Assessing the agroecological status of a farm: a principle-based assessment tool for farmers

Estimando el nivel agroecologico de una finca: una herramienta de evaluacion para agricultores

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A B S T R A C T

Although there are many methodologies available to assess agroecosystem performance (sustainability, resilience, soil quality and plant health, biodiversity levels, etc.), there is still a need to develop a methodology to be used at the field level by researchers and farmers to assess if surveyed farming systems are or not based on agroecological principles. Developing such practical tool is key to determine if farmers in transition are on the right agroecological path. To fulfill this need for a farm-level assessment, a methodological tool was developed and tested with the participation of nine Japanese farmers in three prefectures (Kyoto, Hiroshima and Hyogo). The methodology consists of two parts. The first is a simple and rapid assessment survey based on the grading of eight indicators that match practices used by farmers with agroecological principles. The second part uses the same indicators to define a "threshold level", below which it is estimated that a farm system is not yet "agroecologically based." This process enables farmers to reflect and use the tool as a guide to adopt or adjust their practices based on agroecology principles, by changing farm design and management, in order to further optimize the performance of their agroecosystems.

RESUMEN

Aunque existen muchas metodologías disponibles para evaluar el desempeño de un agroecosistema (sostenibilidad, resiliencia, calidad del suelo y salud de las plantas, niveles de biodiversidad, etc.), aún es necesario desarrollar una metodología para ser utilizada a nivel de campo por investigadores y agricultores para evaluar si los sistemas agrícolas encuestados se basan o no en principios agroecológicos. El desarrollo de dicha metodologia es clave para determinar si los agricultores en transición están en el camino agroecológico correcto. Para satisfacer esta necesidad, se desarrolló y probó una herramienta metodológica con la participación de nueve agricultores japoneses en tres prefecturas (Kyoto, Hiroshima y Hyogo). La metodología consta de dos partes. La primera es una encuesta de evaluación simple y rápida basada en la calificación de ocho indicadores que permite evaluar si las prácticas utilizadas por los agricultores coinciden con los principios agroecológicos. La segunda parte utiliza los mismos indicadores para definir un "umbral", por debajo del cual se estima que un sistema agrícola aún no está "basado en la agroecología". Este proceso permite contextualizar la herramienta para permitir que los agricultores reflexionen y utilicen la herramienta como guía para adoptar o ajustar sus prácticas basadas en los principios de la agroecología, instándolos a cambiar el diseño y el manejo de la finca, a fin de optimizar la función del agroecosistema.

Palabras clave: Agroecologia, principios, umbral, indicadores, evaluacion rapida de granjas.

INTRODUCTION

Today, agroecology has become a popular term to describe an array of farming systems that embrace many production forms: organic, natural farming, zero budget, permaculture, biodynamic, regenerative agriculture, etc. (Gonzalez *et al.,* 2020). Most of these systems emphasize practices that span from elimination of synthetic pesticides, fertilizers and transgenic crops, using alternative biological, microbial and botanical inputs as well as specific preparations or concoctions; to systems that recommend the use of local varieties, crop/animal diversification schemes, rotations and recycling of biomass and on farm resources, etc., in an effort to maximize autonomy (Van der Ploeg, 2014). While agroecology is considered an inclusive term, as a science and movement that work towards more ecologically sound and socially just forms of agricultural systems, it is important to be able to question whether some of these farming methods, considered by many practitioners and researchers as agroecological forms of production, are indeed agroecological. In many instances, it remains unclear if they are so, as most do not necessarily apply all the principles of agroecology. For example, a small-scale peasant system may be diverse and use low input practices, but crop mixtures used may not be synergistic, and there may be limited recycling of organic matter, which are two key agroecological principles that they therefore lack in their practice. Similarly, although a biodynamic or organic farm may closely follow the precepts of their founders and certification standards, many rely on monocultures using an input substitution approach and therefore are not based on agroecology (Rosset and Altieri, 1997). On the other hand, development cooperation actors such as NGOs, UN-FAO, government agencies and academic institutions which have adopted, and often co-opted, the concept of agroecology, are using it interchangeably with sustainable intensification, regenerative agriculture, climate smart agriculture, without explaining their particular perspective on agroecology (Kapgen and Roudart, 2020) thus adding to the confusion on the various competing narratives about agroecology (Rivera-Ferre, 2018; Giraldo and Rosset, 2018).

In agroecology, productivity, sustainability and resilience are achieved by breaking monocultures via enhancement of diversity and complexity in farming systems in which ecological interactions and synergisms between its bio-physical components replace external inputs to provide the mechanisms for sponsoring soil fertility, productivity, and crop protection. By enhancing functional biodiversity in farming systems, a major goal of agroecology is to strengthen the weak ecological functions in the agroecosystem, allowing farmers to gradually eliminate their reliance on external (organic or conventional) inputs altogether, relying instead on ecosystem functions (Nicholls *et al.,* 2016; González-Chang *et al*., 2020).

We contend that simply implementing a narrow set of practices (rotations, composting, cover cropping, etc.) does not make a system "agroecological". Agroecologically based systems emerge from the application of already well defined agroecological principles which include recycling of nutrients and energy, enhancing soil organic matter and soil biological activity, diversifying plant species and genetic resources over time and space at the field and landscape level, integrating crops and livestock, and optimizing interactions of farm components. The application of these principles moves farmers toward the productive redesign of their farms, emphasizing synergisms within the system and reducing their dependence from external inputs, an attractive shift for smallholder producers who cannot afford expensive off-farm resources and technologies (Rosset and Altieri, 2017).

Many researchers have proposed methodologies to assess agroecosystem performance, but most focus on particular properties such as estimating farming system sustainability (López-Ridaura *et al.,* 2002), soil quality and plant health (Nicholls *et al.,* 2004), agrobiodiversity levels (Leyva and Flores, 2018; Vazquez, 2013), food, energy and technical sovereignty (Casimiro *et al.,* 2017), resilience to climate change (Altieri *et al*., 2015) and the recent FAO's Tool for Agroecology Performance Evaluation (TAPE), which characterizes and evaluates the process of agroecological transition, based on their own broadly defined "elements" of agroecology (FAO, 2019). While we recognize that agroecology has necessarily grown to integrate social and economic dimensions of the entire food system, as initially elaborated by Francis *et al*. (2003), our methodology is geared to specifically assess if the design and management of a farm matches agroecological principles. The framework presented by Kapgen and Roudart (2020) is useful to add clarity and avoid misuse of the term agroecology among people in academia and development circles, but it does not offer a practical tool for farmers and practitioners involved at the field level to assess if the target production systems are agroecologically based or not. Furthermore, developing practical tools to assess farming systems is key to determine if farmers in transition are on a path based on agroecological principles.

To fulfill this need for farm-level assessment, a methodological tool was developed and tested with the participation of nine farmers in three prefectures (Kyoto, Hiroshima and Hyogo) in Japan. The methodology consists of two parts. The first is a simple and rapid assessment survey based on eight indicators to evaluate to what extent a farm pursues different agroecological principles. The second part uses the same indicators to define a "threshold level", below which it is estimated that a farm system is not yet "agroecologically based." The tool not only enables a contextualized assessment but, perhaps more importantly, creates a process where it enables farmers to reflect and use the tool as a guide to adjusting their practices following agroecology principles, leading to changes in farm design and management, thus optimizing agroecosystem performance.

METHODS

Surveyed farmers

The tool was used, as part of a pilot survey on nine farms in May 2019 in West-central Japan. Five farmers were located in Kyoto prefecture, three in Hiroshima prefecture, and one in Hyogo prefecture. All farms self-identified as either organic or following natural farming precepts, while only one was certified as organic. All farmers were male of ages ranging between 35–60, with at least 5 years of farming experience, with some more established (10–20 years). Rarely farmers involved their families in the daily operations. The farmers predominantly rented their land (average farm size 1.5 hectares). All farmers were self-employed, specializing in vegetable production for urban consumers, thus the majority of their total income came from their farm.

These farms were selected because they were considered 1) leading examples of farmers practicing organic, natural or other non-conventional methods of production, 2) accomplished or highly capable farmers in each community and 3) representative farmers of Western Japan, which is a mountainous region where small-scale practices prevail, unlike North-eastern Japan characterized by larger-scale monoculture production. It is important to note that these Japanese farmers practiced natural farming and did not self-identify as agroecological – in fact, many had never heard of the term agroecology. Lack of familiarity with agroecology was not an intended criterion in sampling these farms, it serves to demonstrate the tool's applicability to evaluate a range of farming systems.

Agroecological rationale for the methodology

We consider that, at the farm level, a farming system may be considered "agroecologically based" if it implements established agroecological principles in the design and management of the agroecosystem. As depicted in Figure 1, the agroecological principles listed in Table 1 guide the spatial and temporal design of a farm taking the form of different practices (i.e. intercropping, cover cropping, etc.) which, in turn, set in motion key ecological processes (nutrient cycling, pest regulation, etc.). For example, variety mixture is a known strategy to reduce disease incidence through the buffering effects of genetic diversity (Zhu *et al.,* 2000). Intercropping is a commonly applied management practice to enhance functional biodiversity, contributing to all principles in agroecology with multiple benefits (Vandermeer, 1989). Cover cropping is also a practice that reflects principle 1 (recycling) and 3 (organic matter accumulation) and promotes processes such as nutrient cycling, soil biological activation, weed suppression and water conservation, which are key for crop productivity and soil health (Buckles *et al.,* 1998). In this way, the methodology described herein uses indicators to assess how effectively practices aimed at improving landscape and crop diversity, soil quality, plant health, etc., pursue specific or a combination of principles thus promoting vital processes for agroecosystem performance.

The goal of the methodology is to determine if a farming system is based on agroecology, by providing a set of indicators that farmers apply through a series of field observations and simple measurements. After ranking the indicators, farmers can assess the degree to which agroecological principles are being implemented in their farms through the practices they use in the design and management of their farming systems.

Table 1. Agroecological principles for the design of biodiverse, energy efficient, resource-conserving and resilient farming systems.

Cuadro 1. Principios agroecológicos para el diseño de sistemas agrícolas biodiversos, eficientes desde el punto de vista energético, conservadores de recursos y resilientes.

1.	Enhance the **recycling of biomass**, with a view to optimizing organic matter decomposition and **nutrient cycling** over time.
2.	Strengthen the "immune system" of agricultural systems through **enhancement of functional biodiversity** – natural enemies, antagonists, etc., by creating appropriate habitats.
3.	Provide the most favorable **soil conditions** for plant growth, particularly by managing organic matter and by enhancing soil biological activity.
4.	**Minimize losses** of energy, water, nutrients and genetic resources by enhancing conservation and regeneration of soil and water resources and agrobiodiversity.
5.	**Diversify species and genetic resources** in the agroecosystem over time and space at the field and landscape level.
6.	**Enhance beneficial biological interactions and synergies** among the components of agrobiodiversity, thereby promoting key ecological processes and services.

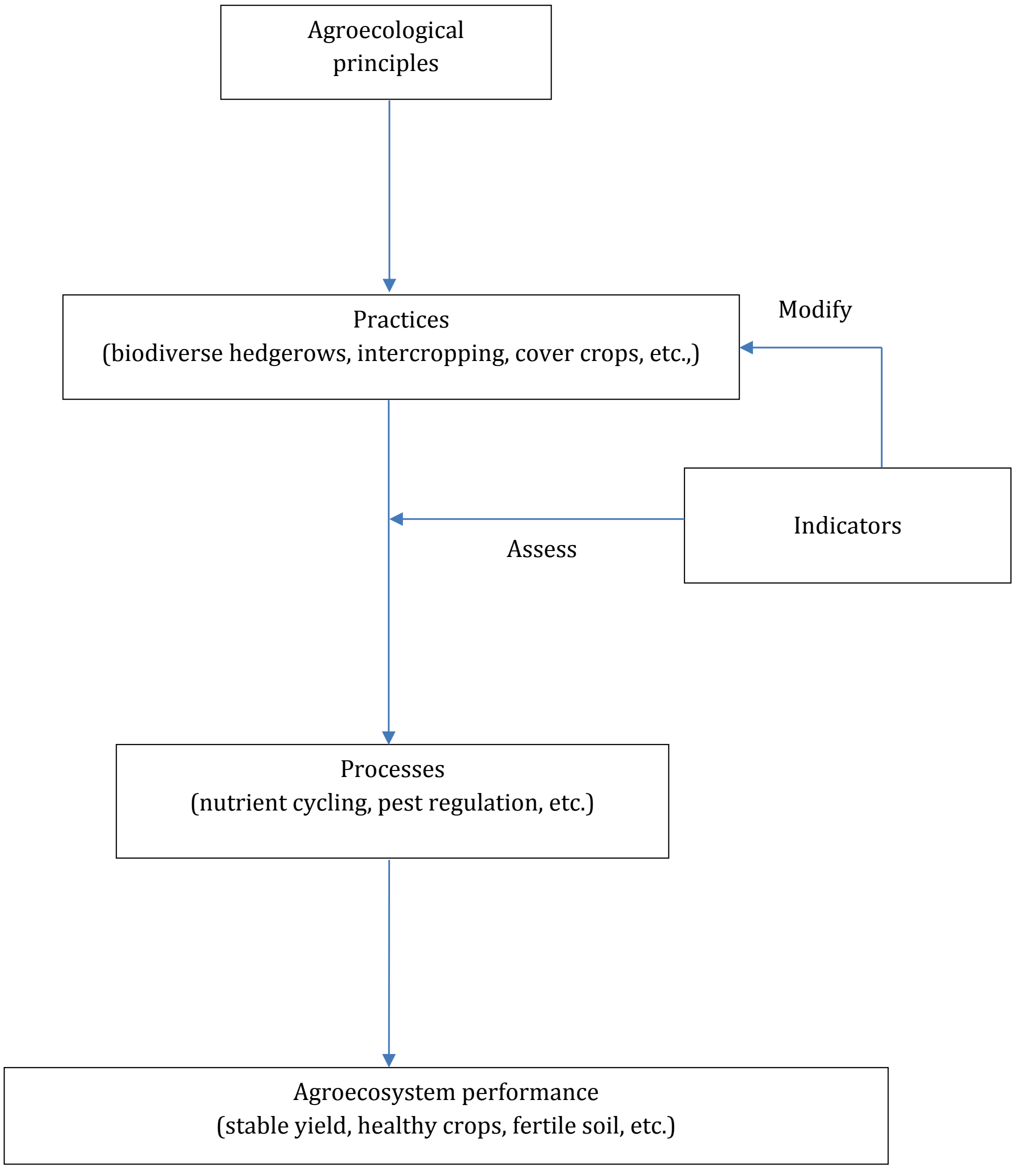

Figure 1. Application of the indicators to assess if practices used by farmers optimize agrooecological processes key for agroecosystem performance.

Figura 1. Aplicación de los indicadores para evaluar si las prácticas utlizadas por los agricultores optimizan procesos agroecológicos claves para el funcionamiento de los agroecosistemas.

On-farm assessment

Through a semi-structured interview approach, data was collected during the surveys to include farm size, land tenure, market outlets for produce, labor, number of crop species and varieties grown in time and space, soil and pest management practices as well as observations of the landscape matrix surrounding the farms. After a general exchange with farmers, covering basic information about each farm, farmers were encouraged to talk freely about their farm and how it is managed, how it has changed over time, identifying any events that could be seen as triggers towards a transition in their approach to farming through various stages. Farmers were also asked to recall important decisions and problems encountered during these transition processes. During the interviews, the team conducted field transects together with the farmers to observe and describe farm features such as landscape matrix, crop diversity, soil quality, plant health, etc. All the information was used to rank the indicators used in the two-part methodology described below. The application of this rapid assessment tool takes about 2–3 hours per farm. Farmers participation in the selection of appropriate indicators, and in defining common criteria on how to rank each indicator is of key importance.

Assessing level of application of agroecological principles

This methodology, inspired by previous efforts to estimate soil quality and plant health in farming systems (Nicholls *et al.,* 2004), was designed to rapidly assess to what extent each surveyed farmer was applying agroecological principles to the design and management of his/her farm. The indicators, described in Table 2, distill the essential dimensions of the six agroecological principles (Table 1), but also include a measure of autonomy and overall yield performance as these are key criteria to determine the integrative effect of principle application. Emphasis on observable diversity (landscape, crop, genetic), soil quality, plant health and managerial decisions reflect the indicators ability to rapidly assess the intentionality of a farm design and management regime to align with agroecological principles. The indicators were assessed and ranked individually and assigned a value between 1 and 5, according to the criteria described for each indicator in Table 2 (1 being poorest performance, 2.5 a moderate or medium value and 5 indicating high performance).

As the purpose of this study was to test the application of the rapid assessment methodology, the research team pre-defined the details associated with each criterion on how to rank each indicator. Therefore, the quantitative values to rank each indicator, although based on farmers responses and close to the reality we observed, are used as a mode of illustration. The optimal way is, of course, to engage in a participatory process with all farmers (process that we did not pursue due to lack of time) to be surveyed to determine the criteria for each indicator and make them more appropriate for local contexts.

Once the indicators are applied, each farmer can visualize, in an amoeba diagram, how they are applying the agroecological principles overall. As measurements are based on the same indicators, the methodology can allow quick comparisons to reveal differences between farming systems in terms of the degree of transition towards an agroecological optimum, theoretically defined by the outer circle with indicator values of 5. This visualization can further allow farmers to monitor their own transition in the same agroecosystem over time.

Determining agroecological thresholds

Using the same indicators and criteria for measuring the application of agroecological principles, the goal of this methodology is to determine a threshold level specified for each indicator, a level that denotes the boundary between values that determine if an agroecological principle is being applied or not. This method draws from the farm sustainability threshold methodology proposed by Gomez *et al.* (1996).

This assessment entails the participation of farmers to define the threshold level of each indicator. In this case, the team was able to derive enough relevant information to establish thresholds from seven out of nine farmers through the interviews. Each agroecological indicator is set at an acceptable level if it exceeds the designated threshold level given in Table 3, which describes the threshold levels and the formulae to calculate them for the agroecological indicators used in the assessment. The threshold levels are tentatively set as improvements on the farmers averages, and indicators are expressed as units of their respective threshold levels, where one equals the threshold (Gomez *et al.*, 1996). On this basis, a farming system is not based on agroecological principles if the average of all the indicators is less than one.

RESULTS

Practices used by surveyed farmers

A step in the assessment is to observe the practices that farmers implement to optimize productivity. All surveyed farmers used a series of management practices aimed at enhancing soil fertility, reducing insect pests, weeds and disease incidence, while increasing crop yields (Table 4). All the farms were located in rural areas predominantly surrounded by natural vegetation. However, the ecological matrix was not the result of intentional enriching of the landscape, but a result of abandonment due to depopulation and undermanagement common throughout Japan. Although farmers favored crop diversification, most had two to three different crops in alternate rows, and only one used intercropping techniques. Along the same line, although farmers planted a number of local as well as improved varieties of the same crop species in alternate rows, only two farmers practiced crop variety mixtures. All farms, however, exhibited temporal diversity, as farmers practiced crop rotations to minimize replant failure, but also as a response to Japan's distinct seasons alongside market demands. Despite the fact that most farmers included legumes in their rotations as green manures, the majority relied on purchased compost or other types of organic amendments from external sources. Only three farmers actively used locally available litter from surrounding forests, thus minimizing their dependence from external biomass inputs. The prominent use of plastic mulch for weed and microclimate control among farmers in Japan is an expensive practice with waste disposal challenges. While plastic mulch minimized the drudgery of weeding, there was

Table 2. Indicators and evaluation criteria to assess level of application of agroecological principles in surveyed Japanese farms.
Cuadro 2. Indicadores y criterios de evaluación para estimar el nivel de aplicación de los principios agroecológicos en las fincas Japonesas muestreadas.

Indicator	Established value	Characteristics/attributes	Valuation Score 1–5
Landscape diversity Presence of hedgerows, vegetation strips, forest or natural vegetation remnants, etc. Efforts to isolate themselves (barrier of some kind?) Neighboring farms are conventional? Organic? Mosaic?	1	Less than 20% of the perimeter of the farm surrounded by diverse natural vegetation (consider if the surrounding vegetation is composed of various plant species, if surrounded by monospecific vegetation receives a lower value)	
	2.5	20–50% is surrounded by a diverse community of natural vegetation	
	5	> than 60% farm is surrounded by a diverse community of natural plants	
Crop diversity: Various crop species and varieties grown in temporal and spatial designs assessed at the time of the farm visit	1	Monoculture: only one crop species grown (give higher values if 2 crop species are grown as monocultures in separate plots)	
	2.5	Between 3–4 crop species grown intercropped or in rotation (Lower value if 3–4 crop species are grown as monocultures in separate plots)	
	5	More than 5 crop species grown intercropped or in rotation (Lower value if more then 5 crop species are grown as monocultures in separate plots)	
Genetic diversity	1	Monoculture: only one variety of each crop species (higher value if local varieties)	
	2.5	3–4 varieties of each crop	
	5	More than 5 varieties of each crop	
Soil Quality and management	1	< 1% organic matter content, 100% soil uncovered, no recycling and incorporation of biomass. No cover crops or green manures used	
	2.5	Between 2–3 % organic matter, 30–50% soil covered. Some level of recycling and incorporation of biomass and limited use of cover cropping or green manuring (Lower value if use plastic mulch)	
	5	More than 4 to 5% organic matter, more than 50-70% soil covered High level of recycling and incorporation of biomass and use of cover cropping or green manuring. No plastic mulch	
Plant health and pest management Use of biological and cultural pest control methods (release of beneficial insects, habitats, antagonists, organic weed control methods, etc.)	1	Farmers use pesticides and no practices of biological and cultural control of pests, diseases and weeds	
	2.5	Farmers use input substitution practices (microbial, botanical or other pesticides) to control pests, diseases and weed. Limited use of practices that enhance beneficial insects and antagonists	
	5	Farmers rely on soil and plant management practices to enhance biological control processes that help them to avoid, withstand and/or recover from pests, diseases and weeds	
Dependency on external inputs	1	High dependency on external inputs, more than 80% of inputs purchased outside the farm	
	2.5	Medium dependency on external inputs, 30–70% of inputs purchased off farm	
	5	Low use of external inputs, less than 20% of inputs purchased off-farm	
Interactions and synergies	1	No observed interactions between agrobiodiversity components	
	2.5	One or two interactions observed	
	5	More than three interactions observed	
Productivity	1	Low total productivity	
	2.5	Medium total productivity	
	5	Higher total productivity	
		Mean value	

Table 3. Indicators and formulae to determine the agroecological threshold index.

Cuadro 3. Indicadores y formula para determinar el índice del umbral agroecológico.

Indicator	Threshold	Formula
Landscape Diversity X_1	50% more than farmers' average	1.5 (mean X_1)
Crop Diversity X_2	30% more than farmers' average when mean is less than 20 species	1.3 (mean X_2)
Genetic Diversity X_3	20% more than farmers' average when number of varieties is less than 10	1.2 (mean X_3)
Soil Cover X_4 *(%)*	20% more than farmers' average when mean is less than 50%	1.2 (mean X_4)
Plant health X_5 *(% of healthy plants)*	20% more than farmers' average if % of healthy plants is < 70%	1.2 (mean X_5)
Dependance X_6 *(% of external inputs)*	50% less than farmers' average when mean is > 30%	0.5 (mean X_6)

Table 4. Practices used by surveyed Japanese farmers.

Cuadro 4. Practicas utilizadas por los agricultores Japoneses evaluados.

Principle	Practices	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8
Landscape diversity	Presence of vegetation around farm (hedgerows, forest remnant, living fences, weedy borders, etc.)			✓	✓	✓	✓	✓	✓
	Plant and/or flower strips					✓	✓		
	Neighboring organic farms							✓	✓
	Neighboring conventional farms	✓	✓	✓					
	Scattered plots in landscape	✓	✓	✓	✓	✓	✓	✓	✓
Crop diversity:	Inter-row diversity (various crops in different rows)	✓	✓	✓	✓	✓	✓	✓	✓
	Intercropping					✓			
	Crop rotation	✓	✓	✓	✓	✓	✓	✓	✓
	High crop density								✓
Genetic diversity	Use of traditional/local varieties			✓	✓	✓	✓	✓	
	Variety mixtures			✓		✓			
	More than one variety grown in separate rows	✓		✓	✓	✓		✓	✓
	Selected varieties (locally adapted, tolerant, etc.)		✓	✓	✓	✓	✓	✓	
Soil Quality and management (biomass and organic matter recycling)	Compost application					✓		✓	
	Green manures	✓	✓	✓	✓	✓	✓	✓	
	Use of Bocashi								✓
	Use of external organic amendments	✓	✓	✓		✓	✓	✓	✓
	Use of animal manure		✓	✓	✓			✓	✓
	Use of forest litter				✓	✓	✓		
	Minimum tillage	✓							
Plant health and pest management	Hand weeding	✓	✓	✓	✓		✓	✓	✓
	Plastic mulch	✓	✓	✓	✓	✓	✓	✓	✓
	Hand picking of insect pests	✓						✓	✓
	Removal of diseased plants							✓	
	No action against pests	✓	✓	✓	✓	✓	✓	✓	✓

minimal use of cover crops, green manures or organic mulches for weed control and water conservation. While many farmers took preventative measures and claimed that their level of pest and disease incidence was generally low, hand picking of insect pests was the preferred practice.

These management practices used by farmers were aligned with the six agroecological principles used here. As observed in Table 5, the six principles were correlated with the application of five areas of management practices which are the improvement/enhancement of landscape diversity; crop diversity (both spatial and temporal); genetic diversity; soil quality; and plant health. For example, we found that eight farms applied spatial and temporal crop diversification schemes, which contributed to all six principles. This quick method of matching principles with practices reveals paths for surveyed farmers to more systematically apply agroecological principles through practices that improve landscape, crop and genetic diversity, plant health and soil quality. Potential practices that enhance and maximize functional biodiversity at multiple scales to promote a series of ecological services include landscape enrichment with multifunctional plants, optimal intercropping patterns and variety mixtures, cover cropping, straw mulching and/or living mulches, flower provisioning for beneficial insects, amongst others.

Rapid assessment of the level of application of agroecological principles

Results from the rapid assessment to determine the extent to which surveyed farmers were applying the agroecological principles on their farms, are presented in Figure 2, which shows values of indicators from the nine surveyed farms. Farms 4, 6 and 7 exhibited values above 3.0 for all eight indicators. Farm 3 had seven indicators at values above 3. For farms 1 and 2, three indicators ranked above 2.5. Farm 8 had four out of eight

Table 5. Management practices used by 9 Japanese farmers and linkages to one or more agroecological principles.
Cuadro 5. Practicas de manejo utilizadas por 9 agricultores Japoneses y su vinculación a uno o más principios agroecológicos.

Practices for improving/ enhancing	# of farmers using practices	Principles to which they contributed *					
		1. Enhance the recycling of biomass, with a view to optimizing organic matter decomposition and nutrient cycling over time	2. Strengthen the "immune system" of agricultural systems through enhancement of functional biodiversity – natural enemies, antagonists, etc., by creating appropriate habitats	3. Provide the most favorable soil conditions for plant growth, particularly by managing organic matter and by enhancing soil biological activity	4. Minimize losses of energy, water, nutrients and genetic resources by enhancing conservation and regeneration of soil and water resources and agrobiodiversity	5. Diversify species and genetic resources in the agroecosystem over time and space at the field and landscape level	6. Enhance beneficial biological interactions and synergies among the components of agrobiodiversity, thereby promoting key ecological processes and services
Landscape diversity	5	✓	✓				✓
Crop diversity in time and space	8	✓	✓	✓	✓	✓	✓
Genetic diversity	5		✓				
Soil quality	7	✓	✓	✓			✓
Plant health	8		✓			✓	✓

indicators ranked above 2.5, while in farm 9, only one indicator (productivity) ranked above 2.5. All farmers that ranked indicators above 3 featured clear diversification schemes, (for example, farmer 6, practiced a well-planned polycultural rotation), recycled organic matter and nutrients, and made better use of the available local resources such as forest litter.

Figure 3 shows the average value for the eight indicators for each farm. Clearly, farms 6 and 7 stand out as being more advanced in the application of agroecological principles, followed by farms 3, 4 and 5. Farms 1, 2, 8 and 9 are far from being considered agroecologically based, with significant room for improvement regarding their design and management practices in order to reflect the agroecological principles described here. More specifically, we found that these farmers lacked in practices that enhance landscape, crop and genetic diversity, soil quality, and productivity. This is a weakness and farmers were encouraged by us to diversify their farm design in order to increase positive interactions between soil, plant, insect and other biodiversity components, thus promoting biological pest control and nutrient recycling, while minimizing use of external inputs.

Agroecological thresholds

To determine if each agroecological indicator measured in each farm exceeds the designated threshold level, only data obtained from seven surveyed farms were analyzed, applying the formulae described in Table 3. Table 6 shows the value for each of the six indicators in the seven farms, the mean value for each indicator across farms, and their threshold value obtained with the following formula. The formula first divides each indicator (i.e. landscape diversity, crop diversity, etc.) obtained in each farm by the threshold value, which converts the indicator values to threshold indexes. This leads to an average of these indexes obtained for each farm. As observed in Table 7, only farm 6 exhibited a mean threshold index value of above one, indicating that this farm surpassed the threshold and thus is moving towards an agroecological optimum. It is important to note that although farm 6 exhibited a threshold index value of above one in four indicators, values for crop diversity and dependence on external inputs were <1, suggesting room for improvement. Farms 3, 5 and 7 exhibited index values of above or close to one for

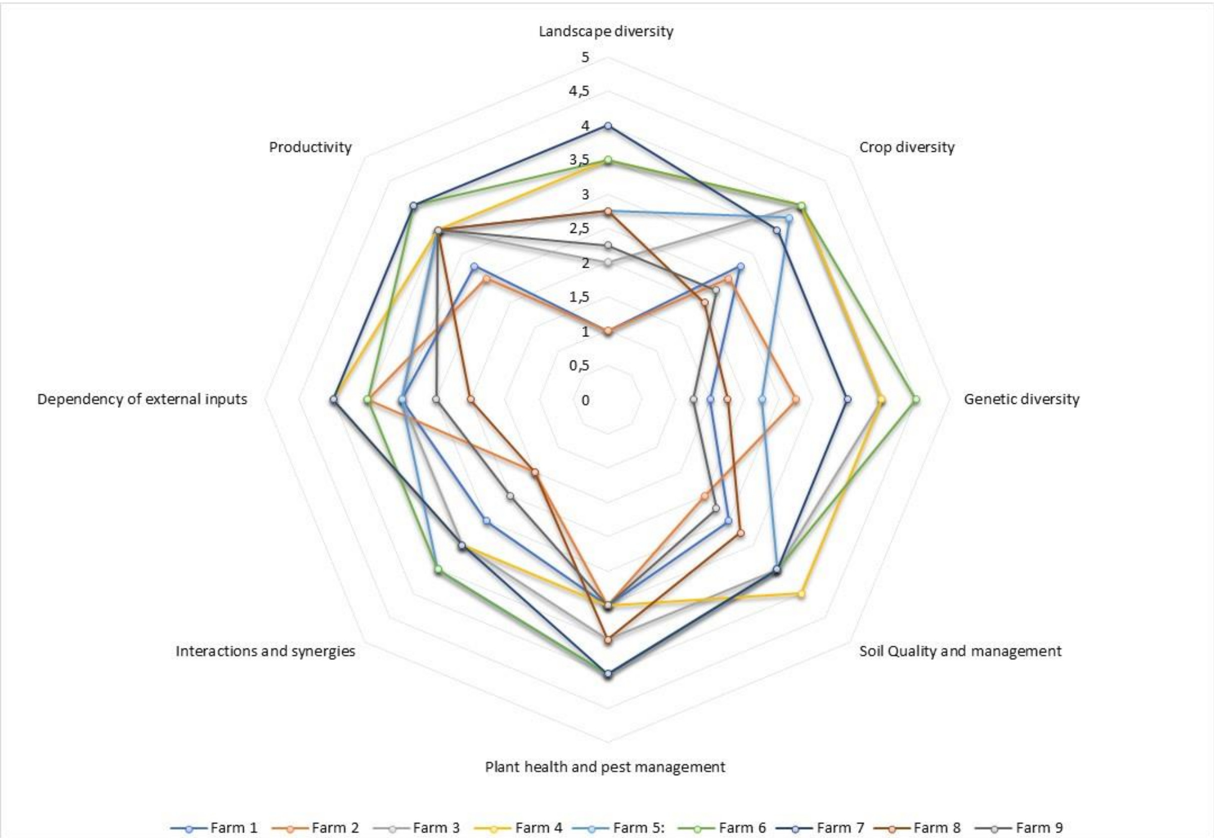

Figure 2. Indicator values from nine surveyed farms in Kyoto, Hiroshima and Hyogo Prefectures

Figura 2. Valores de indicadores de nueve fincas evaluadas en las prefecturas de Kyoto, Hiroshima y Hyogo.

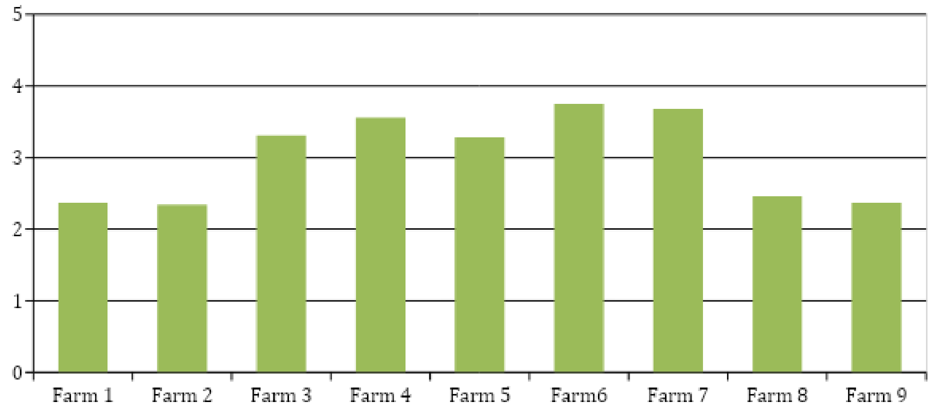

Figure 3. Mean value for all agroecological indicators across the 9 surveyed Japanese farms.

Figura 3. Valor promedio de todos los indicadores estimados en 9 fincas Japonesas evaluadas.

Table 6. Real indicator values obtained from 7 Japanese farmers, showing overall means and thresholds determined applying formula from Table 3.

Cuadro 6. Valores reales de indicadores obtenidos de 7 fincas Japonesas, mostrando promedios generales y umbrales determinados mediante la aplicación de la formula descrita en el Cuadro 3.

Farm #	*Landscape Diversity X_1 (%)*	*Crop Diversity X_2 (number of species)*	*Genetic Diversity X_3 (number of Varieties)*	*Soil cover X_4 (%)*	*Plant health X_5 (% healthy plants)*	*Dependence X_6 (% of external inputs)*
1	1	10	6	50	70	70
2	5	12	8	50	80	60
3	20	20	15	60	80	70
4	35	15	10	60	80	60
5	55	15	12	80	90	60
6	75	15	15	70	80	60
7	80	12	10	60	70	70
Mean	38	14	11	61	78	64
Threshold	57	18	11	61	78	32

Table 7. Agroecological Threshold Index values for 7 Japanese surveyed farmers.

Cuadro 7. Indices de umbrales agroecológicos para 7 fincas Japonesas evaluadas.

Farm #	*Landscape Diversity X_1 (%)*	*Crop Diversity X_2 (number of species)*	*Genetic Diversity X_3 (number of varieties)*	*Soil cover X_4 (%)*	*Plant health X_5 (% healthy plants)*	*Dependence X_6 (% of external inputs) **Inverse*	*Agroecological Threshold Index*
1	0.02*	0.55	0.54	0.81	0.89	0.45	**0.55**
2	0.09	0.66	0.72	0.81	1.02	0.53	**0.64**
3	0.35	1.11	1.36	0.98	1.02	0.45	**0.87**
4	0.61	0.83	0.90	0.98	1.02	0.53	**0.81**
5	0.96	0.83	1.09	1.31	1.15	0.53	**0.98**
6	1.31	0.83	1.36	1.14	1.02	0.53	**1.03**
7	1.4	0.66	0.90	0.98	0.89	0.45	**0.88**

*Converted value = indicator value/threshold three or four indicators, although the overall mean values were < 1, which indicates that they are on the right path but not quite balanced in terms of enhancing the interdependence of each practice on the farm. Farms 1, 2, and 3 exhibited threshold index values < 1 for five out of six indexes, indicating that the application of agroecological principles are below optimum levels, lacking key practices, which they could adopt through enriching hedgerows, practicing intercropping and rotations, and use straw, leaflitter or green mulch for soil cover, which helps to reduce dependence on external inputs while improving overall productivity on the farm.

The threshold index data for the best (farm 6) and worst (farm 1) performing farms is plotted in Figure 4 as a comparison. The line of the inner pentagon in the figure represents the threshold values, showing that farmer 6 is overall more advanced than farmer 1 in the process of applying agroecological principles in the design and management of his farm.

DISCUSSION AND CONCLUSIONS

In light of the increasingly widespread use of the term agroecology to define a variety of alternative agriculture systems, it is important to have a simple, yet comprehensive tool by which we can assess if a farmer is applying the principles of agroecology in the design and management of his/her farm, beyond the implementation of a narrow set of practices. The idea of this tool is not to "judge" farmers that do not follow agroecological principles, but rather to offer them a tool to holistically diagnose the state of their farms, detect weaknesses and offer alternatives based on agroecology to improve its overall operational performance. In fact, although many farmers follow the precincts of organic, and biodynamic agriculture, natural farming or permaculture, these farms can still be analyzed to see whether they are or not pursuing agroecological principles, which underlie the function of all farms whatever their denomination (Nicholls *et al.,* 2016). As in the case of the surveyed Japanese farmers who followed organic and/or natural farming guidelines, we found that many of them exhibited some deficiencies in integrating agroecological principles. The methodology therefore allows them to identify these deficiencies in their design and management practices, that can be modified to improve their agroecosystems. The tool is designed to challenge farmers to engage with the interdependent nature of each principle, to come up with alternative designs and management approaches to achieve a more holistic farming approach.

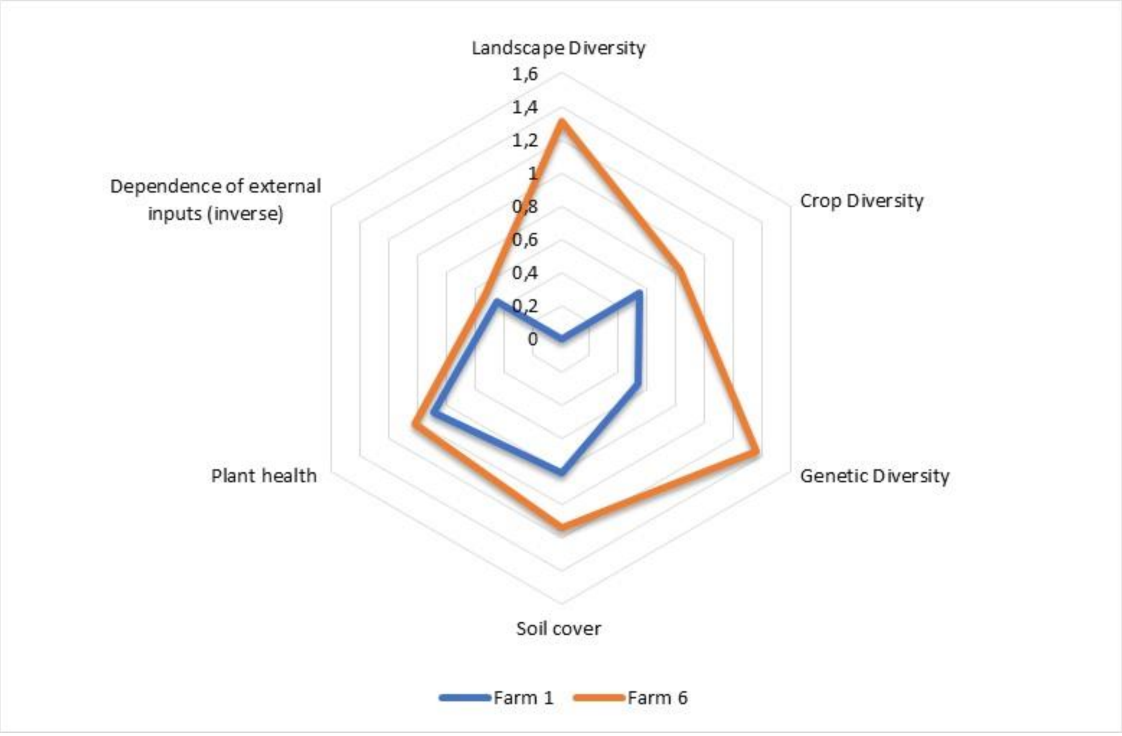

Figure 4. Comparison between two contrasting farms: farm 1 with an average threshold index of 0.55 versus farm 6 with a value of 1.03.

Figura 4. Comparación entre dos fincas contrastantes: finca 1 con un índice umbral de 0.55 versus finca 6 con un valor de 1.03.

The methodology presented herein allows researchers and farmers to use a few simple indicators to rapidly observe to what extent agroecological principles are being applied on a given farm, and if they are, to what degree they are applied in an optimal way. Data obtained from the rapid observations permit individual farmers to make design and management decisions directed at improving specific areas they were found performing poorly in, and thus improve overall agroecosystem performance, regardless of their approach to farming. The methodology should involve farmers' participation in the selection of appropriate indicators, particularly in defining common criteria on how to rank each indicator and to define agroecological threshold values. Because the method presented here is flexible and applicable to a wide assortment of agroecosystems in a series of geographical and socio-economic contexts, it can be used as a tool to incentivize and enhance communication between farmers to share knowledge on more site-specific methods. Farmers that exhibit high scores can play a key pedagogical role as their farms can serve as demonstration sites or agroecological lighthouses (Nicholls and Altieri, 2018). The success of this farmer to farmer learning will depend on the level of social organization of the farmers involved. As mentioned, the methodology allows farmers to assess the evolution of their farming practices over time. Using data from the first rapid assessment proposed here as a baseline, farmers can track if the adoption of recommended design and management practices that emerged from such assessment improved the values of indicators performing poorly. A comparison between two or more farms under different management practices or transitional stages allows a group of farmers to identify the farms that are more advanced in applying agroecological principles (Figure 3) or farms where principles are being applied above the threshold index levels (Table 7). In our survey farm number 6 ranked high under both assessments, while farm number 1 consistently ranked low values.

Of course, the methodology has remaining weaknesses. One limitation is based on the fact that the assessment is done over a short period of time. If the indicators are not properly identified in collaboration with farmers in a specific region, an outside assessor who is not fully familiar with the farm, he/she will only capture the state of the farm in a moment in time, which may lead to an incomplete assessment of the farm. This highlights the importance of determining thresholds collaboratively with the farmers to meet site specific needs and having farmers themselves use the methodology in order to assess their own farms and engage, if so desired, in comparative analysis with their neighbors. Another limitation is linked to the fact that scoring can vary depending on how much experience one has in assessing agroecological farms, as the tool requires the observation of multiple ecological and agronomic factors. However, this tool is not meant to provide an absolute assessment of a farm, but a tool to enable a holistic comparison between farms or the same farm over time. Ranking values might suggest future modifications in the design and management of a given farm, however, socio-economic and cultural contexts in which farmers are imbedded, may pose barriers for the farm, making certain modifications not feasible. For example, hedgerows are a practice that fulfill the objectives of many principles, but when farms are dispersed or adjacent to other fields using conventional or more industrial methods, as is often the case in Japan, hedgerows may not be appropriate and difficult to implement. Furthermore, many surveyed farms were surrounded by a forest monoculture, a landscape feature that farmers have little control over due to differentiated ownership and access to forests. In this way, the development of more local or context-specific management methods applicable for the site to implement a principle on a farm are required (González-Chang *et al.*, 2020). A participatory process to fine tune the interpretation of the assessment factors for each indicator is necessary to be able to capture the local socio-ecological contexts. To this end, we plan to continue testing the tool in a variety of farming contexts through existing agroecological networks to which the authors are linked in various Asian and Latin American countries.

Lastly, farms that exhibit above average values may be considered "agroecological lighthouses" (Nicholls and Altieri, 2018) where farmers and researchers can collectively identify the processes and ecological interactions that explain the advanced performance of certain farms. This information can then be translated into a bundle of site-specific practices that promote the desired agroecological processes in different communities. Ultimately, lighthouse farms can serve to radiate out to other farmers in a whole region, strengthening the basis for an agricultural strategy that promotes and enhances efficiency, diversity, synergy and resiliency at the farm and landscape level.

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REFERENCES

Altieri, M.A, Nicholls, C.I., Henao, A., Lana, M.A., 2015. Agroecology and the design of climate change resilient farming systems. Agronomy for Sustainable Development 35, 869–890.

Buckles, D., Triomphe, B., Sain, G., 1998. Cover Crops in Hillside Agriculture: Farmer Innovation with Mucuna. International Development Research Centre, Canada.

Casimiro, L.R., Casimiro, J.A., Hernandez, J.S., 2017. Resiliencia socioecologica de fincas familiares en Cuba. Matanzas: Editora Estacion Experimental de Pastos y Forrajes Indio Hatuey.

Giraldo, O.F., Rosset, P., 2018. Agroecology and a territory in dispute: between institutionality and social movements, Journal of Peasant Studies 45 (3), 545–564.

Gomez, A.A., David, E., Swete, K., Syers, J.K., Coughlan, K.J., 1996. Measuring Sustainability of Agricultural Systems at the Farm Level. Methods for Assessing Soil Quality. SSSA Special Publication 49**.** Soil Science Society of America, Madison.

González-Chang, M., Wratten, S.D., Shields, M.W., Costanza, R., Dainese, M., Gurr, G.M., Johnson, J., Ketelaar, J.W., Nboyine, J., Pretty, J., Rayl, R., Sandhu, H., Walker, M., Zhou, W., 2020. Understanding the pathways from biodiversity to agro-ecological outcomes: A new, interactive approach. Agriculture, Ecosystems & Environment 301, 107053. https://doi.org/10.1016/j.agee.2020.107053

Francis, C., Lieblein, G., Gliessman, S., Breland, T.A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C., Poincelot, R., 2003. Agroecology: the ecology of food systems. Journal of Sustainable Agriculture 22, 99–118. https://doi.org/10.1300/J064v22n03_10

Food and Agriculture Organization (FAO), 2019. TAPE Tool for Agroecology Performance Evaluation 2019 – Process of development and guidelines for application. Test version. Rome

Kapgen, D., Roudart, L., 2020. Proposal of a principle cum scale analytical framework for analyzing agroecological development projects. Agroecology and Sustainable Food Systems 1–26. https://doi.org/10.1080/21683565.2020.1724582

Leyva, A., Lores, A., 2018. Assessing agroecosystem sustainability in Cuba: A new agrobiodiversity index. Elementa Science of Anthropocene 6 (1), 80. https://doi.org/10.1525/elementa.336.s1.

López-Ridaura, S., Masera, O., Astier, M., 2002. Evaluating the sustainability of complex socio-environmental systems. The MESMIS frame- work. Ecological Indicators 2, 135–148. https://doi.org/10.1016/S1470-160X(02)00043-2

Nicholls, C.I., Altieri, M.A., Dezanet, A., Lana, M., Feistauer, D., Ouriques, M., 2004. A Rapid, Farmer- Friendly Agroecological Method to Estimate Soil Quality and Crop Health in Vineyard Systems. Biodynamics 33–39.

Nicholls, C.I., Altieri, M.A., Vazquez, L., 2016. Agroecology: Principles for the conversion and redesign of farming systems. Journal of Ecosystem and Ecography S5, 1. https://doi.org/10.4172/2157-7625.s5-010

Nicholls, C.I., Altieri, M.A., 2018. Pathways for the amplification of agroecology. Agroecology and Sustainable Food Systems 42 (10), 1170–1193. https://doi.org/10.1080/21683565.2018.1499578

Rivera-Ferre, M.G., 2018. The resignification process of Agroecology: Competing narratives from governments, civil society and intergovernmental organizations. Agroecology and Sustainable Food Systems 42, 666–85. https://doi.org/10.1080/21683565.2018.1437498

Rosset, P.M, Altieri, M.A., 1997. Agroecology versus input substitution: A fundamental contradiction of sustainable agriculture. Society & Natural Resources 10 (3), 283–295. https://doi.org/10.1080/08941929709381027

Rosset, P.M., Altieri, M.A., 2017. Agroecology: Science and Politics. Rugby, UK. Practical Action Publishing Ltd.

Vandermeer, J., 1989. The Ecology of Intercropping. Cambridge University Press, Cambridge.

van der Ploeg, J.D., 2014. Peasant-driven agricultural growth and food sovereignty. The Journal of Peasant Studies 41 (6), 999–1030. https://doi.org/10.1080/03066150.2013.876997

Vazquez, L.L., 2013. Diagnóstico de la complejidad de los diseños y manejos de la biodiversidad en sistemas de producción agropecuaria en transición hacia la sostenibilidad y la resiliencia. Agroecologia 8**,** 33–42.

Zhu, Y., Chen, H., Fan, J., Wang, Y., Li, Y., 2000. Genetic diversity and disease control in rice. Nature 406, 707–716.