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Assessing criteria agroecosystem temheal: a review

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Abstract

Intrusive agriculture development, searching for higher profitability, has inflicted permanent damage to agroecosystems. Rapid deterioration of structure and functional properties in agroecosystems has intensified the need for research on agroecosystem health and agroecosystem management. One of the models proposed recently is the health of agroecosystems. Analysts of agroecosystem health attempt to use the health paradigm to describe and evaluate the state of agroecosystem conditions. While there is considerable ambiguity as to how the health of an agroecosystem could be defined and further analyzed, the model of agroecosystem health does provide new insight into how agroecosystem conditions can be perceived. The assessment of agroecosystem health also represents an insightful advancement from traditional agroecosystem analysis. The theoretical and methodological developments in agroecosystem health assessment can also enhance our capability to understand the complex relationships involved in agriculture.

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Introduction

As ecologists increasingly emphasize the importance of assessment of agroecosystems as holistic systems, ecosystem health has become a hot research field. Nowadays, there are many concepts about ecosystem health. Agroecosystems are of multiple types but need to be seen as holistic, human-centered, highly fluid, and fragile. Agroecosystem health has caused particular concern as we have seen a series of worldwide environmental problem appear as a result of agricultural development. Okey noted that seven system properties lend themselves to a way of doing health interpretation. Five of these stability, resilience, diversity, complexity, efficiency and equality are useful as a basis for defining agroecosystem health (Altieri, 1995). According to Haworth *et al.*, the idea of a healthy agroecosystem is understood from two perspectives. One is the system-functions perspective, identifying the ideal state a healthy agroecosystem would be in that state in which all its health-relevant goals or norms are achieved; the other, the system-goals perspective, identifying the modes of functioning by which the system is enabled to achieve those goals or norms (Okey, 1996). An agroecological framework to achieve crop health through agroecosystem diversification and soil quality enhancement, key pillars of agroecosystem health was provided by Altieri and Nicholls (2003). Also, Xu and Mage focused on assessing the applicability of assorted concepts, norms, and criteria to agroecosystem health assessment and developed a general definition of agroecosystem health, using southern Ontario as a case study to further illustrate the applicability of the developed framework to agroecosystem health research (Xu and Mage, 2001). The present paper aims to provide concepts and interaction between agroecosystem healths and further to establish a science-based agroecosystem health evaluation, so as to provide a basis to support agricultural management and the relevant policy decision making (Zhang and Rao, 2004). The primary objective of this review is to examine the ways by which the health of agroecosystems can be characterized. This review presents a discussion of the concepts of agroecosystem health, and then a working definition of agroecosystem health is proposed with reference to the structural and functional performance of an agroecosystem.

The Concept of Agroecosystem Health

Assessing the health of agroecosystems represents one way of understanding the essential characteristics of the system. Using health as an evaluative norm, agroecosystem health assessment attempts to improve our knowledge about the system's conditions and changes at different spatial and temporal scales. Because of the evaluative nature of agroecosystem health analysis, interpreting the state of agroecosystems is always relative to the way in which the concept of agroecosystem health is defined. Thus, a clear definition of "health" is often necessary so that a meaningful interpretation of health relative to agroecosystem conditions can be reached.

The World Health Organization describes health as one's ability to satisfy needs and realize aspirations, as well as to cope with stresses (WHO, 1992). Waltner-Toews (1994, p. 15) has also made the social context explicit in his definition of agroecosystem health: "The extent to which an agroecosystem is able, on the one hand, to satisfy societal needs for food, employment, and other natural resource products and, on the other hand, to maintain its ability to cope with natural and socio economic stresses placed on it". Agroecosystems are important components of the larger ecosystem. Ecosystem and agroecosystem have homogeneity, while each of them has its own specialty. The main difference between agroecosystems and other ecosystems is its human participation. It is a complex integrated nature-economy-society four-dimensional system (note that they change over time – the 4th dimension-naturally). Therefore, we have to take full account of its characteristics in the process of defining agroecosystem health. We believe that agroecosystem health is an ideal condition in the process of agroecosystem variation with time and space. A healthy agroecosystem can keep itself from sideeffects of occurrence of "disorder syndrome", and it keeps vitality and diversity, coordinating its stability of organizational structure and maintaining high productivity. In non-human external stress, its efficient use of resources can keep the continuous production and service capacity for the entire ecosystem.

Criteria and Approaches to Agroecosystem Health

A Classification Scheme of Agroecosystem Health Criteria

Agroecosystems are complex and open systems. It is possible to take a variety of approaches to analyze the health of agroecosystems. Agroecosystem health can be described according to some essential characteristics of the system; it can be evaluated in terms of established criteria or thresholds of the health state; it can be prescribed using identified desirable goals that the system should achieve; and it can be also predicted based on an understanding of relationships between agroecosystem health change and the driving factors of the change. The multi-dimensional nature of an agroecosystem suggests that the health of one dimension may not necessarily indicate the health of another dimension. Also, the assessment is dependent upon the spatial scale of a defined agroecosystem. The health of an agroecosystem at a lower level of the systems hierarchy does not necessarily mean the health of an agroecosystem at a higher level. This study attempts to describe and assess the agricultural land use change which reflects modifications in the agroecosystem, and to interpret such modifications with reference to the agroecosystem health concept (Conway, 1985).

Structural Criteria

Two aspects of agroecosystem structure are commonly considered. The first is the composition of agroecosystem elements in agroecosystem health analyses. The research focus is on the identification of types and abundance of system components which are critical to the functioning of an agroecosystem, or which are significant structural elements desired by society. The other structural aspect is the distribution or morphology of system elements. The emphasis in research is to investigate their spatial distributions or arrangements which are thought to be supportive of the potential agroecosystem functioning or have a service or amenity value. Many concepts have been employed in assessing and evaluating the structural wellbeing of agroecosystems. In this study, five commonly employed concepts are discussed and appraised as to their utility to agroecosystem health assessment. They are: resource availability, resource accessibility, diversity, equitability, and equity (Saaty, 1980).

Resource availability

Resource availability and accessibility are discussed as descriptive criteria indicating the structural capacity and capability of an agroecosystem in supporting its functioning. The latter three concepts are considered as evaluative criteria capturing the structural characteristics of an agroecosystem desired by our society. Resource Availability refers to the volume of resources necessary to potentially achieve or maintain system functions. Availability describes the existence and capacity of system resource components and indicates the resource potential of agroecosystems. Agroecosystem functions are dependent upon a variety of resources. A certain amount of available resources of various kinds is necessary for the agroecosystem to function at al1 (Gallopin, 1995). Hence, this criterion represents one characteristic of how well an agroecosystem is structured. Furthermore, the importance of resource availability for agricultural production is that it signifies the resource potential for future development. The amount of resources available to an agroecosystem partly determines its capacity to meet the possible expansion of demands for agricultural products, as well as its ability to cope with any environmental change (Wall *et al.,* 1995). Therefore, it is essential to characterize the resource availability in assessing the structural health of an agroecosystem. In light of the concept of agroecosystem health, the interpretation of resource availability is straightforward. An agroecosystem with a higher value of resource availability could be argued to be healthier than the one with a lower value of resource availability, ceteris paribus. There is numerous resource inputs involved in agroecosystems. From a biophysical aspect, land, soil, water, and nutrients are some major biophysical resources necessary for agriculture. Assessing the availability of these biophysical resources can directly indicate the structural state of the biophysical health of an agroecosystem. Agricultural production also requires various resources of socio-economic origins, such as labour, capital, and management skill. The availability of these socio-economic resources is crucial to the production process in agriculture. Hence, resource availability as a criterion is also a valid indicator for describing and assessing the socio-economic health of an agroecosystem.

Resource Accessibility

Resource Accessibility generally refers to the ease with which the system's resources can be accessed and utilized. It depicts another character of agroecosystem structure: the distributive relationship between resource supply and demand. Agroecosystem resource accessibility can be measured in different ways. Generally, it may be measured by examining the distribution of available resources and the locality of resource needs. For instance, people's accessibility to health service in the rural area can be measured by the physical distance between the locations of general health care practitioner and population (Joseph and Bantock, 1984). The importance of resource accessibility is twofold. First, accessibility to various resources and services largely determines how well the economic and social needs within an agroecosystem can be satisfied. Access to health care service in a rural area, for example, is often regarded as a vital component of rural community well-being (Joseph and Bantock, 1985; Smith, 1979). In this sense, accessibility represents one aspect of the structural health of an agroecosystem. Second, an agroecosystem with accessibility to its resources can help maintain its functions over time. When an agroecosystem is under stress, it's normal Functioning fluctuates, and needs to be supported by alternative resources, accessibility become a major determining factor in how well the system is able to adjust to the new situation and maintain its functions. Hence, accessibility as a structural property represents one criterion by which the health of an agroecosystem can be characterized. When an agroecosystem has an easier accessibility to all its resources, the level of system health is higher.

Diversity

The value of diversity for agroecosystem health assessment is that it can depict structural characteristics of an agroecosystem by which the health of the system can be described. Any loss of system diversity indicates dysfunction in an agroecosystem. For example, many studies have provided ecological evidence that the change or loss of ecosystem biodiversity is indicative of potential system dysfunction (Root, 1990). In a socioeconomic context, analysts have argued that a more diversified farming structure and agribusiness are less vulnerable to possible stresses (Napton, 1992). Farm diversification may increase the ability of the system to avoid the economic loss induced by price fluctuation in a market, and to satisfy the societal need for food in a changing pattern of food consumption (Napton, 1992). Furthermore, the value of agroecosystem diversity by itself is a socially desired characteristic for several reasons. Tilman, (1999) state that the biodiversified environment has an inherent aesthetic value which is desired and appreciated by our society. It provides diversified products and services upon which many people depend economically and socio-culturally. It also retains alternative resources for future uncertainty (Tilman,, 1999). Therefore, a more diversified agroecosystem is a more healthy system than a less diversified one, ceteris paribus. Many measures and indices of ecosystem diversity exist in the literature (Tilman, 1999; Goodman, 1975). In ecology, two aspects are central in most diversity measures: number of species and size of population. In agroecosystem analysis, the richness of a system's components and the spatial evenness of the components are commonly used to measure agroecosystem diversity at a hierarchy of scales (Hoag, 1969).

Equitability

Equitability has been defined as how evenly the products of an agroecosystem are distributed among its human beneficiaries (Conway, 1985; Marten, 1988). Conway (1985) claims that equitability can be readily described using distribution parameters of the system's structural components (e.g. land resource distribution among households in a village). From this definition, equitability becomes another measure of the structural distribution of agroecosystem components, which is equivalent to the spatial evenness captured by the concept of diversity. In this sense, the concept of equitability does not offer any utility beyond the concept of diversity. Marten (1988) considers equitability as an agroecosystem property and elaborates on the concept of equitability with respect to the distribution of agricultural products, as well as the access to inputs such as land, capital, or technical information. With this elaboration, his attempt is to derive a concept which captures the structural characteristics of an agroecosystem presented by the concepts of accessibility and diversity. For agroecosystem health assessment, the utility of equitability as a health component of agroecosystems is limited. This is because it mixes together two essential concepts: accessibility and diversity. Equitability is at most a subset or a measure of agroecosystem diversity. Diversity is a much broader notion capturing the structural characteristics of agroecosystems, and is measurable in a hierarchy of scales. It describes spatial and sectoral relationships of different system components. Moreover, the definition of equitability is somehow vague. Conway (1987) uses the same description of equitability for the definition of equity, which is another broad notion in the literature.

Equity

Equity is a normative notion that appears in the discussion of agricultural sustainability. (Burkhardt, 1989). In agricultural sustainability analysis, rather than solely concerning with the structural characteristics of agroecosystems, the equity theme focuses on the protection of rights and opportunity of future generations to derive benefits from resources which are in use today (intergenerational equity), and on the fairness of the distribution of benefits from agriculture between countries, regions or social groups (intra generational equity) (Barbier, 1987; Burkhardt, 1989). In essence, the notion of agricultural equity refers to the distributive fairness of agricultural production among people across space and over time. As a subjective nom, the concept of equity can be accessibility such criteria as accessibility to resources or resource diversity. In this sense, the concept of equity represents a very broad and general notion like the concept of health. The assessment of agroecosystem equity relies on the development of a set of criteria that analysts are striving to derive for agroecosystem health analysis. The above discussion has demonstrated that both availability and diversity possess potential utility for the assessment of agroecosystem health. In particular, these two criteria can also be easily measured in the context of agricultural land use change. Therefore, they will be employed as general criteria for assessing the structural health of the regional agroecosystem in this study.

Functional Criteria

Research into agroecosystem functions mainly concems interactive relationships among various system components. The primary question is how assorted system inputs are together processed to produce agricultural products. The functioning of an agroecosystem is achieved by numerous biophysical and socio-economic processes and these processes have been examined from a variety of perspectives and approaches and at different scales. There are some essential criteria by which various agroecosystem functions can be investigated. At the regional level, commonly used functional criteria include agroecosystem productivity, efficiency, and effectiveness. These concepts represent the essential characteristics of agroecosystem functions. They can be used to show how well an agroecosystem has been doing in carrying out its various functions.

Productivity

Productivity is generally referred to as the output of product per unit of resource input (Conway, 1987). It describes the ability of a system to produce outputs. In ecology, productivity is a term often used to refer to chemical energy transformation. The total amount of chemical energy fixed by an ecosystem per unit area per unit of time is defined as the "gross primary productivity" (Tivy and O'Hare, 1981).

Ecosystem productivity is an essential indicator of the functional performance of an ecosystem. In the context of agroecosystem research, the concept of productivity can provide a meaningful measure as to whether or not an agroecosystem is satisfying societal needs for agricultural products, which is among the key considerations in agroecosystem health research (Gallopin, 1995; Okey, 1996; Waltner-Toews, 1994). While agroecosystem productivity is conditioned by various factors, it does represent one feature which indicates the functional performance or the health of agroecosystems. An agroecosystem with a higher productivity can be considered as healthier than one having a lower productivity, when other conditions associated with the two systems is the same. There are different ways to measure agroecosystem productivity. In general, it is done by some defined output in a given area per unit of time. Relative to agricultural land use, productivity can be measured by the crop yield per unit of cropland or the net income per unit of agricultural land in a defined time period.

Efficiency

Efficiency is another commonly used concept to describe and evaluate the performance of ecosystem functioning. Efficiency is often referred to as the ratio of some defined output or product to the input or cost during the system functioning (Wiegert, 1988). Effectiveness is a concept recently proposed as a criterion for assessing agroecosystem health (Wall *et al.*, 1995; Waltner-Toews and Nielsen, 1995). Waltner-Toews and Nielsen (1995) define effectiveness as the capability of an agroecosystem to meet the reasonable goals of the stakeholder. This concept is closely related to the concept of agroecosystem efficiency, in which the goals of the system are assumed. In the agroecosystem health context, Wall *et al.* (1995) argue that the introduction of effectiveness is to modify or qualify the measurement of agroecosystem efficiency by taking into account the desirability of agricultural outputs. The concept of effectiveness is not derived from ecological analyses. Rather, it is a notion central to the evaluation of public policy and resource management (Mitchell, 1989).

In a general sense, it can be referred to as the adequacy of a system to meet certain requirements or needs through its processing and functioning. In economic analysis, the effectiveness is often assumed as a premise upon which economic efficiency is discussed. This is why the cost effectiveness in a defined economic production system is often a measure of the system's economic efficiency (Samuelson and Nordhaus, 1989). In agroecosystem health analysis, Waltner-Toews and Nielson (1995) argue that the effectiveness criterion explicitly includes the ethical and aesthetic dimensions of human goals and suggest the use of an "overlapping consensus" approach to measure the goals of decision makers in different levels for agroecosystem effectiveness assessment. While this approach seems appealing, they acknowledge that the analysis can become a complex socio-political task. "Effectiveness" is a common criterion used in public policy evaluation, were the goals of public policies are often clearly stated. In the context of evaluation of public policy, the extent to which the policy meets its objective can give an indication of its effectiveness. With this understanding, an agroecosystem can be considered as effective or functionally healthy, as long as it meets its designated goals. Since one of the goals of agriculture is to produce sufficient food for human consumption, one measurement to characterize agroecosystem effectiveness can be derived from assessing the food sufficiency. In conclusion, all three criteria discussed above possess potential utility for the assessment of agroecosystem health. They also represent different aspects of the functional performance of agroecosystems.

Organizational Criteria

The functioning and structuring of an agroecosystem are subject to the influence of various external attributes. Biophysical variables and human attributes beyond an agroecosystem boundary have been recognized as driving factors of the system. These external factors and interactions among them provide a broader environment within which an agroecosystem operates its functions and maintains its structure. They also cause changes in agroecosystem function and structure. One approach to the health of agroecosystems is to assess how decisively those external factor inputs have influenced the function and structure of an agroecosystem. Or alternatively, it is to determine if the self-regulation mechanisms of an agroecosystem dominate the realization of agroecosystem functions and the maintenance of system structure. In essence, the approach is to identify the organizational criteria to assess or evaluate the health of an agroecosystem. Concepts such as integrity, self-organization, autonomy, and self-reliance self-dependence are commonly employed in the literature. Integrity, self-organization and autonomy are the concepts for describing the ability of an agroecosystem to maintain its function and structure through its own regulation mechanisms, white self-reliance and self-dependence are used to describe the extent to which an agroecosystem is dependent upon the external environment.

Integrity

Integrity is often considered as a concept which captures the characteristics of system organization (Kay and Schneider, 1991; Waltner-Toews and Nielson, 1995). While this concept is widely used, particularly in ecosystem research, there is no commonly accepted definition of integrity. Some define integrity as the ability of a system to maintain its organization (Kay and Schneider, 1991). Others consider that a system exhibits integrity if it sustains an organizing, self-correcting capability to recover toward an end-state that is normal and "good" for that system (Regier, 1993). More generally, Waltner-Toews and Nielson (1995) claim that a system has integrity when it maintains its natural, human and economic capital. In essence, system integrity means the wholeness in system functioning. Some analysts have thereby argued that ecosystem health is synonymous with, even a dimension of, ecosystem integrity (Kay, 1990). This is the task that agroecosystem health analysts attempt to undertake (Waltner-Toews *et al.*, 1993).

Self-organization

Self-organization is loosely referred to as the degree to which a system maintains its organization (Kay and Schneider, 1991; Waltner-Toews and Nielson, 1995). The concept of self-organization originated from analyses of physical and chemical systems. The attempt is to understand certain spontaneous behavior when the system is instable or far-from-equilibrium. The self-organizing behavior occurs in open, far-from-equilibrium systems involving nonlinear, autocratic processes, and large flows of energy or matter from outside the system that are dissipated in maintaining its structure. Ecologically, the significance of the self-organization concept is tied to recognition of the chaotic nature of dynamic ecosystems and the role of self-regulation mechanisms in balancing the relationship between the system and environmental attributes. In analyses of ecosystem integrity and agroecosystem health, the concept of self-organization is often considered as a measure or subset attribute of a system's integrity (Wall *et al.*, 1995; Waltner- Toews and Nielson, 1994). Kay and Schneider (1991, p. 13) state explicitly that "(a system's) integrity has to do with its ability to maintain its organization and to continue its process of self-organization. Some have argued that self-organization is an essential attribute of agroecosystem or ecosystem health (Kay and Schneider, 1991; Wall *et al.*, 1995; Waltner-Toews and Nielson, 1995). The utility of the self-organization concept may lie in some qualitative description of "wellness" of agroecosystem organization. However, there is no practical measure of the concept. Furthermore, the meaning of the concept in the context of agroecosystem analysis is not clear at all, and a clarification of the concept is needed if it is to be used as evaluative criteria for agroecosystem health assessment.

Autonomy

Autonomy is another concept which describes a system's organizational identity. The use of this criterion for ecosystem health analysis may be related to the idea that the system has the ability to maintain its function and structure when it possesses "autonomy". The meaning of agroecosystem autonomy is yet to be clarified, although some claim that autonomy is an essential property for assessing the performance of an agroecosystem (Marten, 1988). Marten defines agroecosystem autonomy as the degree of the system's integration. He suggests that agroecosystem autonomy is reflected by the movement of material, energy, and information between its component parts; the movement of materials, energy, and information in and out of the system; and the control of these movements. As he suggests, the utility of the agroecosystem autonomy concept is descriptive. The relationship between the performance of an agroecosystem and the Level of its autonomy is situational.

Self-dependence and Self-reliance

Self-dependence and Self-reliance are two concepts which describe a system's organizational relationship with external environments (Gallopin, 1995). In this sense, they are considered exclusively as interchangeable concepts, and therefore only the meaning and the utility of self-dependence is explored in an agroecosystem context. The concept of self-dependence refers here to the degree to which the system-generated inputs contribute to the accomplishment of its function and the maintenance of its structure. While it is apparently related to the notions of self-organization and autonomy, which emphasize the system's mechanisms to self-regulate its organization, self-dependence is more outward-Looking and focuses on whether or not there are significant external influences on the system's behavior. It stresses that to be self-dependent a system should rely on its own resources and efforts. Generally speaking, a system with a high degree of self-dependence means that the functioning and structuring of the system is not determined by external attributes (Gallopin, 1995).

Various ideas and arguments occur in the literature about the utility of self-dependence in characterizing agroecosystem health. One of those ideas is that the development of agriculture should not excessively depend on human-generated subsidies or damage adjacent ecosystems (Giampietro *et al.*, 1992). Various observations suggest that current agricultural practices depend on massive uses of fossil Fuel energy and human capital (Altieri, 1992; Wilson and Brigstocke, 1980). Agroecosystem self-dependence forms an essential aspect of agroecosystem health, and can be measured in different ways. One possible measure is to consider the level of external inputs used in agricultural production. For example, a high level of chemical inputs in an agroecosystem indicates that the system is greatly dependent upon external resources and therefore possesses a low level of self-dependence and agroecosystem health. Considering the utility of the above organizational criteria and some similarities among them, this study will further explore the applicability of one criterion, self-dependence, to the assessment of agroecosystem health. A practical indicator or measure of self-dependence will be developed and applied.

Dynamics Criteria

The fourth approach to characterizing the health of an agroecosystem examines the system's dynamics. Importantly, when attempts are made to characterize agroecosystem health from a temporal point of view, the system dynamics may themselves provide some indication of the state of agroecosystem health. Such a temporal dimension of agroecosystem health is not necessarily captured by the criteria mentioned earlier. One approach is to directly employ concepts representing the system dynamics as health criteria. Agroecosystem stability, resilience, and capacity to respond are among those considered as the system's dynamic properties. They are often employed to show how the system has changed over time in the face of various stresses (Conway, 1985, 1987; Marten, 1988). Although many analysts have attempted to apply these concepts as central criteria in assessing the performance or health of agroecosystems, interdisciplinary usages of these concepts have led to some ambiguity in the definition of the concepts. Thus, clarifying these concepts will enhance an appreciation of their utility to, and potential for, the assessment of agroecosystem health. Three concepts, stability, resilience and capacity to respond, are discussed in detail in the following sections.

Suability

Suability is one commonly used concept for assessing the dynamics of agroecosystems and ecosystems in general. In the context of agroecosystem analysis, stability is mainly related to the temporal changes in agricultural production. For instance, agroecosystem stability is often loosely defined as the constancy of agricultural production in the face of fluctuations in the biophysical and socio-economic environments (Conway, 1985, 1987; Marten, 1988). It has also been referred to as the steady-state or steady trajectory in agricultural production (Gallopin, 1995). The concept of stability originated from ecosystem analysis, where an ecological system is traditionally described interns of an equilibrium state (Okey, 1996). Despite the debate over definitions of ecosystem and agroecosystem stability, stability indicators can be developed and implemented. Agroecosystems are different from natural ecosystems, and they are composed of socio-economic dimensions. The stable development of agroecosystems represents a societal goal in agriculture. Agricultural stabilization has been the goal of agroecosystem management and public policy initiatives (Pierce, 1993). Hence, from a temporal dimension, agroecosystem stability represents an essential component of agroecosystem health. Defined as production constancy relative to various stresses, the concept of agroecosystem stability describes the dynamic nature of agroecosystem health. In this context, a stable agroecosystem is healthier that an unstable one, ceteris paribus.

Resilience

Resilience, as defined by Holling (1986), refers to the ability of a system to maintain its structure and pattern of behavior in the face of disturbance (Holling, 1973, 1986). It is argued that resilience emphasizes the boundary of a stability domain and events far from equilibrium, high variability, and adaptation to change (Holling, 1986). In the agroecosystem context, resilience refers to the ability of an agroecosystem to cope with natural and socioeconomic stresses (Waltner-Toews, 1994). It is also interpreted as the ability to maintain productivity in the face of stress (Gallopin, 1995). Resilience, although recognized as an agroecosystem property, is similar to stability. Both concepts are pertinent to the maintenance of a system in a changing environment. While stability focuses on the constancy of the structural and functional States of an agroecosystem, resilience describes the system's maintenance ability, or more precisely, the coping mechanisms and strategies of the system. Hence, resilience is related to how the system uses its resources to absorb the external disturbance for maintaining its functionality. According to this understanding, some have suggested the use of resilience as a key component of agroecosystem health (Rapport, 1989, 1995; Waltner-Toews, 1994). Notwithstanding the theoretical appeal of the concept, there are difficulties in implementing the notion of resilience in the practical analysis of agroecosystem health. Few researchers, if any, have proposed a practical measure of resilience. It is also difficult to give a representative description of agroecosystem resilience since little knowledge even exists about the domains of agroecosystem stability and about relationships between the system and its various driving forces.

Capacity to respond

Capacity to respond is one property recognized as an essential element of agroecosystem health in the recent development of agroecosystem health research (Gallopin, 1995; Wall *et al*., 1995). Gallopin (1995) refers to 'capacity to respond' as the ability of the system to react to new situations. He claims that the concept brings into play both the capacity to change and the tendencies towards permanence. This interpretation clearly makes capacity to respond essentially synonymous to resilience. Statements which equate capacity to respond to resilience can also be seen in many ecological writings (Costanza, 1992; Rapport, 1995, 1989), and in agroecosystem health literature (Wall *et al*., 1995). Capacity to respond is also loosely referred to as coping capacity or coping range in the field of impact assessment (Tilman, 1999).

Conclusions

Concerns over the long-term development of agroecosystems are growing. The analysis of agroecosystem health stems from, and contributes to, the emerging body of scholarship relating to research on ecosystem health and sustainable agriculture. As agroecosystem health research is still in its formative stage, concepts and approaches that may have potential utility are scattered in the literature of various research fields. By developing a schematic framework, this review has facilitated the clarification of various concepts, norms, and criteria that seem to have relevance to the study of agroecosystem health. The review has explored the relationships among these concepts according to their commonly used definitions, their contextual bases, and their pertinence to three dimensions of an agroecosystem.

Many concepts possess applicability as general criteria for assessing and evaluating agroecosystem health. For any holistic investigation of agroecosystem health, which is the emerging position of the health paradigm, analysts may need to examine the conditions of agroecosystem health from many aspects of the system including structural, functional, organizational, and dynamic characteristics. Five general criteria are considered as being particularly relevant to characterize the health of regional agroecosystems from a perspective of agricultural land use. They are: resource availability, diversity, productivity, self-dependence, and stability. As indicated, structural criteria are represented by resource availability and diversity; functional criteria by productivity, organizational criteria by self-dependence, and dynamics criteria by stability. In the review, these five general health criteria will be further explored with reference to different aspects of change in agricultural land use. Their practical measurability will be discussed from the land use change perspective.

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