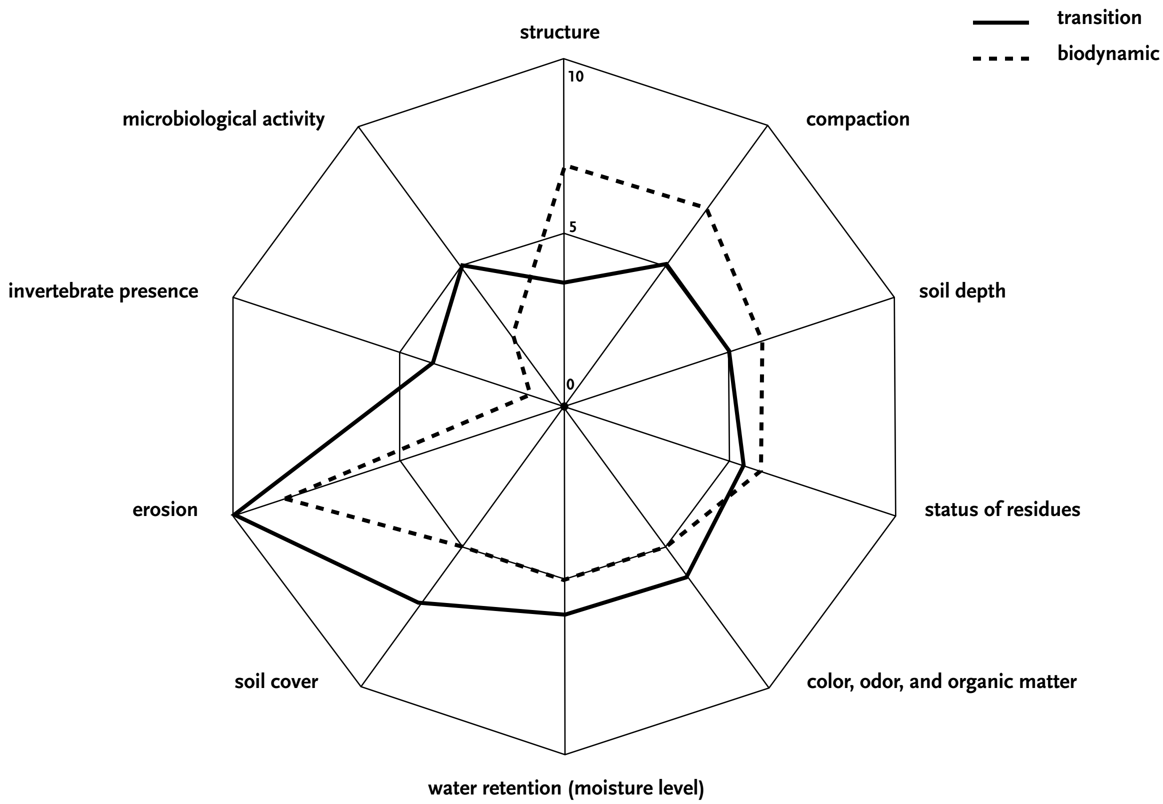
Figure 2. Amoeba representing the soil quality status of two vineyard systems (Cain – transitioning to organic, and Benziger – biodynamic) in northern California.



A Rapid, Farmer-Friendly Agroecological Method to Estimate Soil Quality and Crop Health in Vineyard Systems

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Abstract

We describe a practical methodology to rapidly assess the soil quality and crop health of vineyard systems using simple indicators chosen, applied and interpreted jointly by farmers and researchers. Field measurements are made on agroecosystem properties that reflect soil quality and plant health. As measurements are based on the same indicators, the results are comparable and allow farmers to monitor the evolution of the same agroecosystem along a timeline, or make comparisons between farms in various transitional stages. Once the indicators are applied, each farmer can visualize in an amoeba diagram the conditions of his or her farm, noticing which of the soil or plant attributes are *sufficient* or *deficient* compared to a pre-established threshold. By applying the methodology simultaneously to several farms it is possible to visualize which farms exhibit low or high values of sustainability. Although the indicators reported here are specific to vineyards in northern California, with some modifications, this methodology is applicable to a broad range of agroecosystems in various eco-regions.

Introduction

One of the reasons why many vineyard farmers decide to convert from a conventional monoculture system to a more diversified organic system is to achieve stable production without dependence on external inputs, thus lowering production costs while maintaining and/or enhancing the natural resources of the farm, such as soil, water and biodiversity (Thrupp 2003). On the other hand, the main goal of researchers involved in the development and promotion of organic vine management techniques is to design agroecosystems that exhibit high resilience to pests and diseases, good recycling and nutrient retention capacities, and high biodiversity levels (Altieri 1995 and Gliessman 1998). A more diversified system (usually vines with cover crops) with a biologically active and organic rich soil, may be considered a non-degrading, robust and productive system (Ingels et al 1998). In other words, a vineyard rich in biodiversity, exhibiting a series of biotic interactions and synergisms, which in turn subsidize soil fertility, plant protection, and productivity, is said to be *sustainable and healthy* (Locke 2001).

One of the challenges that farmers and extentionists face involves knowing when an agroecosystem is healthy, or better yet, knowing how healthy the system is after the conversion towards agroecological management has been initiated. Various researchers working in sustainable agriculture have designed a set of *sustainability indicators* to assess the condition of particular agroecosystems. Unfortunately, few of the proposed methods are farmer-friendly (Gomez et al. 1996, Masera et al. 1999). The few practical methods available offer a set of proposed indicators consisting of observations or measurements that are done at the farm level to assess soil fertility and level of degradation and whether crop plants are healthy, strong and productive. In other words, the proposed indicators are used to *check the pulse* of the agroecosystem.

In this article we describe a practical methodology to rapidly assess the soil quality and crop health of vineyard systems using simple indicators. Although the indicators are specific to wine grapes in northern California, with some modifications this methodology is applicable to a broad range of agroecosystems in various regions. The indicators described herein were selected because:

- they are easy to use by farmers
- they are relatively precise and easy to interpret
- they are practical for making new management decisions
- they are sensitive enough to reflect environmental changes and the effects of management practices on the soil and the crop
- they possess the capability of integrating physical, chemical and biological properties of the soil
- they can relate to ecosystem processes, for example the relationship between plant diversity and pest population stability and/or disease incidence (Altieri 1994).

There is no doubt that most viticulturalists possess their own indicators to estimate soil quality or the health condition of their crop. For example, some farmers recognize some weeds as indicative of certain soil conditions (i.e. as growing only on acidic or non-fertile soils). Other indicators of quality or health may be the presence of earthworms, signaling a living soil, or the color of the leaves, reflecting the nutritional status of the plants. In northern California, it is possible to compile a long list of local indicators used by farmers. The problem with many of the indicators is that they are site-specific and may vary according to the knowledge of the farmers or the conditions of each farm. It is difficult to make comparisons between farms if the analysis is based on results derived from site-specific indicators interpreted in various ways by farmers.

In order to overcome this limitation, we selected qualitative indicators of soil and crop health which are relevant to farmers and the biophysical conditions of vineyards typical of Sonoma and Napa counties. With these already well-defined indicators, the procedure to measure the sustainability is the same from site to site, and independent of the diversity of situations found in the different farms on the studied region. *Sustainability* is defined as a group of agroecological requisites that must be satisfied by any farm, independent of management, economic level, or landscape position. As all the measurements made are based on the same indicators, the results are comparable and it is possible to follow the evolution of the same agroecosystem along a timeline, or make comparisons between farms in various transitional stages. Most importantly, once the indicators are applied, each farmer can visualize the conditions of his or her farm, noticing which of the soil or plant attributes are sufficient or deficient compared to a pre-established threshold. When the methodology is applied to various farms simultaneously, it is possible to visualize which farms exhibit low or high values of sustainability. This is useful for farmers as it allows them to understand why some farms perform ecologically better than others. It also helps to stimulate thinking about management modifications that may improve the functioning of farms exhibiting lower values.

Sustainability indicators

The indicators were initially discussed with professional viticulturists and farmers at a field workshop organized by the Napa Sustainable Winegrowing Group in the summer of 2002, and later validated on two farms (Benziger Vineyards and Cain Vineyards) by the authors of this article in collaboration with respective vineyard managers. Once the desired sustainability requirements were defined by the participants, ten soil quality and ten crop health indicators that

Table 1. Soil quality and crop health indicators in grape systems, with corresponding characteristics and values (values between 1 and 10 can be assigned to each indicator).

Indicators of soil quality	Established value	Characteristics
Structure	1	Loose, powdery soil without visible aggregates
	5	Few aggregates that break with little pressure
	10	Well-formed aggregates – difficult to break
Compaction	1	Compacted soil, flag bends readily
	5	Thin compacted layer, some restrictions to a penetrating wire
	10	No compaction, flag can penetrate all the way into the soil
Soil depth	1	Exposed subsoil
	5	Thin superficial soil
	10	Superficial soil (> 10 cm)
Status of residues	1	Slowly decomposing organic residues
	5	Presence of last year's decomposing residues
	10	Residues in various stages of decomposition, most residues well-decomposed
Color, odor, and organic matter	1	Pale, chemical odor, and no presence of humus
	5	Light brown, odorless, and some presence of humus
	10	Dark brown, fresh odor, and abundant humus
Water retention (moisture level after irrigation or rain)	1	Dry soil, does not hold water
	5	Limited moisture level available for short time
	10	Reasonable moisture level for a reasonable period of time
Soil cover	1	Bare soil
	5	Less than 50% soil covered by residues or live cover
	10	More than 50% soil covered by residues or live cover
Erosion	1	Severe erosion, presence of small gullies
	5	Evident, but low erosion signs
	10	No visible signs of erosion
Presence of invertebrates	1	No signs of invertebrate presence or activity
	5	A few earthworms and arthropods present
	10	Abundant presence of invertebrate organisms
Microbiological activity	1	Very little effervescence after application of water peroxide
	5	Light to medium effervescence
	10	Abundant effervescence

best reflected the discussion were selected (see Table 1 above and continued on page 36).

Each indicator is valued separately and assigned with a value between 1 and 10, according to the attributes observed in the soil or crop (1 being the least desirable value, 5 a moderate or threshold value and 10 the most preferred value). For instance, in the case of the soil structure indicator, a value of 1 is given to a dusty soil, without visible aggregates; a value of 5 to a soil with some granular structure whose aggregates are easily broken under soft finger pressure; and a value of 10 to a well-structured soil whose aggregates maintain a fixed shape even after exerting soft pressure (Burket et al 1998). Values between 1 to 5 and 5 to 10 can also be assigned accordingly. When an indicator is not applicable for the particular situation, it is simply not measured or if possible, replaced by another indicator the farmer and researcher deem more relevant.

As the user gets more familiar with the methodology, the observations become more accurate and can be refined using additional, but simple instruments. For example, in the case of soil quality indicator 2 (compaction) a wire flag is pushed vertically into the soil at various locations in the field, and users record the depth at which it bends due to resistance in the soil. In the case of soil quality indicators 9 and 10 (relating to earthworms and biological activity), users may apply small amounts of water peroxide to a soil sample to observe its effervescence (amount of bubbles produced). If there is little or no effervescence, this usually indicates a soil with little organic matter and poor microbial activity. When there is significant effervescence, the

Table 1, continued. Soil quality and crop health indicators in grape systems, with corresponding characteristics and values (values between 1 and 10 can be assigned to each indicator).

Indicators of crop health	Established value	Characteristics
Appearance	1	Chlorotic, discolored foliage with deficiency signs
	5	Light green foliage with some discoloring
	10	Dark green foliage, no signs of deficiency
Crop growth	1	Uneven stand; short and thin branches; limited new growth
	5	Denser. but not uniform stand; thicker branches; some new growth
	10	Abundant branches and foliage; vigorous growth
Disease incidence	1	Susceptible, more than 50% of plants with damaged leaves and/or fruits
	5	Between 25–45% plants with damage
	10	Resistant, with less than 20% of plants with light damage
Insect pest incidence	1	More than 15 leafhopper nymphs per leaf, or more than 85% damaged leaves
	5	Between 5–14 leafhopper nymphs per leaf, or 30–40% damaged leaves
	10	Less than 5 leafhopper nymphs per leaf, and less than 30% damaged leave
Natural enemy abundance and diversity	1	No presence of predators/parasitic wasps detected in 50 random leaf sampled
	5	At least one individual of one or two beneficial species
	10	At least two individuals of one or two beneficial species
Weed competition and pressure	1	Crops stressed, overwhelmed by weeds
	5	Medium presence of weeds, some level of competition
	10	Vigorous crop, overcomes weeds
Actual or potential yield	1	Low in relation to local average
	5	Medium, acceptable
	10	Good or high
Vegetational diversity	1	Monoculture
	5	A few weeds present or uneven cover crop
	10	With dense cover crop or weedy background
Natural surrounding vegetation	1	Surrounded by other crops, no natural vegetation
	5	Adjacent to natural vegetation on at least one side
	10	Surrounded by natural vegetation on at least two sides
Management system	1	Conventional
	5	In transition to organic with IPM or input substitution
	10	Organic, diversified with low external biological inputs

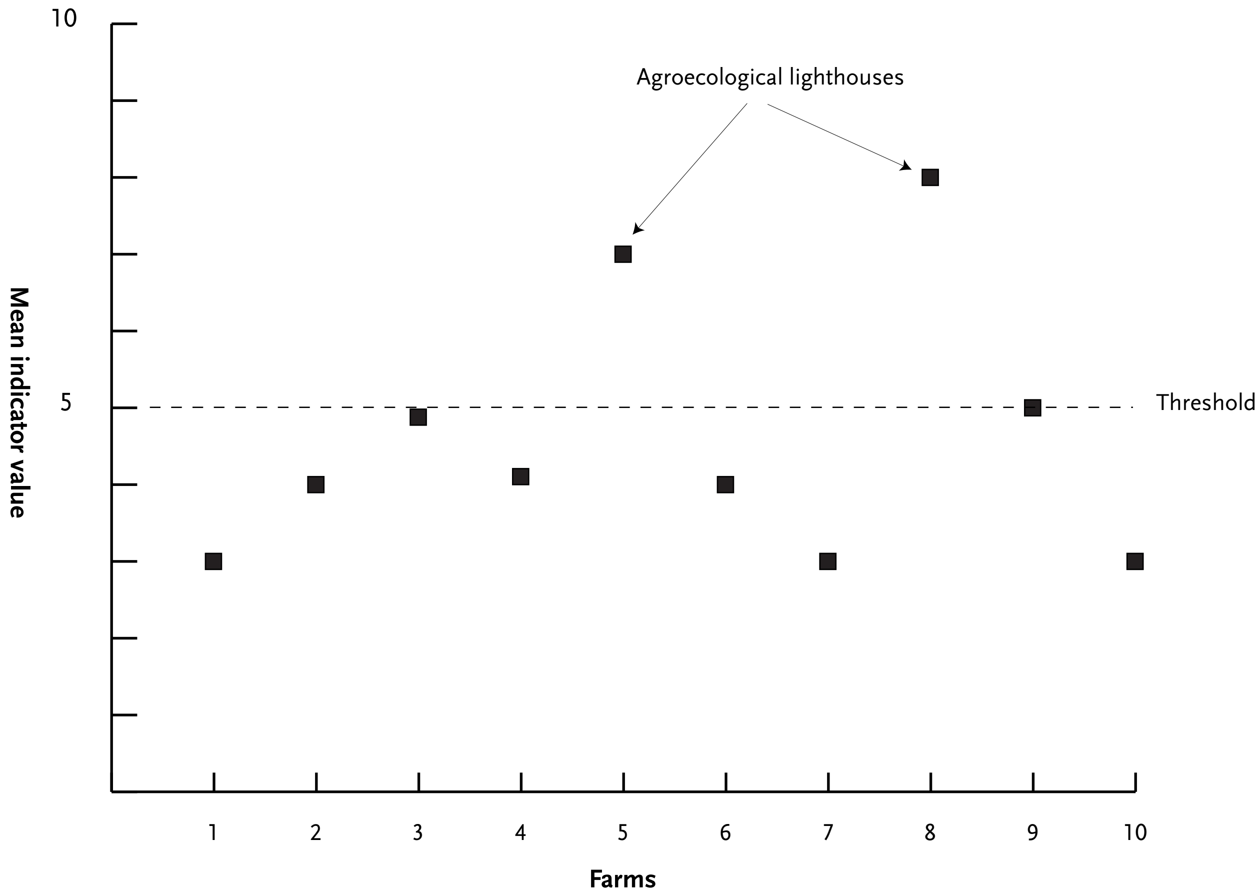
soil is usually rich in organic matter and microbial life (USDA – NRCS 1998).

The crop health indicators refer to the appearance of the crop, the level of pest and disease incidence, tolerance to weeds, growth of the crop, and potential yield. Insect pest densities are determined and in the case of grape leafhoppers, obtained values are interpreted based on known thresholds (Flaherty 1992). A value is then assigned to crop health indicator 4 (insect pest incidence). The observations on plant diversity levels (number of cover crop and weed species), diversity of surrounding natural vegetation, and system management types (i.e. organic system in conversion with many or few external inputs) are conducted to evaluate the ecological infrastructure of the vineyard. The assumption is that a vineyard under a diversified management, with low external inputs, and diverse vegetation margins, should benefit by the synergies of biodiversity and thus exhibit a higher level of sustainability (Altieri and Nicholls 2003).

Once the values are assigned to the indicators they are added and divided by the number of measured indicators. A mean value for soil quality and another for crop health is recorded. Farms with an overall value lower than 5 in soil quality and/or crop health are considered *below the sustainability threshold,* and rectifying measures should be taken to improve the low indicators on these farms.

The indicators are more easily observed by using an *amoeba*-type graph as it allows one to visualize the general status of soil quality and crop health, considering that the closer the amoeba approaches the full diameter length of the

Figure 1. Hypothetical comparison of combined averages of soil and crop health indicators in several vineyards in Napa and Sonoma counties, featuring farms exhibiting high indicator values (agroecological lighthouses).



circle the more sustainable the system (a 10 value). The amoeba shows which indicators are weak (below 5) allowing farmers to prioritize the agroecological interventions necessary to correct soil, crop or system deficiencies. At times it may be possible to correct a set of deficiencies just by intervening on one specific attribute. For instance, increasing the species diversity or the soil organic matter will in turn affect other system attributes. By adding organic matter one is increasing the soil's water carrying capacity, augmenting soil biological activity, and improving soil structure.

The average values of various farms can be plotted, allowing researchers and farmers to visualize how each farm fares in relation to the threshold level (5) of soil quality and crop health (Figure 1 above). This graph clearly depicts the "above-average" farms, which may be considered *agroecological lighthouses.* The idea here is not for farmers to copy the techniques that *lighthouse farmers* use, but rather to emulate the processes, synergisms and interactions that emerge from the ecological infrastructure of the lighthouse farm, which are assumed to determine the successful performance of such systems in terms of soil quality and crop health. Simply copying the practices used by successful farmers does not work for diffusing principles underlying the performance of lighthouse farms. Agroecological performance is linked to processes optimized by diversified systems and not to specific techniques (Altieri 1995). The synergy associated with diverse vineyards makes it difficult to evaluate individual practices (i.e. one or two cover crop mixes) effectively, because experimental tests of individual practices or subsets of practices are unlikely to reveal the true potential of a complex vineyard system. A more productive line of research is to understand the processes and mechanisms at play in successful systems, and indicators provide guidance in this direction.

It may be that in a *lighthouse farm* the key is high soil biological activity or live soil cover, but this does not mean that the neighboring farmers have to use the same type of compost or cover as the *lighthouse farmer;* rather they should use techniques that are within their reach but which optimize the same key processes operating in the lighthouse farm.

Table 2. Assigned soil quality and crop health indicator values in an organic-biodynamic vineyard (Benziger) and a transitional vineyard (Cain) in northern California

	Indicators	Benziger vineyard (organic/biodynamic)	Cain vineyard (in transition)
Soil quality	Structure	7	3.5
	Compaction	7	5
	Soil depth	6	5
	Status of residues	6	5.5
	Color, odor, and organic matter	5	6
	Water retention (moisture level)	5	6
	Soil cover	5	7
	Erosion	8.5	10
	Invertebrate presence	1	4
	Microbiological activity	2.5	5
	Average of soil quality	**5.3**	**5.7**
Crop health	Appearance	8.5	6.5
	Crop growth	8.5	8
	Disiease incidence	9	10
	Insect pest balance	9.5	10
	Natural enemy abundance & diversity	1.5	2
	Weed competition & pressure	9	10
	Actual or potential yield	8	6
	Vegetational diversity	4	3.5
	Natural surrounding vegetation	9	8
	Management system	7	4
	Average of crop health	**7.4**	**6.8**

Case Studies

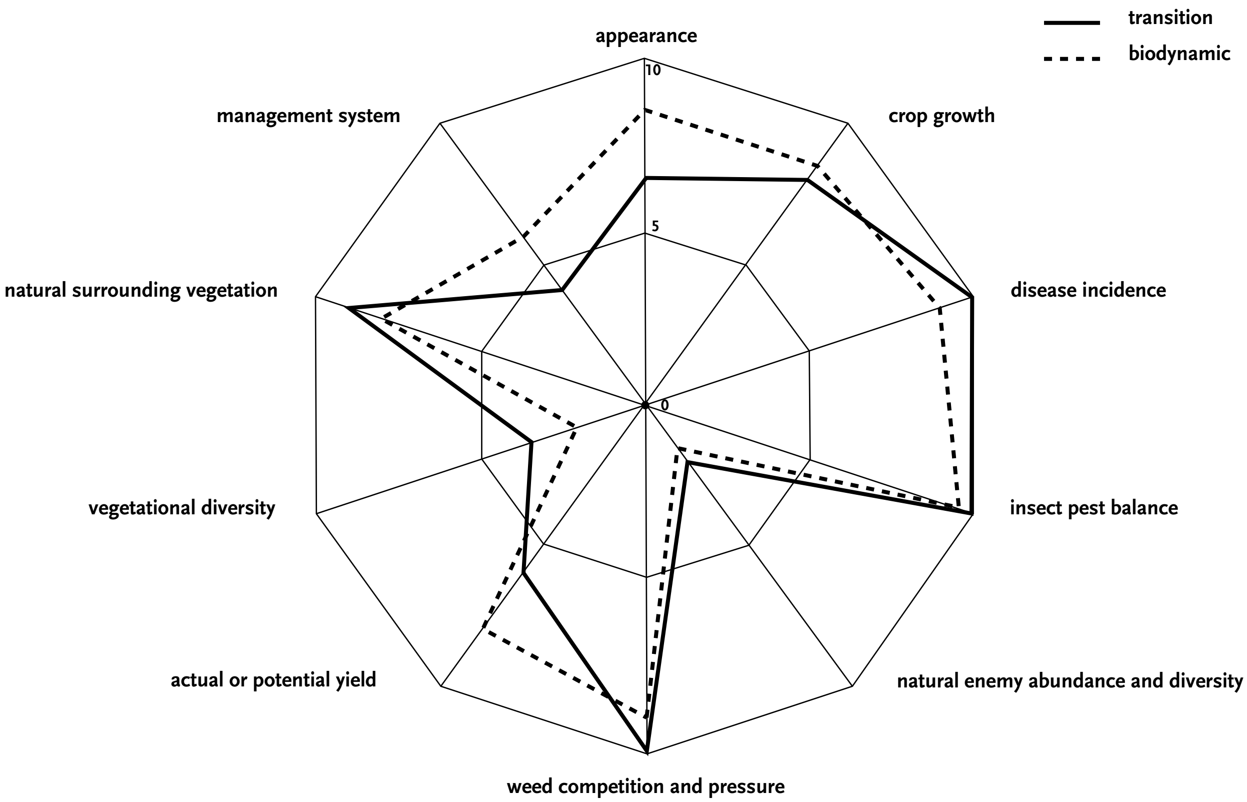
In September of 2003 our group visited Benziger vineyard, near Sonoma, for a four-hour period. The group applied the methodology to assess the soil quality and crop health indicators in two Cabernet Sauvignon blocks of the farm. The vineyard is managed using biodynamic methods of production, which emphasize cover cropping in the fall and winter and the use of a series of eight herbal-based preparations applied to the soil to promote soil health and vitality (<www.benziger.com>). This farm system exhibited an average value of 5.3 for soil quality and 7.4 for crop health (see Table 2 above).

In the afternoon of the same day, the group assessed the indicators in Cain vineyards, located uphill from St. Helena, Napa. This eighty-four-acre terraced farm is under transition to organic management, and is located between 450-750 meters above the sea level (<www.cainfive.com>). Cover crop residues are left in the field during the summer. Average soil quality reached a value of 5.7 and 6.8 for plant health. Table 2 presents the assigned values of all twenty indicators on both farms. Average values for soil quality and plant health observed in the two vineyards are quite similar.

The amoeba for soil quality (Figure 2 on page 33) allows one to compare all relevant indicators on both farms, showing that the biodynamic farm exhibits better soil quality values for structure, compaction, status of residues, and soil depth, while the transition farm exhibits higher values for biological activity, soil cover, water retention, and organic matter, probably reflecting the positive effects of maintaining the dry cover as mulch. On the measured attributes, one farm has more desirable physical characteristics while the other seems to have a more biologically active soil, features that may differentially influence vineyard performance.

In terms of plant health, both systems exhibited very low levels of pest and disease incidence, and good rates of vine growth and appearance (Figure 3). Although within-field plant diversity was low (cover crops were dead in summer)

Figure 3. Amoeba representing the crop health status of two vineyard systems (Cain – transitioning to organic, and Benziger – biodynamic) in northern California.



both systems are surrounded by natural vegetation, which enhances the overall biodiversity and the environmental opportunities for natural enemies. The biodynamic farm contains an island of flowers in the middle of the vineyard; such flowers are constantly visited by predators and parasites that continually move back and forth between the island and the vineyard. For this reason the group gave this farm higher values for plant health indicators (vegetational diversity, natural surrounding vegetation, and management system).

After the diagnosis, our group discussed with the farm managers the problems that they considered most critical and in need of attention in both vineyards, and the types of interventions needed to overcome the limitations implied by the indicators. The biodynamic farm requires improvements in soil cover and other edaphic conditions to optimize root development and activate soil biological activity. In terms of crop health, both agroecosystems require key interventions to increase plant species diversity, as this in turn can enhance diversity and abundance of natural enemies (Altieri and Nicholls 2003). The transitional "system" requires additional practices to improve vine vigor and appearance.

Conclusions

How to assess agroecosystem sustainability is today an important challenge for many farmers and researchers. Many lists of indicators that can be used to estimate the productivity, stability, resilience, and adaptability of agroecosystems have been proposed (Masera et al. 1999), but few methodologies exist that allow farmers to use a few simple indicators to rapidly observe the status of their agroecosystems. Such tools would permit them to make management decisions directed at improving the attributes that are performing poorly, and thus improve agroecosystem functions.

The methodology presented is a step in this direction, and consists of a preliminary attempt to assess the sustainability of vineyards according to values assigned to relevant indicators of soil quality and crop health. The methodology involves a participatory activity and is applicable to a wide assortment of agroecosystems in a series of geographical and socio-economic contexts, as long as some indicators are replaced by others more relevant for each particular situation.

The methodology allows farmers to measure the sustainability in a *comparative or relative way,* either by comparing the evolution in time of the same agroecosystem, or by comparing two or more agroecosystems under different management practices or transitional stages. The comparison of various systems allows a group of farmers to identify the *healthier* systems, *lighthouses,* where farmers and researchers can together identify the processes and ecological interactions that explain the good performance of these lighthouses. This information can afterwards be translated into specific practices that promote the desired agroecological processes in the "vineyards" that exhibit indicator values below the threshold level.

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