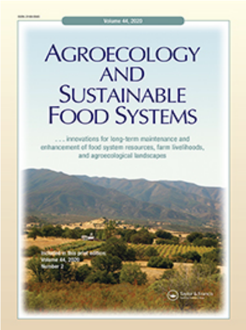




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# Revising the concept of crop health from an agroecological perspective

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**ABSTRACT**

The concept of health has been widely used to refer to soils, crops or agroecosystems. It resembles the idea of wholeness or general well-being, which is interesting to integrate different disciplines. There have been valuable contributions in the area of agroecological management of diseases, pests and weeds with the aim of promoting crop health. Nevertheless, they remain relatively disconnected and lack of a comprehensive conceptual framework that helps to define crop health and how to promote it. The aim of this article is to re-conceptualize the notion of crop health from a transdisciplinary and holistic perspective. The system of reference is redefined by including the relationships between the populations of domesticated plants and the farmers. This implies a multidimensional approach and assumes that crop health is related to farmers' objectives, knowledge, point of views and values. Based on the review of studies in the field of agroecology, four components are proposed to evaluate crop health status: *usefulness, adversities, safety* and *autonomy*. Three components of health promotion were adapted from the salutogenic model proposed for human health: *meaningfulness, comprehensiveness* and *manageability*. This article intends to make a contribution on theoretical and conceptual aspects of a key concept for agroecology.

**KEYWORDS**
Crop protection; disease; pest; weed; transdisciplinarity

## Introduction

The notion of health has been widely mentioned in the long history of agricultural studies. In 1943, Albert Howard in his book *An Agricultural Testament* suggests that the real problem of agriculture is "how to grow healthy crops" and not how to manage pests, diseases or weeds. "Agriculture needs to be considered as an art; the researcher needs to keep in mind all involved factors" (Howard 1943). His ideas

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on health of agriculture express the strong relationships between fertile soils and the health of crops, animals and people. Similar ideas were expressed by Eve Balfour, an English farmer, in her book entitled *The Living Soil*: "The health of soil, plant, animal and man is one and indivisible" (Balfour 1943). Since then, the notion of health has been frequently used in the literature in relation to agriculture, with references to plants (Altieri y Nicholls, 2003), agroecosystems (Costanza 1992; Rapport, Costanza, and McMichael 1998; Xu and Mage 2001; Yiridoe and Weersink 1997), and the soil (Abawi and Widmer 2000; Doran and Zeiss 2000; Park and Cousins 1995).

Agroecology can be defined in three levels: as a *critical theory* in agricultural sciences, as a *practice* of farmers and agriculturalists, and as a *social movement*, which comprises many social actors that are interested in promoting this critical point of view (Van der Ploeg 2012; Wezel et al. 2009; Toledo 2011). As a science, it is understood here as a transdisciplinary, participatory and action oriented approach, socially and politically engaged towards a transformation of agri-food systems, but the term "agroecology" is also used as a synonym of an applied ecology to agricultural systems (Méndez, Bacon, and Cohen 2013). From these diverse theoretical frames, there are valuable contributions for a conceptualization of crop health in the field of pest, disease or weed management, which have been gradually adding ecological, social, political and cultural aspects, thus contributing to a more holistic approach (Altieri 1987; Barrera Gaytán 2006; Chaboussou 1980; Iermanó et al. 2015; Lewis et al. 1997; Nicholls 2006; van Bruggen 1995; Vázquez Moreno 2012). In these articles, despite the extended use of the notion of health, there is still no explicit definition and there prevails a certain disconnection. The transdisciplinary paradigm is adequate to articulate different disciplines by constructing concepts that integrate them (Max-Neef 2005).

Perhaps the more extended conceptual problem in this subject is the use of negative health definitions (Döring et al. 2012), which are usually not made explicit. For example, a recent publication includes "crop health" in the title (Nelson 2017), and studies diseases and plant pathogens, assuming health as a synonym of absence of disease. In disease inoculation trials, plants that are not inoculated are usually defined as healthy. In discussions on human health, negative definitions have been strongly criticized, because the absence of disease is a restrictive criterion that does not reflect well the complexity that encompasses the notion of health (Döring et al. 2012). The World Health Organization (WHO) defines human health not only by the absence of diseases, but as a state of complete physical, mental and social well-being.

The concept of plant health has been recently revisited (Döring et al. 2012). These authors state that, despite its importance, it is still an ill-defined term and various problems associated with the existing definitions prevail. They base their revision on concepts borrowed from human health, which have a greater development, and identify philosophical controversies that should be taken into account for this conceptualization. Here, we intend to contribute to the debate on the application of the concept of health in the domain of crop protection from an agroecological perspective. Hence, we propose a (re)elaboration inspired in agroecological literature in crop protection and the *salutogenic model* developed for human health by Antonovsky (1996), physician and sociologist. This notion of human health considers the total spectrum of well-being instead of limiting to isolated diseases, promoting the movement towards health in a health-disease continuum and to focus on the factors that promote health (Antonovsky 1996).

For this reconceptualization, we begin with the definition of the system of reference. Then, we discuss from an epistemological frame some controversies proposed in Döring et al. (2012). In the next section, we revise contributions of alternative approaches in crop protection (including publications in Spanish). Finally, with the aim of integrating the different contributions, we propose a re-elaboration of the concept of crop health from a holistic-transdisciplinary approach.

## Defining the system. What plants do we consider to define health?

The clarification of the biological organizational level is relevant to define what health is and how to evaluate it, as a plant population has different attributes from a plant individual. Inaccurate identification of this point is common in plant health definitions. George Agrios, a plant pathologist well known for his book Agrios (2005), states that "*it is accepted that a plant is healthy, or normal, when it can carry out its physiological functions to the best of its genetic potential*". Although this definition is constructed for a plant individual, the entire book considers plant populations. Cook (2000), another classical author in phytopathology, defines the "management of plant health" as a "discipline that allows overcoming scientifically and technically all limitations of yield, utility, appearance or quality of final use of cultivated plants". As Agrios, Cook also refers to plants, albeit the plural seems to be the population not the individual.

Classical definitions of plant health generally refer to one life cycle of plant populations grown in a field, but this is usually not made explicit. The use of this time and spatial scale does give rise to some limitations. As there are ecological processes that operate at different scales, several researchers have argued that a multi-scale approach is necessary to manage different organisms: Irwin et al. (2000) for viruses and both Cardina et al. (1999) and Jordan et al. (2016) for weeds. Soil health, for example, has an effect on the susceptibility of crops to attacks by pests or diseases and depends on the design and management of the entire farm such as rotations, the type and intensity of ploughing, and degree of integration between animal and plant production.

Finally, the vegetation type needs to be characterized when defining health. In agroecosystems, vegetation can be domesticated plant populations (planned biodiversity), spontaneous communities in cultivated fields (associated biodiversity) or in natural or semi-natural habitats (Altieri 1999; Perfecto, Vandermeer, and

Wright 2009; Vandermeer et al. 2002). Cook (2000) explicitly refers to cultivated plants, and although the definition by Agrios (2005) does not make reference to cultivated plants, his book covers mainly diseases of cultivated plants.

Up to this point, we intentionally avoided the use of the word "crop" for referring to cultivated plant populations in order to discuss here a key difference with human health. In general, a crop is defined as a plant population comprised by individuals of the same species that coexist in time and space. Although it might seem quite obvious, the previous definition ignores that there would not be such a crop without the people who cultivate it. The purposes and actions of a farmer (a community of farmers or the society) determine that a population of plants becomes a crop, and thus, crop health is necessarily related to these purposes and actions. Ignoring this crucial aspect necessarily leads to misunderstandings or limitations in the construction of a crop health concept.

Based on the previous discussions, we (re)define a *cropping system* as a population or a set of domesticated plant populations and their relationship with a farmer (or community of farmers) (Figure 1). Including this interaction into the system implies that there are necessarily economic, cultural, social, ethical, as well as ecological and biophysical aspects involved in the system, that are interconnected. As in any complex system, the limits are necessarily diffuse (García 2011). Populations of domesticated plants are part of a wide range of biological interactions (Altieri 1999; Shennan 2008), and the farmer is not isolated, but it is part of a society where processes that affect the system occur at different levels (García 2011; Jordan et al. 2016). Defining the system specifying the relationship with a human dimension implies that crop health necessarily requires discussing the different ways of practicing agriculture and, therefore, values, view-points, worldview and even ideology. For this, the epistemological paradigms and theoretical frameworks that are behind the different conceptualizations need to be differentiated.

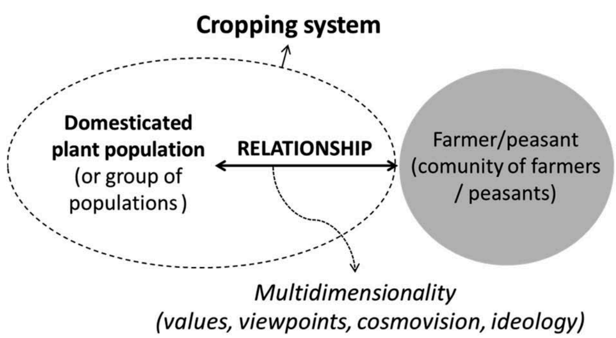


**Figure 1.** Graphical representation of the cropping system. The center of the system is the relationship between the domesticated plant population and the farmer/peasant. The multidimensionality arises from this relationship and explains the necessity to consider other aspects that usually remain occult in the positivist paradigm. The dotted line represents the diffuse limits of this complex system.

## Differentiating epistemological paradigms and theoretical frameworks

Based on the conceptual debates on human health, Döring et al. (2012) identified a series of philosophical controversies in relation to plant health that remain relatively disconnected. We argue that these discussions on plant/crop health need to be framed in epistemological paradigms. The analytical paradigm, also called conventional or Cartesian (Álvarez-Salas, Polanco-Echeverry, and Ríos-Osorio 2014; Ríos Osorio, Lobato, and Del Castillo 2009) can be characterized as reductionist, universalist and objectivist (Norgaard and Sikor 1987; Ríos Osorio, Lobato, and Del Castillo 2009), while the transdisciplinary or complexity paradigm is rooted in the holism, contextualism and subjectivism (Álvarez-Salas, Polanco-Echeverry, and Ríos-Osorio 2014).

The reductionism or atomism (Norgaard and Sikor 1987) consists in separating the natural phenomena in its minimal parts to better understand them, which results in the specialization of scientific disciplines (Álvarez-Salas, Polanco-Echeverry, and Ríos-Osorio 2014; Ríos Osorio, Lobato, and Del Castillo 2009). Classical definitions of health tend to be anchored in highly specialized disciplines, which are typically found in the natural sciences (Döring et al. 2012). Such is the case of plant health in plant pathology. Perhaps the most obvious limitation is that other disciplines related to crop protection (i.e. entomology, weed research, botany, among others), are usually either not considered or integrated. Another manifestation, even more relevant, is the separation of the population of cultivated plants from the action of farming, characteristic of the Cartesian paradigm, separating the "natural" and "social" worlds (Novo 2006).

Another problem associated with the reductionism of the classic definitions is that a plant population can be defined as healthy if it reaches its genetic potential but by means of a regular application of fungicides (Döring et al. 2012). This is contradictory for at least two reasons: a) as plants "require" constant treatment, they should be considered diseased plants, and b) the use of fungicides, as a toxic product, could be a threat for environmental or human health and this would not be consistent with the concept of health. In short, in the definitions of crop health based on specialized disciplines problems arise that are intrinsic of the Cartesian epistemological paradigm. The notion of health as a wholeness cannot be comprehensively understood under this paradigm.

Another characteristic of the same paradigm is that a definition of health applied in a situation or case is universally valid. This ignores the fact that there is a high heterogeneity of typologies of farmers, situations, contexts and farming systems. Rural sociologists identify different types of farmers, such as business oriented-farmers, stakeholders, smallholders and peasants (Cáceres, 2003; Obschatko et al. 2007). Within each category, there is also heterogeneity not only in socio-economic aspects (Cáceres 2003; Obschatko et al. 2007), but also in the values, knowledge, perceptions, learning processes, access to information, among others (Hecht 1987; Morales 2009; Segura et al. 2004). For example, farmers that practice an alternative type of agriculture (e.g. organic, biodynamic, permaculture), have objectives, assessment criteria, experiences and knowledge that are different from other types of farmers. In two peasant communities in Mexico, very similar in socio-economic or even cultural aspects, Segura et al. (2004) detected significant differences in knowledge and perception about pests and diseases.

The Cartesian paradigm is objectivistic (naturalist *sensu* Döring et al. 2012). It conceives science as neutral and assumes that values or ethics do not intervene in the construction of scientific concepts (Norgaard and Sikor 1987). Health is linked to "nature" and biological attributes that are likely to be determined by an expert, objectively and independent of human values (Döring et al. 2012). This is the case of the classical definitions (Agrios 2005; Cook 2000), that avoid expressing that the health assessment criteria are of human nature. Döring et al. (2012) state that for developing a viable concept of "plant health", it is necessary to consider human health and well-being and the socio-economic functions of cultivated plants. This conceptual construction cannot be solved from objectivism, because a position on the ways of practicing agriculture needs to be defined. Here arises an important point that needs further clarification. To take a position in the scientific research does not mean to express a personal opinion. It means that there is a logical necessity to explain the theoretical framework in which the research is being developed.

The transdisciplinary or complexity paradigm (Álvarez-Salas, Polanco-Echeverry, and Ríos-Osorio 2014) studies phenomena from a multidimensional and holistic approach and intends to distinguish (but not to separate) and reconnect (Morin 1994). This does not question the existence of a natural or material basis of the phenomenon under study, or discharge concepts or studies from various disciplines, but it proposes to integrate them. This paradigm considers the context, different forms of knowledge and values, and it therefore also recognizes the coexistence of various theoretical frameworks. Agroecology, defined as a critical theory (Van der Ploeg 2012) is necessarily subjectivist. This implies that classical plant health definitions omit usually (but not always: see Browning 1998) to express openly their theoretical frame of reference and thus the values and ideology on which it is based.

## Contributions and limitations of the alternative approaches applied in crop protection

In his discussions on human health, Antonovsky (1996) differentiates between *curative* and *preventive* medicine. Some analogies can be found in the domain of crop protection, perhaps with more diffuse limits (Figure 2). Integrated management (IM) is an agronomic approach based on combining a group of tools that are used to manage biotic adversities relying on the

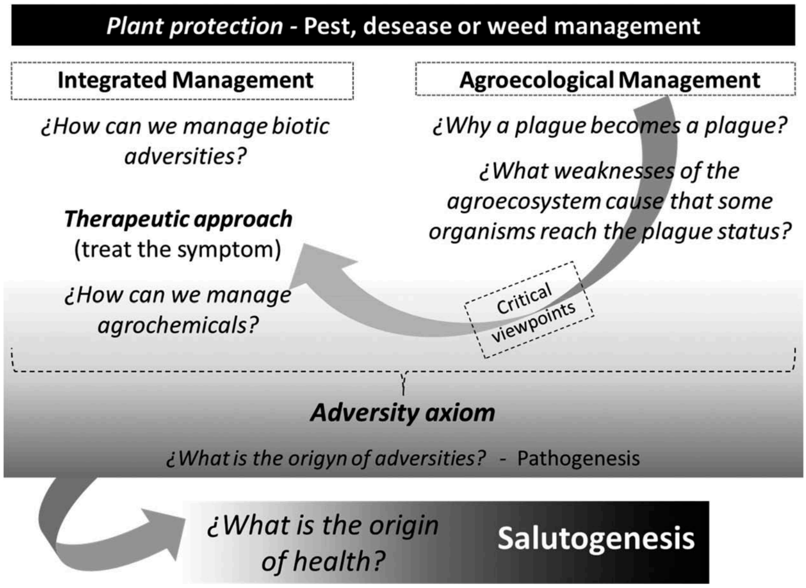


Figure 2. Conceptual map of the different approaches in plant protection and the proposal of a new theoretical framework for crop health based on the salutogenic model proposed by Antonovsky (1996) for human medicine. Change desease to disease in title. In the line below Adversity axiom, origyn must be changed to origin.

ecological and biological knowledge of organisms (Cardina et al. 1999). While the spirit of IM is based on the principle of prevention, several authors (Altieri 1987; Barfield and O'Neil 1984; Lewis et al. 1997; Morales 2009) state that in the implementation, the IM programs usually end up pursuing objectives closer to the management of agrochemicals than of pests. They are generally restricted to the monitoring of populations for the application of agrochemicals based on damage thresholds, while usually fail to incorporate preventive tools (Barfield and O'Neil 1984; Morales 2009). Lewis et al. (1997) argue that this is due to a "*therapeutic approach*", which is based on treating the symptom, rather than asking *"why a plague is a plague"*, i.e. what are the weaknesses of the agroecosystem, what agricultural practices or farmer´s decisions explain that these organisms reach the population level to become a plague. This is the key question behind the theoretical proposals and empirical investigations related to the agroecological management of pests, weeds and diseases, as well as of those researchers who claim that priority should be given to a preventative approach within IM (Morales 2009). In this section, the evolution in conceptual terms of alternative approaches is briefly described. This does not intend to be a thorough review, but to enrich the conceptual discussion.

Briefly, the strategy of agroecological management of weeds, pests and diseases is based on vegetation diversification and the promotion of soil health (Altieri, 1999). The first strategy refers to an increase in functional diversity which aims at strengthening the regulation processes of the system (Moonen and Bàrberi 2008), and includes multiple levels of biological organization, from the genetic, the agroecosystem and the landscape (Cardina et al. 1999; Irwin et al. 2000; Altieri, 1999; Jordan et al. 2016). Several researchers agree that the homogenization of agroecosystems and landscapes, in extreme cases with uniform monocultures planted in extended areas, reduced intra-specific diversity, homogeneous farming practices and shorter rotations create conditions that predispose the development of plagues and epidemics (Agrios 2005; Altieri 1987; Nicholls 2006; van Bruggen 1995; Vega et al. 2019). Therefore, a greater spatial and temporal diversity of vegetation, as well as a greater landscape heterogeneity and landscape arrays more favorable to natural enemy populations, reduces risks. The other strategy is the promotion of soil health, which is an essential part of plant nutrition. Fertilization practices also affect susceptibility to pathogens or pests (Walters and Bingham 2007). The relationship between soil health and plant nutrition with susceptibility to pests or diseases has been suggested for some time (Balfour 1943; Howard 1943). A renowned researcher in the field of agroecology is Francis Chabousso, who worked for INRA (*Institut National de la Recherche Agronomique* of France). His theory, called *"trophobiosis"*, proposes that fertilization practices may make crop plants more vulnerable to the attack of pests or diseases through changes in the concentrations and types of solutes in plant tissues (Chaboussou 1980).

In addition to the ecological-productive aspects, various researchers have highlighted the importance of considering the perceptions, knowledge and experience of the local farmers and peasants, their ability to solve problems, their organizational networks, the processes of social learning, and aspects of the socio-economic and institutional context (Barrera Gaytán 2006; Segura et al. 2004; Vázquez-Moreno, 2006). Ethnographic studies systematize diverse aspects of the knowledge of indigenous peoples or communities as local taxonomies or agricultural knowledge (Altieri 2002). Specific studies on ethno-phytopatology or ethno-entomology emphasize knowledge and practices on the management of diseases or pests (Bentley et al. 2009; Bentley and Thiele 1999; Silva and Castaño-Zapata 2014). Other approaches take a holistic pest management approach, and present diversity in what they consider to be the "whole" (system), the objectives they pursue and the procedures (Barrera Gaytán 2006).

Perhaps one of the most well-developed proposals is holistic pest management (HPM, Barrera Gaytán 2006), which arises from work with Mexican peasant farmers mainly around the problem of the coffee pests. As suggested by other authors (Altieri and Nicholls 2003; Lewis et al. 1997), he starts searching for the causes that provoke the pest as a starting point for the design of healthy production systems. For this, he builds up a set of principles (named as: holistic, participatory, safety, agroecological and equitable market) on which the HPM is based, which are as follows: (a) in order to confront the problem of pests, it is necessary, first, to improve the income and welfare of farmers and their families, as well as their capacity to organize themselves in productive and commercializing aspects; (b) to promote the self-management of men and women and link producers and consumers to strengthen the decision-making processes and actions on pest management; (c) to make more efficient use of internal resources, and minimal use of external inputs, and encourage synergies between processes and components of the agroecosystems that treat the causes of pests outbreaks; (d) pest management must promote processes and products that are safe and of good quality, both for the ecosystem and for the subsistence of farmers and the consumer; (e) pest management should contribute to achieving adequate prices both for producers and for consumers.

Barrera Gaytán (2006) focuses mostly on people rather than on pests, which implies a radical change in pest management. In a similar sense, but considering more extensive spatial and temporal scales, Vázquez Moreno (2012) has studied the relationship between the social and institutional context and practices of pest management in Cuba from a historical perspective. Vázquez-Moreno discusses the role of different public policies in this process (land reform law, the national biological control program, and the program of urban agriculture), the organization of the service of plant health and the organization of farmers in cooperatives (Vázquez Moreno 2012). He also studies the organization of basic and applied national research projects, as well as innovations in territorial programs, the experimentation with farmers and public institutions and policies.

Recently, Jordan et al. (2016) proposed a transdisciplinary approach to deal with weed problems. They rescue the conception of Jantsch (1972), who understands research as a process where the collaborative learning, subsequent collective action and critical evaluation of the consequences of the action, serve to identify knowledge "holes" that can be studied from applied sciences. In this process, it is essential to consider the existence of different forms of knowledge – local, professional, practical and traditional in addition to the academic (Funtowicz and Ravetz 1993) and the need to find forms of democratic governance of food systems (Loos et al. 2014). For this reason, it is necessary to consider the various actors and their different points of view and interests (Jordan et al. 2016). In similar ways as other authors for pests and diseases (Barrera Gaytán 2006; Segura et al. 2004), Jordan et al. (2016) understand that weed problems have multiple interrelated dimensions and levels/scales, which have feedback dynamics.

All contributions from alternative approaches in crop protection consider a broad spectrum of aspects, and present a gradual process of incorporation of multiple dimensions and scales, following the same development of research in agroecology in general (Polanco-Echeverry et al., 2015). Perhaps the biggest weakness in this area is that there are still separations between disciplines, and thus different contributions remain relatively disconnected in conceptual terms. Here, we suggest that the concept of health can be used to integrate the diversity of these alternative approaches.

## The salutogenic model applied to crops

Antonovsky (1996) identified an axiom that is shared by preventive and curative human medicine. Both conceive health as a questioning about the origins of diseases, i.e., its pathogenesis. Preventive medicine, which aims to promote health, focuses on identifying risk factors of particular diseases of patients and it is usually restricted to a given disease-risk population (Antonovsky 1996). Interestingly, something analogous seems to occur in the area of crop protection, where the word 'protection' gives a hint of the same axiom identified by Antonovsky. In the classical approach of integrated pest management (IPM) as in the alternative approaches, the point of departure is the adversities that threaten a crop. All these are based on the adversity axiom, as we have translated for the case of crops (Figure 2).

Antonovsky (1996) suggests asking ourselves about what is the origin of health. He proposed a novel approach and developed a model based on the origin of health, called salutogenesis. Döring et al. (2012) resumes Antonovsky´s proposal on the following postulates: (1) instead of being interested in an isolated disease, they are more interested in the total spectrum of well-being; (2) people are not sick or healthy; there is a continuum between both poles; (3) they put the focus on a movement towards health in that continuum; (4) instead of focusing on the risk factors of diseases, they ask what factors are responsible for moving towards health (healthy factors); and (5) they question the image of the "sick role" and the identification of the person with the disease, and proposed to search for new social roles and to pay attention to people's compensatory abilities. Here, an adaptation of these postulates to crop health is proposed (summarized in Table 1), and from this framework we discuss how a healthy crop can be defined, what constitutes a crop health problem, and particularly on how healthy crops can be promoted.

### *Adaptation of the salutogenic postulates to crop health*

(1) *Instead of focusing on an isolated disease, weed, pest or a limiting factor (a nutrient or water), we should pay attention to the 'holistic' full spectrum from a systemic approach, and the well-being of the cropping system, including the relationships of the components between each other and especially the relationship with the farmer.* This postulate assumes a holistic approach

**Table 1.** Main differences between the pathogenic/therapeutic approach and the salutogenic model applied to cropping systems.

| Pathogenic/therapeutic approach | Salutogenic model |
|---|---|
| Study of *isolated* diseases, plagues or weeds as yield limiting factors | *Total spectrum of well-being* of the cropping system (centered in relationship with farmer/peasant) |
| Crops are *healthy or sick* (affected by an adversity) | There is a *continuum* between the poles health and disease |
| Centered in the *state* | Focuses on the *movement towards health* |
| *Risk* factors | *Salutogenic* factors |

to health, where the different dimensions that arise with the phenomenon of agriculture can be integrated. Thus, by thinking on crop health, the welfare of farmers is also considered, his/her economy and viability, cultural aspects, their values, knowledge and worldview, taking into account the objectives of this activity.

(2) *Crops are not healthy or affected by an adversity ("sick"), but there is a continuum between these two poles*. This postulate allows us to break with the notion of health as something dichotomous (healthy or "sick") and proposes a gradient. The proposal of a continuum assumes the existence of a certain state or condition of health.

(3) *It puts the focus in the movement towards health in that continuum*. This premise provides a dynamic look of health, understood as a process and not only as a state. To understand health as a process it is necessary to establish the main factors linked to this process, how they are interrelated and what are their feedback dynamics. The same is proposed by Jordan et al. (2016) to solve the problems of weeds in a transdisciplinary way. One of the main processes associated with health is social learning (Jantsch 1972; Shennan 2008).

(4) *Instead of focusing on risk factors (that lead to disease, pests or weeds), the main question is what factors are responsible for moving toward health (salutogenic factors)*. This is perhaps the central point of this theoretical construct. Various theoretical and empirical contributions developed by agroecologists go in this direction, promoting crop health through ecological, social learning and socio-organizational processes.

(5) *We should question the image of plague, disease, weed, water deficit or nutrients as a limiting or quality reducing factor, and search for new categories or new interpretations of these ideas and pay attention to the response and learning capabilities of farmers*. This last assumption is very similar to the ideas of Howard (1943): our goal should not be to study how to destroy or minimize populations of pathogens or plagues, but to question what we can learn from them, reserving for them the role of "teachers of nature" (Heckman 2006).

## Re-defining crop health and crop health problems

*What is a healthy crop?* Based on the theoretical framework of agroecology, we identified four major aspects that can help to define the "full spectrum of well-being" and evaluate the condition/status of crop health: usefulness, adversities, autonomy and safety (Figure 3). At the scale of a crop field, a series of attributes can be identified: the capacity of the cropping system to provide ecosystem services, its productivity and stability, associated with its tolerance and resistance to adverse conditions and the subsequent recovery (Altieri, Nicholls, and Funes 2012). As a general criterion, Altieri, Nicholls,

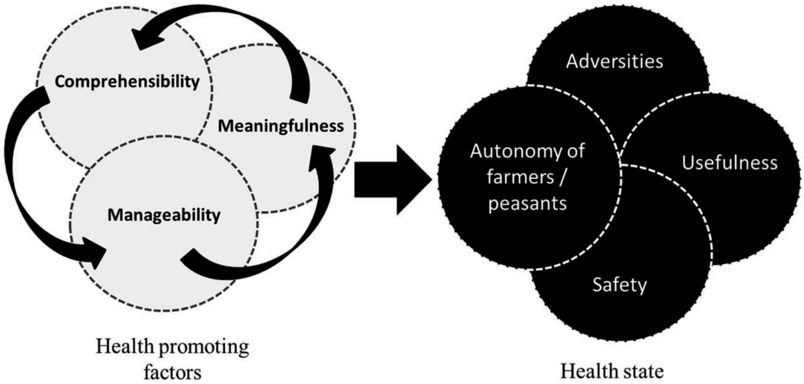


**Figure 3.** Graphical representation of the concept of health understood as a process. The components of the salutogenic model applied to cropping systems are organized in those that promote crop health and those that describe crop health state.

and Funes (2012) takes into account the *usefulness* of the cropping system in a broad sense in temporal and conceptual terms, but also considers the *adversities*, that should also be understood in the broad sense. On the other hand, at the "farm level", the criterion of *autonomy* of the farmer should be included (Coolsaet 2016; Das Chagas Oliveira, Collado, and Leite 2013; Kremen, Iles, and Bacon 2012; van der Ploeg 2009). This is a counterpart to the dependence on inputs in the ecological-productive dimension, or to socio-organizational or economic attributes (all of them interrelated) (Gliessman 2002). Finally, the criterion of *safety* proposed by Barrera Gaytán (2006) is tacit behind the various contributions of agroecologists. It covers multiple actors, from the farmer to local populations in rural communities, farm neighbors, rural workers, consumers and ecosystems.

We define a *healthy cropping system* as one that tends to achieve short-, medium-, and long-term goals of the farmer (or community of farmers), contributing to meeting the needs of society, enhancing ecological and social processes by minimizing reliance on external inputs and maximizing safety for humans and ecosystems. This definition allows the incorporation of the criteria of the theoretical framework of agroecology, without excluding the diversity and heterogeneity of farmer´s objectives. These can be very variable, as for example, to increase incomes of the farmer, to reduce the labor that agriculture demands, or to achieve certain product quality to sell in a particular market, or that a population of plants provide certain ecosystem services (nitrogen fixing, control of weed populations, recovery of degraded soil, reduction of wind speed), provision of food to its family group, savings (such as a forest crop), or having greater economic stability or reduced problems of marketing. This definition recognizes that the objectives of agriculture can be highly variable, and they are not restricted to a maximization of productivity or reaching the genetic potential of a plant population, as proposed by the classic conceptualizations of crop health (Agrios 2005; Browning 1998; Cook 2000). At the same time, it recognizes the heterogeneity of social contexts, farmer typologies, as well as values, criteria and local knowledge.

*What is a crop health problem?* This question can be broken down into two parts: (a) to who, with which criteria and based on what conceptual framework (local or academic, and in the latter case, what discipline and theoretical approach) defines what a health problem is; and (b) what are the limits of the problems linked to crop health. IPM responds to the first question with the concept of economic threshold, while alternative approaches incorporate local criteria and knowledge (Barrera Gaytán 2006). The economic threshold, however, has many theoretical problems in ecological and economical terms (see: Barrera Gaytán 2006; Rosset 2008). With respect to the second question, if we consider that a cropping system includes the relationship with the farmer, then pests, weeds or diseases are not the only possible adversities. As the system of reference has no strict limits, it will also be diverse what should be considered as a health problem and what not. For example, if a farmer aims to maximize his/her income and has a single marketing channel, which suffered a drop in the price that threatens economic viability, is this an adversity for the cropping system? In another context, if the purpose of the cropping system is to maximize food self-sufficiency but this is not reached because not enough protein sources are included in the design, are we facing a crop health problem? On another level, if a cropping system meets economic objectives of a farmer, but this is detrimental for the society's food needs, is there a health problem? Analogous to human health, limits for health problems of the cropping systems are fuzzy.

## How can we promote crop health?

Antonovsky (1996) proposed a theoretical construct that he called "sense of coherence" (SOC). The SOC has three main components: (a) the *meaningfulness*, i.e., that the challenge imposed makes sense to the person; (b) the *comprehensibility*, the cognitive aspect; and (c) *manageability*, which is related to the behavior, i.e. the world of actions, what he/she does or can do in response to a challenge. Of course, these components are not suitable to a plant or a plant population, but they are for a cropping system if the relationship with a farmer is included as part of the system.

Alternative approaches discussed above considered the three components of the SOC in different ways. The *meaningfulness* is related to the motivation, objectives, needs and values of the farmers in their agricultural activity, which is proposed by Barrera Gaytán (2006) and Segura et al. (2004). The *comprehensibility* is related to the perceptions, knowledge and experience of the farmer or community of farmers, which is considered by all authors of alternative approaches, in ethnographic studies (Bentley et al. 2009; Bentley and Thiele 1999; Silva and Castaño-Zapata 2014), and the works by Segura et al. (2004), Barrera Gaytán (2006), Vázquez Moreno (2006) and Nicholls et al. (2004). This includes not only the ecological-productive dimension, i.e. the design and management of the agroecosystem, but it can also refer to knowledge linked to forms of marketing, or socio-organizational processes as proposed by Barrera Gaytán (2006). Finally, the *manageability* component is linked with the capacity to organize productive aspects and marketing and with the ability to respond to a problem, which are considered by Barrera Gaytán (2006) within the concept of Holistic Pest Management. This ability to respond can be understood on different time scales, since at the short-, medium- and long-term the responses to health problems can be different. The manageability can also refer to different levels of environmental governance (Jordan et al. 2016) or decision, as demonstrated in various levels studied by Vazquez Moreno (2006) for Cuban agriculture.

All three components are interrelated and conceive health as a process (Figure 3), where the key issue is the ability of the system to recover from disturbances, which can be considered as its resilience (Altieri, Nicholls, and Funes 2012; Alvarez Salas et al., 2014; Nicholls et al., 2015; Ríos Osorio et al., 2009). This is consistent with the theoretical proposals of Döring et al. (2015), who propose resilience as a universal criterion for the concept of health. It is also consistent with the theoretical proposals from agroecology which attribute a central role to resilience (Altieri, Nicholls, and Funes 2012; Álvarez-Salas, Polanco-Echeverry, and Ríos-Osorio 2014; Salas-Zapata 2011).

Extensionists or field technicians that are specialists in plant pathology, plagues and weed management could start incorporating this approach by including in any diagnosis the socio-economic and cultural context of the system. This involves considering the type of farmers and their motivation and values, and rescuing their knowledge and perceptions of the problem/s (Sevilla Guzmán, 2006). Participatory methodologies include the construction of the problem with people. This is in part the beginning of a social-learning process in which extensionist/researchers promote a dialogue of knowledge (Cuéllar-Padilla and Calle-Collado 2011; Freire 1973). It is important to note, that this proposal does not question the importance of these disciplines or the value of the specific knowledge, on the contrary, it intends to give a more comprehensive framework from which the problems of crop health can be addressed. The professional needs to be open to a holistic construction of the crop health problem, because what might seem the problem from a reductionist/conventional framework might not necessarily be the main problem from a holistic point of view. An interesting example is the experience of the entomologist Morales (2009) with Cakchiqueles peasants in Guatemala. When she asked peasants what pest they had, they answered that they had no pests. Insect species that where pests in other systems were present in these systems too, and they were well known by peasants, but they did not reach the problem status for them (Morales 2009). The study of these systems where herbivores, spontaneous plants or pathogens are not a problem for the farmers are an interesting and important subject of research in the field of "crop protection" that can be better understood from a holistic crop health approach.

There are many extensionists, researchers and social organizations that work under these premises for improving crop health. Mainly entomologist (cited above) that worked with peasants in Latin America included interviews in their research or developed participatory methodologies (Segura et al. 2004; Barrera Gaytán 2006; Nicholls et al. 2004; Vázquez Moreno, 2006; Morales 2009). An important example is the "campesino a campesino" (peasant to peasant) methodology, developed by social rural movements in Central America and in Cuba to share technological solutions between peasants through exchange visits between farms (Mier Y Terán Giménez Cacho et al. 2018; Martínez-Torres and Rosset 2014).

## Example of application: tobacco production in Misiones (Argentina)

In this section, a hypothetical study case of crop health is presented to illustrate how the conceptual model proposed here could be applied to a real situation and is more convenient as a guide for professional practice and as a theoretical framework for research. We selected the production system of tobacco in the province of Misiones in northeastern Argentina. The information of the case is hypothetical, because no field data collection has been done, but it is based on bibliography and the experience of the authors in the region based on interactions with local actors.

From the conventional point of view, tobacco crops in the production system of Misiones are healthy. Production is maximized in terms of quantity and quality (complete leaves without symptoms or damages). The problems that arise are infectious diseases, plagues and weeds that are regularly controlled by pesticides. Fertilizers, mainly nitrogen based, are also added to maximize productivity. With this set of technologies crop health is achieved and the commercialized product is acceptable for the industry.

From an agroecological viewpoint, the farmer/s and the context of the system is considered. In Misiones, a humid subtropical province of Argentina, tobacco is produced by peasant communities (Diez 2011). These farms are usually of 20–25 ha and have, apart from tobacco, another highly diversified sub-system based on the low use of external inputs for self-consumption: crops (maize, sorghum, sunflower, yucca and squash), horticulture, small farm animals (chickens, ducks, rabbits, pigs) and cattle for meat and milk production (Sarandón et al. 2006; Figure 4). This sub-system, which integrates plant and animal components, allows the families to have a


**Figure 4.** Tobacco production in peasant communities in Misiones (Argentina). Highly industrialized tobacco crop (a) and diversified sub-system based on a low use of external inputs mainly produced for self-consumption: horticulture (b; c) and yucca and maize crops (d).

diverse diet and to sell some excess production. Tobacco production requires a high amount of external inputs, and provides an important monetary income to the peasant families as well as social security, offered by the company that buys the dried tobacco leaves (Diez 2011; Sarandón et al. 2006). This firm is very powerful in the area and has strong influence on the tobacco production systems of peasants, since it supplies them with pesticides, makes recommendations and controls the quality of the production that it buys (Diez 2011).

Based on our proposal to evaluate crop health, safety, autonomy, adversities and usefulness all need to be considered. Safety is highly affected in this system. The high pesticide load represents a risk for farming families, not only because of their use by people that apply the products, but also water contamination is a risk for human health as peasants rely on local water resources for their domestic use. For the consumer, pesticide is also a risk and increases the toxicity of tobacco, which is toxic itself. The autonomy of the peasant unit is reduced, because of the high dependence on external inputs, provided by only one firm that also buys the production, and the reduced number of the marketing channels of the commercialized product. In contradiction to the conventional viewpoint, biotic adversities are actually an unsolved health problem, which is evidenced by the regular need to use pesticides. Usefulness for the farmers can be considered medium, because in the short term the monetary incomes are increased, but these are not stable in different years, as they depend on market variability and on the demand of the tobacco industry.

To understand health as a process, the meaningfulness (motivation, needs and values), comprehensiveness (construction of knowledge) and manageability can be evaluated. The main factor involved in this tobacco production system is the motivation and the needs of the farmers to have monetary income and social security. This is a central point as it addresses one of the reproduction strategies of these peasants. Many of them are aware of the problems associated with pesticide use, as they express that they intentionally do not use "poisons" for the crops they eat (self-consumption subsystem). Interestingly, peasants have experience and knowledge of how to produce food without pesticides, as the self-consumption subsystem in the farm is radically different in terms of diversification and health management. Finally, manageability is related to socio-organizational skills and ecological processes. They have not been able yet to diversify commercialization channels, not only for tobacco but also for alternative products. In the tobacco subsystem the process of regulation of pest populations is reduced because of mono-cropping, the high use of pesticides that affect natural enemies, and the low soil biological activity associated with the mono-cropping and tillage. All these practices reduce the manageability of biological adversities.

To guide the action of professionals in agroecology in this case, motivation and needs of the farmers as well as their perceptions and values are the central aspect to consider. In order to move towards health, the monetary income of peasant families should be diversified with other crops and/or diversified marketing channels. The perceptions and values of peasants are points of departure for problem solving of tobacco production, using participatory methodologies. By this, we are working on the *meaningfulness*, that the challenge has a meaning and a reason for peasants. The same process involves working on the *comprehensiveness*, the construction of knowledge around the problems of tobacco production and the valorization of their local traditional knowledge. The way of practicing agriculture without pesticides in the self-consumption subsystem should be systematized by different means of educational processes that also valorize this local knowledge. This learning process is a key element of the promotion of crop health. Finally, improving *manageability* implies socio-organizational skills as well as the promotion of ecological processes that reduce the needs of external inputs. The capacity to organize productive aspects and marketing channels for tobacco or alternative products could be addressed by promoting, in the long term, a greater socio-political organization of peasants. The improvement of ecological processes, as population regulation or nutrient cycling for plant nutrition by diversification of the planned biodiversity in the tobacco subsystem, and the improvement of soil health, are also strategies for a greater manageability.

## Conclusions

The conceptual framework proposed here defines crop health in positive and holistic terms and allows integrating the contributions of alternative approaches in the area of crop protection and is consistent with the theoretical-epistemological framework of agroecology. It also provides clear criteria to guide the action in professional practice. The main goal is to promote crop health and for this we need to work with people: value farmer's local knowledge, interact in a collaborative social learning process and look for means to strengthen the natural resource base (i.e. promotion of ecological processes) and collective organization of farmers. In addition, to fully contribute to the diagnosis of a crop health problem, the type of farmer and his/her/their socio-economic and cultural context has to be taken into account (no problem is a problem by itself), and the diagnose includes the identification of the weaknesses and strengths of the system considering its multidimensionality and context.

This approach also provides a comprehensive framework for research, facilitating the identification of key factors promoting crop health from a holistic perspective. It facilitates the study of interrelationships and dynamics of factors belonging to different dimensions. This should be addressed with case studies, which allow revising these concepts in empirical situations. In doing so, an operationalization of these concepts into sets of methodological tools needs to be developed. The sustainability multi-criteria evaluations based on indicators, commonly used in research related to agroecology (Sarandón and Flores 2009; Lopez-Ridaura et al., 2002; Altieri 2002), may serve as inspiration. It would be necessary to develop indicators to assess health status (i.e., a moment in the process of health) and the factors that promote it.

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