# Biodiversity Indicators for Sustainability Evaluation of Conventional and Organic Agro-ecosystems

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## Abstract

Previous studies suggest widespread positive responses of biodiversity to organic farming. However, the effect of organic farming management on biodiversity over time needs to be better understood and this paper aims to compare agricultural biodiversity in a long-term experiment including three different agroecosystem management patterns (old organic, young organic and conventional). The level of agroecosystem sustainability related to plants has been assessed both for the structural and the associated biodiversity, using biodiversity Indicators. The data collected in three years (2003-2005) show that the system under organic agriculture management is better than conventional one for every indicator and it improves each aspect over the time. This trend holds especially for the associated biodiversity while the planned biodiversity can still be improved.

*Key-words*: biodiversity, sustainability indicators, organic vs conventional agriculture.

## 1. Introduction

Biodiversity in farms refers to all plant and animal organisms present in and around farms that interact as components of an agroecosystem (Nicholls and Altieri, 2005) and implements many different functions: biomass decomposition, nutrient cycling, soil structure enhancement, pest regulation, pollination, detoxification, local idrological process regulation and macroclimate control (Altieri, 1999). Biodiversity components of farms can be classified in relation to the role they play in the functioning of cropping systems, as follows:

– *Productive biota*: crops and livestock chosen by the farmers. They depend on the farm organisation (spatial and temporal) and the intensity of management (type and quantity of input and output). This component can be classified as *structural or planned biodiversity*;
– *Resource biota*: organisms that contribute to productivity with positive functions (pollination, pest regulation, decomposition);
– *Destructive biota*: organisms (weeds, pest insects, pathogens, etc.) that obstacle productivity with damaging functions.

The latter two, can also be classified as *associated biodiversity* since they colonize the farm from the surrounding environments and influence the agroecosystem depending on its management. Thus, agricultural practices are directly involved either in the construction or in the maintenance of a certain level of desired biodiversity.

If organic agriculture is based on correct managements, it increases the agrobiodiversity components (Stolze et al., 2000; Stolton, 2005) and more biodiversity provides a fundamental service for natural control of pest and disease, soil fertility improvement and stability of production.

The use of sustainability indicators has become a frequent instrument in the evaluation of both biodiversity and agricultural systems (Bockstaller et al., 1997; Dalsgaard and Oficial 1997; Morse et. al 2001; Lopez-Ridaura et al. 2002; Caporali et al., 2003) especially when the comparison of organic vs conventional methods

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is performed, both in commercial farms (Migliorini, 2000; Pacini et al., 2003) and in experimental long term experiments (LTE) (Leight and Jhnston, 1994; Mäder, et al. 2002; Pimentel et al., 2005; Raupp et al. 2006).

A large number of studies have developed biotic indicators for evaluation of biodiversity in sustainable agriculture. A significant pilot research study, entitled 'European network for the planning and the management of Ecological and Integrated Arable Farming System (E/IAFS)' (Vereijken, 1997 and 1999; Vazzana et al., 1997) which aimed at the evaluation of sustainability using a systemic approach, provided an important contribution both for the definition of a reference frame for agro-environmental indicators and for the assessment of a prototype agro-ecosystem methodology.

Comparative researches on biodiversity in conventional and organic systems show that 66 over 76 studies show positive effect of organic farming on individual taxon of birds, mammals, butterfly, spider, earthworms, beetles, other arthropods, plants, soil microbes, in comparison to conventional (Hole et al., 2005). These studies review that some agricultural practices (prohibition/reduction of chemicals pesticide and inorganic fertilisers; managements of non-cropped habitat; preservation of mixed farming) are beneficial to a wide range of taxa and in particular to farmland wildlife. However, both for methodological and for the spatial and temporal dimension of analysis, the potential role of biodiversity in organic farming needs to be better understood and this paper aims to describe agricultural biodiversity under different farm managements.

## 2. Materials and methods

The experimental area is in the farm of the University of Florence (Montepaldi) situated in the municipality of S. Casciano, Val di Pesa, FI (Long. 11° 09' 08'' E, Lat. 43° 40' 16'' N.). A biodiversity sustainability evaluation has been applied to the Montepaldi Long Term Organic Experiment (MOLTE) active since 1991. MOLTE includes the following three different micro agro-ecosystems (AES):
a) "Old Organic" area of 5.2 ha, divided into 4 fields, organic since 1991;
b) "Young Organic" area of 5.2 ha, divided into 4 fields, organic since 2001;
c) "Conventional" area of 2.6 ha divided into 2 conventional fields.

Each field covers 1.3 hectares (260 m x 50 m). The agroecosystems are surrounded by the following ecological infrastructures: 1) old organic: natural and artificial hedges; 2) young organic: natural hedges and herbaceous strips of spontaneous flora; 3) conventional: herbaceous strips of spontaneous flora). Following the local land use, a four-year crop rotation is adopted in the organic agro-ecosystems: green manure (barley + vetch) + corn – hard wheat + red clover – red clover – barley; whilst a biennial rotation (barley – corn) is adopted in the conventional agroecosystem.

In order to evaluate the sustainability of the different agroecosystems (old organic, young organic and conventional), the level of biodiversity related to plants has been assessed according to the following aspects: 1) for the structural biodiversity: landscape and crop rotation; 2) for the associated biodiversity: vegetation.

The collected data refer to the period 2002-2005 (Migliorini, 2006). Different agro-ecological indicators characterize different aspect of biodiversity, in order to estimate a specific attribute of the system (Tab. 1). For each single indicator, an optimal (desirable) reference value was selected from the literature (Vereijken, 1997; Vazzana et al., 1997; Caporali et al., 2003), taking into consideration the territorial context and in agreement with the threshold (minimal) level that is in compliance with the EU Reg. 2092/91 and following modifications and integrations.

The landscape within the farm was evaluated through the following indicator
– ecological infrastructure index (EII). Farm area with herbaceous, shrubs and tree vegetation, both natural/untouched and planted/managed, can serve as natural habitat and corridors (ecological infrastructures) for agroecological and landscape purpose.

For the evaluation of crop rotation the following indicators were calculated:
– crop rotation (CR). Species diversity in space and time is the base for sustainable agriculture. The crop rotation of farming systems is defined in relation to many factors like environment, climate, soil, resources, market. Some methodologies (Vereijken, 1997; Vazzana et al., 1997) indicate 6 years as minimum value;

– species adjacency (SA). It refers to the di-
versification of the crop rotation with dif-
ferent crop every year (Vereijken, 1997);
– share species (SS) and share group (SG).
They indicate the percentage of certain
species and botanical groups within the crop
rotation respectively. The prevalence of a
specie or group has to be limited (Vereijken,
1997) to avoid homogeneity.

The associated biodiversity was evaluated
through the following indicators:
– ecological infrastructure arboreal richness
(EIRa) and ecological infrastructure herba-
ceous richness (EIRh). The number of veg-
etable species present in shrubs and arboreal
(hedges) ecological infrastructures (Fig. 1);
– ecological infrastructure arboreal diversity
(EIDa). For the analysis of tree species in
the ecological infrastructures the Braun-
Blanquet method (Braun Blanquet, 1932)
has been used. Covering percentages of
botanical composition were attributed to
each hedge section (Capelletti, 1976). These
indexes were transformed (Van der Maaler,
1972) in order to calculate the Shannon Di-
versity index (Shannon and Weaver, 1963);
– ecological infrastructure herbaceous diversi-
ty (EIDh). For the analysis of herbaceous
species in the ecological infrastructure a lin-
ear analysis (Daget and Passionale, 1969)
was used. Within each sample, the number of
individual for each species was determined
every 20 meters along a transect (Fig. 2). The
Shannon diversity index was calculated;
– crop weeds (number) diversity (CWDn) and
crop weeds (biomass weight) diversity
(CWDw). At crop level – in this case maize
– the spontaneous flora was sampled in the
experimental field, botanically classified,
dried and weighted (Migliorini et al., 2005).
The collected data are the following: weed
density (n. of plant m$^{-2}$); biomass of each
species (gr m$^{-2}$). With these data is possible

Figure 1. List of vegetable species founded in hedges of
Montepaldi agroecosystems.

*Acer campestre, Clamatis vitalba L., Cornus sanguinea
L., Crategus monogyna Jacq., Fraxinus ornus, Populus al-
ba L., Prunus spinosa L., Pyrus pyraster, Quercus cerri,
Robinia pseudoacacia, Rosa canina L., Rubus ulmifolius,
Ulmus campestre.*

Figure 2. List of vegetable species founded in herbaceous
strips of Montepaldi agroecosystems.

*Acer campestre, Adonis aestivalis, Amaranthus deflexus,
Amaranthus retroflexus, Anagallis arvensis, Atriplex
papula, Avena fatua, Bambuseae, Biancospino, Bromus
Hordeaceus, Bromus sterilis, Calystegia spium, Cirsium
arvense, Clematis vitalba, Convolvulus arvensis, Cynodon
dactylon, Dactilis glomerata, Datura stramonium, Daucus
carota, Equisetum arvense, Fallopia convolvulus, foenicu-
lum volgare, Fumaria officinalis, Galium aprine, Hyper-
icum perforatum, Inula viscosa, Javone, Kickxia spuria,
Lathirus, Linaria spuria, Lolium multiflorum, Lolium
perenne, Marrubium volgare, Medicago lupolina, Melilo-
tus alba, Melilotus officinalis, Mercurialis annua, Phalaris
paradoxa, Picris echioides, Plantago lanceolata, Plantago
minor, Poa pratensis, Polygonum aviculare, Polygonum
lapathifolium, Potentilla erecta, Prunus spinosa, Quercus
cerri, Ranunculus arvensis, Rosa canina L., Rubus ulmi-
folius, Rumex acetosa, Sambucus ebulus, Senecio vulgaris,
Sinapis arvensis, Sorghum alepense, Stachys annua,
Taraxacum officinale, Trifolium repens, Ulmus campestre,
Verbena officinalis, Veronica persica, Vicia faba minor, Vi-
cia sativa, Viola arvensis, Vitis vinifera.*

to calculate the Shannon diversity index for
species number and biomass weight.

## 3. Results and discussion

In Table 1 the achieved values of the Biodiver-
sity Indicators are listed for each agro-ecosys-
tem (Old Organic, Young Organic and Conven-
tional) as a mean value for the years 2002/2005.
In order to better underline the comparison, the
indicator value is transformed in relative short-
fall (discrepancy) of achieved (A) to desired
(D) results according to the following formula:
(A-D)/D. Discrepancy values can result between
0 and 1 (Vereijken, 1997; Vazzana et al., 1997).

The amoeba graph (Fig. 3) shows the dis-
crepancies of the three different systems under
analysis for the analysed indicators. The land-
scape indicator, Ecological Infrastructure Index
(EII), results with no discrepancy in the Old Or-
ganic agroecosystem, some discrepancy in the
Young Organic (0,12) and even more in the
Conventional (0,7) that results with higher lev-
el of discrepancy. The Old Organic system is sur-
rounded by strips of natural vegetation and by
two hedges (one natural and the other planted)
which in time reached a good complexity (high
number of species of different typology): this
fact confers to the system an optimal level of
infrastructures, with a positive impact on the

Table 1. List of Agro-ecological Indicators used to evaluate structural and associated biodiversity: algorithm, desired result (D), Achieved result (A) and relative shortfall (discrepancy) in the OldOrganic (OO), NewOrganic (NO) and Conventional (CO) agroecosystems management patterns of Montepaldi farm as average of 2003/2005 years.

| Aspects | Acronym | Indicators | Algorithm | m.u. | Desired result (D) | Literature reference | Achieved result (A) | | | Relative shortfall (A-D)/D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | OO | NO | CO | OO | NO | CO |
| **Structural/planned biodiversity — Landscape and Crop rotation** | EII | ecological infrastructure index | $EII = \dfrac{\sum SupInfrEco}{SAU}$ | % SAU | x > 5 | (1) | 5,69 | 4,40 | 1,50 | 0 | 0,12 | 0,7 |
| | CR | crop rotation | | years | x ≥ 6 | (1) | 4 | 4 | 2 | 0,33 | 0,33 | 0,67 |
| | SA | spices adjacency | | n. | x = 0 | (1) | 0 | 0 | 0 | 0 | 0 | 0 |
| | SS | share spices | $SSi = \dfrac{Mc/12}{\sum^n Mc/12}$ | % tot. Sp | x ≤ 0,167 | (1) | 0,28 | 0,28 | 0,5 | 0,68 | 0,68 | 1 |
| | SG | share group | $SGi = \dfrac{Mg/12}{\sum^n Mg/12}$ | % tot. Gr | x ≤ 0,33 | (1) | 0,33 | 0,33 | 0,5 | 0,32 | 0,32 | 1 |
| **Associated biodiversity — Vegetation** | EIRa | ecological infrastructure arboreal richness | | n. | x > 30 | (1) | 13,00 | 14,00 | 0,00 | 0,57 | 0,53 | 1 |
| | EIDa | ecological infrastructure arboreal diversity | $EID = -\sum_1^n n/N * \log n/N$ | n. | x > 2 | (2) | 2,44 | 2,06 | 0,00 | 0 | 0 | 1 |
| | EIRh | ecological infrastructure herbaceous richness | | n. | x > 40 | (1) | 44,00 | 48,00 | 44,00 | 0 | 0 | 0 |
| | EIDh | ecological infrastructure herbaceous diversity | $EID = -\sum_1^n n/N * \log n/N$ | n. | x > 2 | (2) | 2,22 | 2,10 | 2,07 | 0 | 0 | 0 |
| | CWDn | crop weeds number diversity | $H = \sum_{i=1}^n p_i \ln p_i$ | n. | x > 2 | (2) | 1,69 | 1,19 | 0 | 0,31 | 0,81 | 1 |
| | CWDw | crop weeds weight diversity | $H = \sum_{i=1}^n p_i \ln p_i$ | n. | x > 2 | (2) | 1,34 | 0,86 | 0 | 0,66 | 1,14 | 1 |

Literature reference for fixed desired results: (1): Vereijken, 1997; Vazzana e Raso 1997; (2): Shannon e Weaver, 1963.

overall biodiversity. Furthermore, over the past decade, research has accumulated evidence that long term organic systems are beneficial to biodiversity (Stolton et al., 2000).

For crop rotation, 3 over the 4 analysed indicators are below the desired values for all the three systems, even if the organic systems (Old
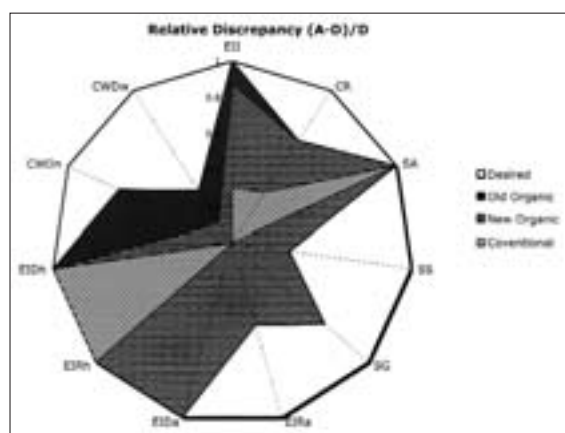


Figure 3. Relative discrepancy of achieved (A) to desired (D) results of agro-ecological indicators used to evaluate biodiversity in the OldOrganic (OO), NewOrganic (NO) and Conventional (CO) agroecosystems of Montepaldi farm as average of 2003/2005 years. A larger area corresponds to fewer discrepancies and, thus, to more desired value results.

and Young) result with discrepancy values that are half of the Conventional, due to the a larger crop rotation. To improve the rotation, nitrogen-fixing, polyannual leguminous crops could be introduced in mixed farms where forage is used for animal feeding. More difficult is to find a solution in agroecosystems without animals.

The evaluation of associated biodiversity (vegetation) presents very interesting results. The diversity both of herbaceous (EIDh) and trees and shrub hedge (EIDa) plants in the ecological infrastructure is higher in the Old Organic followed by the Young Organic and the Conventional. Moreover, for that concerns the weed flora in the field, a more equilibrated community evolved in time under organic management, with higher number of species (CRWn) each represented by a lower weight of individual (CRWw).

The conventional system treated with chemical herbicide resulted with the maximum discrepancy for weed's biodiversity.

## 4. Conclusions

The analysis of agroecosystem sustainability, performed through the calculation of biodiver-

sity indicators, evidences that the system under organic agriculture management improves each of the studied aspects over the time and it is better than conventional for every indicator.

Organic agriculture after many years of application can reach satisfaction level of biodiversity. This tendency is emphasised if we consider the associated biodiversity. The impact on biodiversity of organic farming, in relation to conventional agriculture, results in agreement with a review of comparative studies of the two methods (conventional and organic), in order to determine whether it can deliver beneficial services to biodiversity. However, organic agroecosystems considered in our experiment can be improved with larger crop rotation and the introduction of polyannual leguminous crops.

In order to fill in the gaps in our knowledge of the impacts of organic farming on associated biodiversity, there is a real need for system-level (holistic-whole-farm approach) studies before a full use of its potential role in biodiversity conservation in agroecosystems can be made.

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