for instance) may have little or no impact on eventual plant performance].

Also, integrity is not easily defined, and some authors such as Agrios (2005), although using it, prefer not to define it at all:

> Disease in plants, then, can be defined as the series of invisible and visible responses of plant cells and tissues to a pathogenic organism or environmental factor that result in adverse changes in the form, function, or *integrity* of the plant and may lead to partial impairment or death of plant parts or the entire plant.

Lammerts van Bueren *et al.* (2003) give several definitions of integrity:

> Plant-specific integrity is the state of wholeness or completeness of a plant, allowing it to perform all its plant-specific functions. […] Genetic integrity can be defined as the state of wholeness or completeness of the species-specific genome. […] Phenotypic integrity is the state of wholeness or completeness of an individual plant or crop, including its health.

This brings us back to the term ‘wholeness’. Unfortunately, Lammerts van Bueren *et al.* (2003) do not explain how wholeness should be assessed, but only state what wholeness is not:

> Perceiving a specific kind of wholeness indicates that plants are more than the sum of isolated characteristics that can be registered by computers.

The second level is the consideration of the plant in and with its natural environment, taking into account the complex web of ecological interactions and feedback loops among the various elements of a pathosystem (e.g. Cook, 1988). Pautasso *et al.* (2010) write:

> There is thus a need to broaden the traditional definition of plant health, from the study of specific pathosystems in controlled conditions to broad and interconnected issues at the landscape and species distributional range level.

This approach can take us to a position where the presence of pathogens is regarded as part of a healthy plant community (Ostry & Laflamme, 2009). At this level, holists would consider health to be a complex property of plants and plant communities, the study of which would require interdisciplinary approaches (Comeau *et al.*, 2005).

The final level of the holistic perspective relates to the human factors in assessing plant health, including social, economic, cultural and spiritual aspects of human life, thus taking the interdisciplinary approach a step further (Rapport *et al.*, 1998). The holist acknowledges that the observer of the plant is part of a larger system, i.e. that there can be no true separation between the observer-subject and the observed object (the health of the plant, or in fact, the plant itself). For example, Lammerts van Bueren *et al.* (2003) stress that the perception of wholeness is based on an individual viewpoint and explicitly refer to the relationship between human and plant:

> The appreciation of the perception of wholeness of a plant depends on the breeder’s individualized inner view of plants and on his personal, basic attitude toward nature. [...] It has to do with what breeders call the *breeder’s eye* after years of personal dedication to and relationship with their crop, constantly comparing populations and *knowing* whether a plant deviates from or is in

harmony with a certain dynamic, inner reference of a plant ideotype.

However, even if many people do agree on the wholeness or integrity of a particular plant, it is difficult to imagine how building individuality of opinions, and therefore potential disagreement, into the very definition of wholeness could be convincing as the basis of potentially controversial decisions in plant protection issues, such as the application of genetic engineering.

Holism, although intellectually stimulating, therefore appears to be potentially messy. As Janich (2002) pointed out, holistic approaches often show a lack of clarity. There is the risk that with holistic approaches there is no gain of knowledge, because each case must be taken as an individual whole, so there would be the need to start from scratch each time a new case is considered. Furthermore, it is not always clear where the system actually ends, making it potentially necessary to study 'everything'.

Convergence of holism and reductionism

A criterion of health on the second level of holism is the connectedness of a plant with the ecosystem of which it is part. The holist would see this connectedness as a potential criterion of health. The plant is only considered as healthy if it is connected with the rest of the ecosystem. This connectedness could even be measured by the extent of nutrient cycling in the ecosystem.

Reductionists would object that holists have moved themselves into a corner by making connectedness an *a-priori* criterion of plant health. Before actually testing whether connectedness is of any importance to plant health, it is decided by definition that connectedness should be part of plant health. Therefore, for the holists it is impossible to test whether there is a relation between plant health and plant connectedness. In response, the holist may reply that the mistake the reductionist has made is not to consider connectedness at all.

This hypothetical argument shows that there is an important distinction to be made which can bridge the gulf between reductionism and holism: an unaware (or dismissive) reductionism discards criteria (of health) without consideration. A naïve holism makes the opposite mistake of incorporating criteria of health without examining them. An informed reductionism, however, discards criteria only after testing them and finding that they are not significant. What could be called 'critical holism' would consider as many criteria as feasible in studying plant health and would subject these to appropriate tests.

Eve Balfour: holism, reductionism and the transmission of health

An important point of reference regarding holistic health concepts in agricultural contexts is an idea suggested by the English farmer and author Lady Eve Balfour:

> The health of soil, plant, animal and man is one and indivisible (Balfour, 1943).

Balfour hypothesized that health is transferable from soil to plant and from plant to livestock and humans [see also Kelly & Bliss (2009)]. Before discussing this hypothesis, there is an even more radical interpretation of Balfour's statement to consider. In this view, health of soil, plant, animal and humans are not merely interdependent phenomena, but any violation of health in any one group must always be regarded as affecting health in all other groups. There would be no plant health, because it would be conceptually wrong to separate it from health of soil, animal and man.

However, this (naïve-holistic) interpretation is not what Balfour meant. Balfour strove to test her hypothesis with a long-term field experiment. Her approach is therefore an example of the critical holism outlined above. Plant health is considered in the context of the entire agricultural system, with health of soil and livestock as conceptually separate from plant health but potentially intimately connected to it. While it is self-evident that many animal diseases are not directly linked to plants, Balfour's focus on health was more of a nutritional nature. Surprisingly, despite her broader perspective on the issue, Balfour's criteria of plant health remain relatively restrictive, focusing merely on freedom from disease. While Balfour recognized the difficulty of defining health at all, she shied away from discussing the deeper meaning of health.

Reductionism and holism in the plant protection controversy

Proponents of chemical plant protection might consider a whole range of complex factors when designing spraying programmes (Wilcox & Seem, 1994). Conversely, ecological plant protection strategies might also neglect important parts of the agricultural system. However, in general, a reductionist view may be seen to be linked mainly to chemical plant protection and the holist perspective to an ecological approach (Østergård *et al.*, 2009).

The question of interference: functionality versus resilience

A further question is whether or not a plant can be considered as healthy when there is human interference with the plant, the pest or the pathogen. For example, should plants be regarded as healthy when they have been sprayed with fungicides that kill the pathogens? Although the spraying would result in freedom from fungal infections and the sprayed plants would then be fully functional (e.g. in terms of photosynthesis, growth or reproduction), they would otherwise easily be infected by fungal pathogens and would fail in their functionality. A functionalist view would regard the sprayed plants as healthy. On the other hand, it could be argued that the plants are only healthy ephemerally, and that true health must be longer lasting, independent from the application of fungicides. The alternative view therefore demands that health requires a degree of resilience, i.e. the ability to maintain functionality in the face of stress.

Focus on functionality

An example of a functionalist view in relation to plants is found in Agrios' plant pathology textbook (2005), which spells out the physiological functions of the plant in great detail:

> the meristematic cambium cells of a healthy plant divide and differentiate as needed, and different types of specialized cells absorb water and nutrients from the soil; translocate these to all plant parts; carry on photosynthesis, translocate, metabolize, or store the photosynthetic products; and produce seed or other reproductive organs for survival and multiplication. [...] When the ability of the cells of a plant or plant part to carry out one or more of these essential functions is interfered with by either a pathogenic organism or an adverse environmental factor, the activities of the cells are disrupted, altered, or inhibited, the cells malfunction or die, and the plant becomes diseased.

However, there is an obvious conceptual question: what is the role played by human interference with the pathogen, ensuring the plant's ability to function, in the definition of health?

Examples focusing on resilience

Health concepts that take resilience into account require, as an additional criterion for health, the system's ability to maintain or restore functionality in the face of crisis or environmental change, without help from outside through treatment. For example, in his definition of plant health, Gäumann (1951) writes:

> [A]n organism is healthy as long as its inner conditions of life are capable to adjust themselves to the environmental influences.

More recently, an account of plant health with a strong emphasis on resilience can be found in a paper on the ethical evaluation of breeding techniques (Lammerts van Bueren *et al.*, 2003):

> Phenotypic integrity is the state of wholeness or completeness of an individual plant or crop, including its health. It can be violated from an organic agricultural point of view by, for example, cultivating and developing plants or crops in such a way that they cannot maintain themselves and perhaps cannot complete their life cycle without chemical crop protection.

The dilemma of functionality and resilience

The use of the word health is problematic when restoration or maintenance of functionality requires constant treatment. It therefore seems inevitable that an element of resilience must be a part of health concepts. But what should be considered as a treatment? Decisions on whether or not a plant is healthy are then completely dependent on the arbitrary borderline between interference and non-interference – if non-interference exists at all. The question of interference becomes even more complicated when intended versus non-intended (but tolerated) or unknown side effects of agricultural actions are to be judged. There does not appear to be a straight logical solution to this problem. Obviously, there will be a continuum between direct intervention (such as killing the pathogen with a fungicide) and softer measures, which are indirect, preventive, or not directly targeted at the pathogen (e.g. design of crop rotations).

A second problem with the focus on resilience is illustrated when it is taken to its extreme. Imagine two plants attacked by a pathogen. Only the first plant is (successfully) treated, the other one is left untreated and slows down in its growth. In the extreme resilientist view, restored functionality would not count at all, i.e. the two plants would be judged as equally (un)healthy, although they are different in their ability to function because one of them was treated.

Therefore, neither of the two views in their pure form is sufficient to provide a convincing meaning of health; both perspectives are needed.

The role of functionality versus resilience in chemical and ecological plant protection

At first, the borderline seems clear: restoring and maintaining plant functions by treating plants against pests and diseases would be a view easily adopted by proponents of chemical plant protection, whereas ecological approaches would place more emphasis on resilience in plant health concepts.

Again, however, a closer look reveals a more heterogeneous picture. For example, classical biological control – i.e. the release of natural enemies of crop pests or weeds – is a valued tool in the ecological plant protection toolbox but does not help to increase the plant's own ability to cope with pests, and therefore is more at the functionalist than the resilientist end of the spectrum.

Another example is the application of organic compost, which helps to establish high suppressiveness of the soil against root pathogens (Hagn *et al.*, 2008) and can help to induce plant defences. On the functionality–resilience continuum, should this practice be assessed in the same way as spraying synthetic fungicides for the control of the same pathogens? It should, if the focus is solely on the plant and its ability to cope with the pathogen, and if the compost does indeed not improve this ability. If, however, the view is broader and encompasses the soil as well, the assessment is likely to change towards resilience being promoted with the compost and functionality with the fungicide approach. Thus, the judgement will ultimately depend on the position that is taken on the reductionist–holistic continuum (Table 1).

Materialism versus vitalism and related concepts

In relation to concepts of health, another relevant controversy is the debate between materialism and vitalism (and their many variations) – a long-lasting dispute over fundamental questions (e.g. what is the mind? what is life? what is death? do plants, animals, and humans have a soul? etc.).

The materialist and mechanistic view of plant health

For the materialist, what matters is matter; all phenomena (including living organisms, their health, their thoughts and their actions) can be explained in terms of material interactions, i.e. by the workings of atoms and molecules. In the materialist (or, more generally, physicalist) view, health is a question of material functioning and the right concentrations of chemicals in the organism's physiology. Materialism is frequently linked to a mechanistic view, which proposes that life processes can be fully described by the laws of mechanics of their components. In the mechanistic world view, the living organism is often likened to a machine, and nature represented as a giant clock. A more general form of materialism, called physicalism, holds that all things are physical objects (including matter), and can be explained by physical laws in the language of mathematics.

The materialist–mechanistic way to study plant health, therefore, focuses on the mechanisms and material fundamentals that underlie the relationships between plant, pests and pathogens. Its research programme is typically concerned with the biochemical pathways of plant defence, the genomics, proteomics and metabolomics of plants and their parts. A good example of a plant health concept that stresses the material aspect is Agrios' definition cited above: here, 'different types of specialized cells absorb water and nutrients from the soil; […] carry on photosynthesis, translocate, metabolize, or store the photosynthetic products' (Agrios, 2005).

The vitalist view of plant health

Vitalists believe that there is more to life than just matter and maths. For them, what distinguishes life from machines and other dead material is a vital energy or life force, called *vis vitalis* or *élan vital* in the Western tradition, *Prana* in the Indian Yogi tradition, and *Qi* in Chinese traditional medicine. Crucially, its strength is seen as an indicator of the health of the organism (although the Chinese tradition also interprets an excess of *Qi* as a cause of ill-health). Some modern vitalists have linked their view to quantum physics. Notably, however, Erwin Schrödinger, who based his understanding of life on quantum theory, rejected the idea of life energy (Schrödinger, 1944). Nevertheless, modern quantum physicists, although not directly advocating the existence of a *vis vitalis*, maintain that life cannot be reduced to mere material (e.g. Dürr *et al.*, 2002).

That plants do have a *vis vitalis* (and indeed, a soul) was a widespread view for centuries but disappeared almost completely in the 20th century (Ainsworth, 1981; Ingensiep, 2001). With claims of such an inner life in plants comes a familiar problem. In humans, the experience of varying levels of one's own energy makes the concept of *vis vitalis* at least accessible to description (although the materialist would just put these down to physiology). In plants, however, it is not directly evident how to describe, assess, let alone measure, this life energy – if it exists at all. Even if someone were to come up with suggestions as to how life energy should be measured in plants, it would not be clear in which way life energy was indeed being measured, as the connection between the measured variables and *vis vitalis* would remain in the dark.

Alternative approaches

A criticism of vitalism is that the alleged life force remains both unexplained and inexplicable, and can hardly be the object of scientific inquiry. However, vitalism is not the only possible opposition against a materialist–mechanistic world view (Nagel, 1961). In fact, the focus on mere material can be criticized from (or supplemented by) several alternative approaches.

First, the materialist, while concentrating on matter, tends to forget form (Sheldrake, 1988). A step towards an alternative, non-materialist conceptualization of plant health could therefore be to revisit morphology. Inspiration comes from evolutionary biology, where fluctuating asymmetry has been used as a morphological measure of stress (Kozlov *et al.*, 2009).

Secondly, we can move from pure matter (molecules and atoms) to other entities of physics, such as radiation (Dürr *et al.*, 2002). Here, an interesting development is the (re-)discovery of biophotons (Yan *et al.*, 2003). Popp (1999) contrasts biophoton emissions from 'fresh, healthy' and 'diseased, wilted' leaves, with the fresh leaves showing a stronger emission and a slower decay. The potential of biophotonics for plant health research lies in the ubiquity, universality and measurability of biophotons.

The ethical perspective: biocentrism versus anthropocentrism

It has been discussed above how we can know when a plant is healthy, and how plant health could be measured. In addition to these epistemological questions, thinking about plant health also raises ethical questions: can plant health be used as a justification for actions, i.e. in the form 'we do X because it improves plant health'? Why should we promote plant health at all? Is health good for plants? Thus, would the promotion of health be for the sake of the plant or would it just serve human purposes?

The biocentric view

Biocentrism claims that plants, like all organisms, have interests (e.g. Schweitzer, 1923; Lockwood, 1996) and are therefore eligible to be included in ethical considerations. Thus, the biocentrist would see a justification for the promotion of plant health in the benefit for the plant.

In ecological ethics, it has mainly been debated if and why various classes of organisms (such as animals or plants) would qualify as ethical entities, whether the justification is based on their interests, their ability to suffer, their cognitive abilities, their rights, or other criteria (von der Pfordten, 1996). Whatever the position taken, on entering the arena of plant health, the biocentrist faces a major problem.

If all organisms, including plants, have an interest, then plant pathogens and pests have interests too. However, there is no reason why plants should be preferred over their pests or pathogens. Therefore, promoting plant health, necessarily at the cost of other organisms such as pests or pathogens, seems unjustifiable. Many philosophers have even argued for an ethical preference of animals over plants, e.g. in order to justify vegetarianism (Hofmeister, 2000; Ingensiep, 2001). Killing pests would be difficult to support in this theory.

Indeed, whilst botanic gardens focus on plant conservation, the conservation of pathogens has also been advocated (Ingram, 1999). Also, disease may play a role in maintaining plant biodiversity, by reducing the likelihood that some plants become dominant and increasing survival chances for rare species (Janzen, 1970).

Thus, a solution to the biocentrist dilemma is to move from the level of individual organisms to the community level. To decide whether or not actions should be taken to promote plant health in a particular plant species, the benefits for that species must then be weighed against the costs for other species, including pathogens and pests. In this scenario, it is necessary to employ community-level criteria, such as the stability of the community, or the long-term conservation of a maximal number of species.

However, from a purely biocentric view, there is no reason to give a particular value to the development and survival of any organism or community. In the absence of any human consideration, what happens, happens – evolution will pursue its blind course. Here, the notion of health effectively disappears.

The anthropocentric view

Anthropocentrism ignores or denies the possibility of plants having interests and justifies actions for improving plant health purely by pointing at the benefits for humans, such as higher yields or food quality. From a purely anthropocentric view, plant health becomes important because it affects the success and happiness of humans. The concern for plant health is based, then, on the importance of plants in supporting humans in terms of food, fibre, fuel, medicine, beauty, etc.

The dominance of the anthropocentric view is illustrated by looking at common wild plants to which no direct conservation value is ascribed. Here, human interference for improving plant health is rarely called for unless their ill-health affects human interests, e.g. through some ecosystem functions.

A serious flaw of the anthropocentric view on plant health is its tendency to ignore its own arguments. Its central point is that promoting plant health serves human goals; consequently, an important task is to always test whether plant health does indeed correlate with the goal in question. For example, does the removal of a particular pathogen indeed increase the yield or quality of the crop (see the *Septoria* example above)? Too many studies fail to show the link between plant health (however it is defined) and such goals, simply assuming that lower pest or disease levels are in all cases beneficial for humans; such assumptions should be challenged.

Also, a purely anthropocentric view is inadequate because it tends to neglect the dependence of human goals on the survival, evolution and functioning of organisms not directly used by humans. This recognition of the value of biodiversity approaches a more biocentric view.

Developing a viable plant health concept

As demonstrated, for any single view of plant health it is possible to find examples that weaken its plausibility. Indeed, there is no single plant health definition that provides satisfying clarity and consistence. A radical response would be the refusal to define or use the term at all. Indeed, many textbooks on plant pathology make do without any plant health definition (e.g. Holliday, 1993).

As a deliberate approach, this abstinence has received backing by Wulff (2002), who argues that people will never be able to agree on what health is, and that it is therefore not a word with scientific merit. Instead, it would be much easier to agree on concrete diseases and the aim to reduce their incidence and strive for 'elimination of concrete miseries'.

At a first glance, this move appears reasonable, pragmatic and even elegant. However, the problem is that, as the normativist would argue, there are no 'concrete diseases' out there as objective entities, but that these are also constructs with a historical and social context and that it is possible (and necessary) to question their validity and their conditionality. Also, Wulff's view keeps positive aspects of health out of the arena, because it just focuses on the 'miseries'. However, Wulff is probably right in that it is easier to agree on single issues than on a complex concept.

So is there an alternative to refusing plant health a place in scientific debate? It will be shown below that plant health does have merit in science, despite the theoretical shortcomings and contradictions of the various approaches discussed above. However, it is not a trouble-free solution.

What should a plant health definition achieve? Health is a complex construct; however, a definition of plant health should be concise and short, perhaps inevitably reducing the complexity it can capture. Such a dictionary-type definition would be expected to clarify by providing logical consistency. It would need to be without circular references and contradictions, and should not contain any empty phrases or refer to any broad undefined terms. Ideally, it would help to achieve plant-health-related goals, by translating these goals into measurable objectives.

On the other hand, a definition of plant health needs to be adoptable by many users. It should be close to the everyday use of (plant) health as a colloquial, non-scientific term. Otherwise, it would be artificial and unlikely to be used. Ideally, it would have the ability to evolve. It would have to prove its validity by showing that it can capture many individual cases of healthy or diseased plants. These contrasting sets of desirable properties of a plant health definition are difficult to reconcile. All attempts to define plant health struggle to keep a balance between these many criteria.

The fundamental tension between the requirements for health concepts is a key reason why the different schools of thought discussed above are unable to create a convincing concept of plant health on their own. Individually, these views are always too narrow, or cases can be constructed to argue against them. Therefore, the complexity of health can only be captured by a concept that incorporates and tolerates different and even contradicting views.

Thus, fuzziness in conceptualizing plant health is inevitable. Indeed, several authors have – at least indirectly – concluded that a clear definition of health (and disease) in plants is difficult to achieve (Schlösser, 1997; Lucas, 1998; Agrios, 2005).

Still, with no clear border between healthy and diseased, why is it so easy to imagine a healthy plant? Most likely, people thinking about a healthy plant have some indicative properties such as colour, turgor, size, etc. in mind that together provide the impression of a healthy plant. Also, imagination presumably selects a single picture of one plant or a group of plants representing a healthy state. The complexity of the concept, however, is too high to be captured in the mind's eye, represented by a single plant. Instead, by forcing ourselves to imagine a diverse range of pathosystem situations, we must recognize that plant health is too multifaceted to be portrayed by a short, classical dictionary-type definition. The inevitable fuzziness of the term 'plant health' has consequences for its use in scientific and extension literature; in short, it should be used with caution.

As 'plant health' is a fuzzy term it needs to be accompanied by transparency regarding context, interests and potential consequences. Otherwise, there is the risk that the fuzziness is exploited to mislead. For example, when pesticide-treated plants are called 'healthy' in advertisements (Döring & Finckh, 2006) the direct contrast with the untreated plant generates a specific and narrow meaning of health. Here, healthy is just the state of the plant that is not infected with the particular disease against which it has been treated. However, the readers' understanding of health is likely to be more complex. While the use of the word health in the advertisement is reductionist and negative, the meaning of what might be read into it is more comprehensive, because health is associated with more than just the absence of a particular disease. Without proving these other aspects of health, the advertisement therefore exploits such broader connotations.

Thus, the fuzziness of plant health has some undesirable consequences. What is needed, therefore, is a plant health concept that can prevent such misuse.

As shown above, the contrasting requirements for a plant health definition make it difficult to develop a viable definition as an objective and unambiguous entity. Also, plant health itself is inappropriate as a rationalization on which to base actions and decisions. It therefore seems that a dictionary-type definition of plant health might actually neither be possible nor, in fact, needed.

What is necessary, however, is to keep the term plant health alive in scientific debates because it helps to raise questions about practices that affect human goals (reliable yield, high food quality, human health, and the provision of ecosystem services), and because the very term serves as a reminder for the positive aspects of health, i.e. to look beyond diseases.

Therefore, it is suggested that plant health is an instigator of thought and debate rather than an objective entity – Table 1 provides a tool to assess views of plant health. As such, this concept of plant health is neither descriptive nor prescriptive but procedural: it is a bundle of rules for the debate of plant health issues; these rules concern both the contents of questions around the term 'plant health' as well as the procedures for debating. This open concept of plant health as a set of procedural rules combines different views presented in the previous sections:

1 Debating plant health issues should consider as many of the following questions as possible:
   - What is the perception of the pathosystem by the people involved?
   - Are pathogenic organisms present on the plant that can negatively affect reproduction, growth, survival or development as compared to plants without the presence of these organisms?
   - Have the plant and the pathogen/pest coevolved?
   - Is the state or the development over time changed or affected?
   - Are plant individuals or plant populations affected?
   - What roles do the environment and management play (e.g. should this crop species be grown in this environment)?
   - How is the ability of the plant or plant population to maintain survival and growth and reproduction affected under stress conditions, including the

presence of pathogenic organisms? Are any compensatory effects detectable?
- What is the genetic potential of the plant or plant population?
- Is the physiology and morphology of plants or plant populations affected?
- How are the yields of the plants, their quality as food or feed, the ecosystem functions they provide, or human health and welfare and socioeconomic functions affected?
- Any other questions that are deemed relevant.

2 The process of debating these questions should:
- be fair and equal between discussion partners and involve appropriate stakeholders;
- allow enough time to be comprehensive and consider possible repercussions of decisions;
- be transparent, by ensuring good availability of the material on which decisions or assessments are based, good visibility of the respective decision criteria, and transparency of interests by those involved in the process.

Conclusions

Despite the importance and high profile of health for agriculture, forestry and conservation biology, the notion of plant health has so far remained conceptually underdeveloped. This has created a vacuum in which strong but potentially misleading claims about health benefits could be made. Therefore, a concept of plant health is needed to prevent such misuse.

Instead of trying to give yet another plant health definition, this paper has developed a procedural concept of plant health that suggests ways to approach the issue. Similar approaches might work for the terms 'soil' (Janvier *et al.*, 2007), 'forest' (Holdenrieder, 1991), 'ecosystem' (Kimmins, 1997), 'landscape' (Ferguson, 1994), 'animal' (Rushen, 2003), and indeed, 'global health' (Rapport & Maffi, 2010).

Meanwhile, the following guidelines are suggested for the use of the term 'plant health':

1 It should continue to be used as a technical term for issues related to plant hygiene and international plant trade.
2 It should not be used as a short-cut for 'not having a particular disease', because, as explained above, this use is misleading, evoking a more complex picture of health than might be justified by the case.
3 It should be used in conceptual debates to inspire new insights, to develop visions, to discuss aims, and to rethink concepts of plant protection.
4 In these debates, plant health should be remembered as a derived goal, which should not be used to justify actions on its own. Instead, plant protection needs to be re-integrated with agronomy, food quality science and ecology, and true primary goals, such as yield, food quality and biodiversity need to be prioritized.

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