

Health cards for the evaluation of agricultural sustainability

Tarjetas de salud para la evaluación de la sostenibilidad agrícola
Cartões de saúde para avaliação da sustentabilidade agrícola

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ABSTRACT

Agroecosystem Health Cards are handbooks that provide straightforward, practical information on how to assess agroecosystem health through the analysis of a group of aboveground (crop) and, above all, belowground (soil) indicators. In addition, they allow for the assessment of the impact of specific agricultural practices on agroecosystem health. The main objective of these Agroecosystem Health Cards is to provide farmers and other stakeholders related to agroecosystem management (technical staff, scientists and administration staff) with a practical tool that allows them to evaluate the impact of agricultural practices on agroecosystem health by themselves, so that they can choose those management options that prove to be more sustainable. To this purpose, these Agroecosystem Health Cards explain which health indicators can be measured, how to do it properly, the meaning of the different indicators and, finally, the reference values considered “good”, “medium” and “bad”. Indicators are divided into two categories (basic and advanced) in order to carry out a basic and advanced diagnosis of health, respectively, depending on the interests and possibilities of the user.

RESUMEN

Las Tarjetas de Salud de los Agroecosistemas son manuales que explican de manera sencilla y práctica cómo puede realizarse un diagnóstico global del estado de salud de los ecosistemas agrícolas, a través del análisis de una serie de indicadores a nivel superficial (cultivo) y, sobre todo, subterráneo (suelo). Asimismo, nos permiten valorar el impacto de una determinada práctica agraria en la salud de los agroecosistemas. El objetivo fundamental de las Tarjetas es dotar a los agricultores y demás agentes implicados en la gestión de los agroecosistemas (técnicos, científicos y administración) de una herramienta práctica que les permita evaluar por sí mismos el impacto de sus prácticas agrícolas sobre la salud de los agroecosistemas, pudiendo así optar por aquellas alternativas de manejo que demuestren ser más sostenibles. Para ello, estas Tarjetas detallan qué indicadores de salud se pueden medir, cómo hacerlo correctamente, el significado de los diferentes indicadores y, finalmente, los valores de referencia considerados “buenos”, “regulares” y “malos”. Los indicadores se dividen en dos categorías (básicos y avanzados) que permiten realizar un diagnóstico de salud “básico” o “avanzado”, respectivamente, en función de los intereses y posibilidades del usuario.

RESUMO

Os Cartões de Saúde dos Agroecosistemas são manuais que fornecem informação de forma prática e simples sobre como avaliar a saúde global de um agroecosistema através da análise de indicadores de superfície (culturas) e, principalmente, indicadores subterráneos (solo). Além disso, os indicadores permitem a avaliação do impacto de práticas agrícolas específicas na saúde dos agroecosistemas. O principal objetivo destes cartões é o de proporcionar aos agricultores e outros intervenientes relacionados com a gestão dos agroecosistemas (pessoal técnico, cientistas e

pesoal de administração) uma ferramenta prática que lhes permite avaliar o impacto das práticas agrícolas na saúde dos agroecossistemas por si só, por forma a que possam escolher as opções de gestão que provem ser mais sustentáveis. Para o efeito, estes cartões definem quais os indicadores de saúde que podem ser medidos, como fazê-lo corretamente, o significado dos diferentes indicadores e, finalmente, os valores de referência considerados como "bom", "médio" e "mau". Os indicadores são divididos em duas categorias (básica e avançada), a fim de levar a cabo um diagnóstico básico e avançado da saúde, respectivamente, de acordo com os interesses e possibilidades do utilizador.

1. Introduction

Soils perform a wide variety of functions, allowing them to provide different ecosystem services from an environmental, economic, social and cultural point of view, including plant biomass production; storage, transformation and filtering of substances; habitat and genetic reservoir; potential carbon sink; and physical and cultural environment for humanity, among others (Larson and Pierce 1994).

Nonetheless, agricultural soil is being degraded at an alarming rate (Steiner 1996), especially taking into consideration the current human population growth rate and the associated increasing demand for food production.

Not surprisingly, in the last decades, *soil health/quality* (both terms are often used interchangeably to describe the soil's ability to support crop growth without becoming degraded or otherwise harming the environment) has become an issue of the utmost importance (Doran and Parkin 1994; Garbisu et al. 2011). In this respect, good, reliable indicators are essential for measuring the impact of agricultural practices on soil health.

The aim of this work was to develop Agroecosystem Health Cards as a tool for the assessment of the impact of agricultural practices on four ecosystem services (crop production, biodiversity conservation, soil conservation and combating climate change). The intention of producing this document is to present and make available for those interested the Agroecosystem Health Cards. The ultimate goal of these Cards is to provide farmers and other stakeholders related to agroecosystem management with a practical tool that allows them to evaluate the impact of agricultural practices on agroecosystem health by themselves, so that they can choose those management options that prove to be more sustainable.

Our Agroecosystem Health Cards are handbooks that provide straightforward, practical information on how to assess agroecosystem health through the analysis of a group of aboveground (crop) and, above all, belowground (soil) indicators. Relevantly, they allow a quantitative assessment of the impact of agricultural practices on agroecosystem health. Our Agroecosystem Health Cards have been specifically designed for horticultural and cereal producing agroecosystems; besides, interpretation reference values have been set for the specific edafoclimatic conditions of Aquitania (France) and the Basque Country (Spain) and then cannot be directly extrapolated to other regions or crops.

KEY WORDS
Agricultural practices, indicators, soil health, soil quality

PALABRAS CLAVE
Prácticas agrícolas, indicadores, salud del suelo, calidad del suelo

PALAVRAS-CHAVE
Práticas agrícolas, indicadores, saúde do solo, qualidade do solo

2. Agroecosystem Health Cards creation process

Initially, several meetings between farmers, scientists and other stakeholders helped to clarify the goals and relevant questions, with special emphasis on the list of soil health indicators to be included in the Agroecosystem Health Cards. Then, researchers from NEIKER-Tecnalia (Basque Institute for Agricultural Research and Development, Spain) elaborated a draft version that was later subjected to discussion with farmers and other stakeholders in order to improve them. This strategy was repeated six times until we agreed on a final version of the Cards.

Subsequently, the Cards were applied to different farms in an attempt to obtain quantitative reference values for the different agroecosystem health indicators. To this purpose, samples were taken in 18 farms located in Aquitania (France) and the Basque Country (Spain), covering from conventional cereal farms to organic/ecological farms. Interpretation reference values were based on the specific results obtained during the application of the Cards to these farms, although they were later adapted following expert judgement in the different meetings abovementioned. In particular, our Cards answer the following questions:

What indicators must be measured?

Figure 1 shows the indicators included in our Cards for a basic and advanced diagnosis of agroecosystem health, as well as results from a case study. In our Cards, information is included to understand not only the meaning of each specific indicator but, importantly, the variety of ecosystem services provided by a healthy soil, together with recommendations on sustainable agricultural practices aimed mainly at soil conservation. Both basic and advanced indicators are grouped into four ecosystem services delivered by healthy agroecosystems (crop production, biodiversity conservation, soil conservation and combating climate change), in order to facilitate interpretation by decision-takers and, above all, provide stability to long-term monitoring programs against changes in methods, parameters, etc.

The basic diagnosis can be carried out by any person, without any special training or qualification, simply by following the instructions provided in the Cards and using homemade tools and equipment. There are some basic indicators that are considered indispensable: crop production, pests, crop diversity, macrofauna diversity, soil compaction, number of earthworms, organic matter content and production system used. For a more comprehensive assessment of agroecosystem health (advanced diagnosis), a number of advanced indicators, which require more sophisticated equipment and prior training and qualification, have to be measured. Some of these advanced indicators are: structural and functional community profiles for soil bacteria and fungi (e.g., through community-level physiological profiles with Biolog™ plates and genetic profiles with ARISA), soil physicochemical properties (e.g., organic matter content, total nitrogen, Olsen phosphorus, extractable potassium) and CO₂ emissions from soil.

In our Cards, many microbial indicators of soil health have been included due to the fact that soil microbial properties, particularly those related to the biomass, activity and diversity of soil microbial communities, have been reported as very useful indicators of the impact of disturbances on soil health (Epelde et al. 2009; Muñoz-Leoz et al. 2011). Indeed, microorganisms, especially bacteria and fungi, form the majority of the soil biomass and biodiversity and are responsible for providing many of the soil ecosystem services on which human society relies (Gómez-Sagasti et al. 2012). In particular, soil microorganisms have key functions in the decomposition of organic matter, nutrient cycling, nitrogen fixation, maintenance of soil structure, detoxification of contaminants, etc. (Reichle 1977). Furthermore, microorganisms respond quickly to changes in the soil ecosystem and have intimate relations with their surroundings due to their high surface to volume ratio (Nielsen and Winding 2002).

How to measure them properly?

As a general rule, measurements must be carried out, on a yearly basis, under similar conditions, since soil properties (especially, biological properties) can vary significantly depending on

temperature, humidity, agricultural practices, etc. In our region, a recommended time for measurement/sampling is just before autumn or spring harvest, when temperatures are milder and tillage and other agricultural practices were applied long ago.

When possible, measurements should be taken 2 to 3 days after a significant rainfall to avoid the soil being either too wet or too dry. It is important to avoid very hot or cold days, as this might affect the activity of soil organisms. In addition, soil samples must be taken between crop lines and

avoiding irregularities. It is important to always measure the indicators in the same way (same person, same technique, same hour of the day, etc.) to increase the reliability of the diagnosis. If different areas can be visibly identified in the plot (in terms of vegetation, slope, humidity, etc.), they must be assessed separately.

What is the meaning of the indicators and how should we interpret the obtained values?

It is essential that the users of the Cards understand the meaning and fundamental

Ecosystem services	Basic Indicators	Bad 0...3	Medium 3...7	Good 7...10	Indicator value (0-10)	Service value (0-10)
1. Crop production	1.1. Crop production (g/plant) *	See AHC	See AHC	See AHC	6	6.3
	1.2. Pests (% healthy plants) *	0-45	45-85	85-100	6.5	
2. Biodiversity conservation	2.1. Crop diversity (n° species) *	0-3	3-7	7-10	10	7.3
	2.2. Plant diversity (n° strata)	1	2	3	8.5	
	2.3. Invasive species (n° species)	2	1	0	8.5	
	2.4. Soil macrofauna diversity (n° types) *	0-6	6-14	14-20	7	
	2.5. Soil mesofauna diversity (mesofauna index)	0-30	30-70	70-100	5	
3. Soil conservation	3.1. Erosion (gaining soil vs. losing soil) (cm)	(-3.5)-(-2)	(-2)-0	0-(+1.5)	-	8.4
	3.2. Infiltration time (min)	60-30	30-10	10-0	9.7	
	3.3. Compaction (cm) *	0-10	10-20	20-40	7.8	
	3.4. Acidity/Alkalinity (pH)	3-4.5 or >9 None or very strong	4.5-5.5 or 8-9 Mild or strong	5.5-8 Medium	7.6	
	3.5. Organic matter (reaction and colour)	None Pale	Mild Medium	Strong Dark	8.5	
	3.6. Mineral nutrient (colour)	Pale or abnormal	Medium	Uniform and dark	7.5	
	3.7. Pesticides (use)	See AHC	See AHC	See AHC	10	
	3.8. Biological activity (% degradation)	0-10	10-20	20-40	-	
	3.9. Earthworms (n°) *	0-3 or >20	3-7 or 10-20	7-10	10	
	3.10. Root (development)	Shallow	Medium	Deep	8	
4. Combating climate change	4.1. Organic matter (reaction and colour) *	None Pale	Mild Medium	Strong Dark	8.5	8.3
	4.2. Production system (gaining C vs. losing C) *	See AHC	See AHC	See AHC	8	
BASIC HEALTH DIAGNOSIS						7.5

Ecosystem services	Advanced Indicators	Bad 0...3	Medium 3...7	Good 7...10	Indicator value (0-10)	Service value (0-10)
1. Crop production	1.1. Crop production (t/ha)	See AHC	See AHC	See AHC	6	6.3
	1.2. Pests (% healthy plants)	0-45	45-85	85-100	6.5	
2. Biodiversity conservation	2.1. Crop diversity (species-varieties)	0-3.2	3-7.5	7.5-11	10	5.6
	2.2. Plant diversity (n° species)	0-9	9-21	21-30	10	
	2.3. Fungal functional diversity (NUS)	0-10	10-40	40-95	5.9	
	2.4. Bacterial functional diversity (NUS)	0-10	10-20	20-31	6.6	
	2.5. Fungal genetic diversity (S)	0-10	10-30	30-50	3.6	
	2.6. Bacterial genetic diversity (S)	0-10	10-30	30-50	6.4	
3. Soil conservation	3.1. Water storage (%)	0-9	9-21	21-30	4.7	7.0
	3.2. Compaction (Mpa)	4-2.5	2.5-1.5	1.5-0	7.3	
	3.3. Acidity/Alkalinity: pH Al Active limestone	3-4 or >9 Al >10% Ca >5%	4.5-5.5 or 8-9	5.5-8 Al <10% Ca <5%	9.7	
	3.4. Organic matter (%) C/N ratio	0-1 or >8 <4 or >14	1-2 or 8-4 4-8 or 10-14	2-4 8-10	6.6	
	3.5. Minerals (N, P, K)	See AHC	See AHC	See AHC	5	
	3.6. Salinity (dS/m)	9-3	3-1	1-0	10	
	3.7. Pesticides/pollutants (ppm)	See AHC	See AHC	See AHC	-	
	3.8. Microbial activity (ppm C-CO ₂ /h)	0-0.6	0.6-1.4	1.4-3	6.2	
	3.9. Microbial abundance (ppm C-CO ₂ /h)	0-6	6-18	18-36	5.9	
	3.10. Respiratory quotient (qCO ₂)	0.6-0.2	0.2-0.1	0.1-0.05	7.7	
4. Combating climate change	4.1. Organic matter (%)	0-1	1-3	3-6	6.9	7.5
	4.2. CO ₂ emissions (gCO ₂ /m ² h)	0.9-1.2	0.5-0.9	0.2-0.5	8.2	
ADVANCED HEALTH DIAGNOSIS						6.6

Figure 1. Basic and advanced diagnosis of agroecosystem health (indicators and ecosystem services). Results from a case study are included. * Indispensable indicators that must always be measured. See AHC = see information provided in the Agroecosystem Health Card for that specific indicator.

principles of soil health indicators and, in general, agroecosystem health assessment.

After measuring each indicator, we have to compare our results with the quantitative interpretation values provided in the Agroecosystem Health

Cards (**Figure 1**). In this way, we can find out to what qualitative category our results belong to: bad, medium or good health category. In addition, we must assign a score from 1 to 10 to our results (indicator value). This can be done by means of establishing linear relationships

between extreme reference scores and our values. In the case study provided (see Indicator Values in **Figure 1**), it can be seen that the only indicators that obtained a score below 5 were fungal genetic diversity and water holding capacity.

The mean value of all indicators included in a particular ecosystem service indicates to what extent our agroecosystem can provide that specific ecosystem service (ecosystem service value from 1-10). In the case study provided (see Services Values in **Figure 1**), all the ecosystem services showed scores above 5.

A value of overall agroecosystem health (from 1-10) can be obtained by calculating the mean value of all measured ecosystem services. It must be taken into consideration that a healthy agroecosystem is expected to properly provide all the essential ecosystem services listed in the Cards. Therefore, if we obtain a low value for a specific ecosystem service, the agroecosystem cannot be claimed to have a good overall health, independently of the mean value obtained from all the ecosystem services included in the Cards.

When all the indicators listed in the Cards cannot be measured, the same calculations can be performed. However, this might affect the reliability of the diagnosis. The objective should be to observe temporal trends (i.e., how indicator values improve or get worse from year to year).

Finally, our Cards provide some general information on recommended changes and agricultural practices (such as, for instance, liming, organic amendment, no-tillage, crop rotations, etc.) when facing a bad diagnosis. For a more detailed set of recommendations for each specific case, we suggest contacting experts at NEIKER-Tecnalia or similar centres.

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4. Supplementary material

Agroecosystem Health Cards (in Spanish).

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