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Evaluation of sustainability: results from a long term experimental arable systems in Tuscany

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Summary

The research is aimed at implementing a methodology in order to estimate the sustainability of an agricultural system, through the use of Agro-ecological and Sustainability Indicators. The methodology is applied to three stockless, experimental agricultural systems, part of a long- term experiment (MOLTE) managed with diverse typologies (old organic, new organic vs conventional). The results derived from the three different management systems are estimated by considering crop rotation and efficiency in terms of energetic, macro-element (N, P, K) and organic matter flow. These are related to the landscape and biodiversity system, as well as the soil and the environmental system. The research shows that the agro-ecosystems managed with the organic agriculture method has succeeded to attain optimal levels of sustainability. Independently of time duration from conversion, the organic systems are better than the conventional system for all indicators, with the exception of the soil indicators that showed remarkable resilience.

Key Words: Sustainability and agro-ecological indicators, organic *vs* conventional agriculture, long-term experiment, crop rotation, farm efficiency, biodiversity, soil quality, environmental risk

Introduction

Agricultural sustainability is defined as a `property', that is the ability of an agro-ecosystem to either maintain or to implement the productive characteristics over time when subject to an action of disturbance (Conway, 1987), taking into consideration both the ecological-environmental and socio-economic aspects (Altieri, 1987).The use of sustainability indicators has become a frequent instrument in the evaluation of agricultural systems (Bockstaler *et al*., 1997; Dalsgaard *et al.,* 1997; Tellaini & Caporali, 2000; Mancinelli, 2000; Morse *et al.* 2001; Lopez-Ridaura *et al*., 2002; Nicholls *et al*., 2004;). 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, 1999; Vazzana & Raso, 1997) was aimed at the evaluation of the sustainability using a systems approach, and was applied on farms from 17 countries The methodology provided an important contribution both for the definition of a reference levels for agro-environmental indicators and for the assessment of a prototype agro-ecosystem with respect to its ability to achieve specific objectives. Long-term experiments (LTE) are essential in order to supply empirical data for a sustainability estimation of an agricultural system. As far as organic agricultural systems are concerned, sustainability is strongly linked to the acquisition of a self-regulatory ability within the system that is in need to re-establish relations and an equilibrium between the various biotic and abiotic components (Leight & Johnston, 1994; Mader *et al*., 2002; Pimentel *et al*., 2005; Raupp *et al*., 2006). According to the organic vision, the farm is a complex system and a living organism that aspires to a closed cycle. The livestock activity is strategic as it aids the cycling of the elements through the production of manure and the maintenance of soil fertility. Unfortunately, animals are not always present on organic farms (Migliorini, 2005). However, are such stockless organic farms sustainable over a long period? Furthermore, is this type of management better than the conventional method? If so, for which aspects and under which conditions?

Material and Methods

For the evaluation of sustainability of both stockless organic and conventional agro-ecosystems, a methodology has been adopted in which the following steps have been implemented: agro-ecological characterisation of cases studies, through description of the climate, topography, land use, landscape and biodiversity; description of the production processes that characterize and quantify both the system inputs (diesel oil, lubricants, seeds, fertilisers, manure, pesticides), and outputs (product yields, re-use, cultural residues); calculation of the Sustainability and Agro-ecological Indicators for the following aspects: 1) biodiversity and the landscape; 2) crop rotation; 3) soil fertility; 4) the efficiency of macro-elements, organic matter and energy; 5) environmental risk.

The collected data refer to agrarian years, 2002/2003, 2003/2004 and 2004/2005. Each of the five aspects is characterised by various indicators, in order to estimate a specific attribute of the system (Table 1). An optimal (desirable) value, for every indicator, is selected from the scientific literature, adapted to the territorial context and to the threshold (minimal) level in compliance with requirements by organic agricultural regulations (Reg. the EEC 2092/91 and following modifications and integrations). This methodology has been applied to the Montepaldi Farm of the University of Florence situated in the municipality of S. Casciano, Val di Pesa, FI, subject to a long term organic experiment (MOLTE). The sustainability evaluation methodology has been

1 WA: Wood area (Lazzerini *et al.*, 2001; Caporali, 2003): FA: Field adjacency; CFS: crop field size; FLW: Field length-with (Vereijken, 1997; Vazzana & Raso, 1997); FD: Field density (Caporali, 2003); EII: ecological infrastructure index; EIRar: ecological infrastructure arboreal richness (Vereijken, 1997; Vazzana *et al.*, 1997); EIDar: ecological infrastructure arboreal diversity (Shannon & Weaver, 1963); EIRhe: ecological infrastructure herbaceous richness (Vereijken, 1997; Vazzana *et al.*, 1997); EIDhe: ecological infrastructure herbaceous diversity (Shannon & Weaver, 1963); CR: crop rotation; SA: Spices adjacency; SS: share spices; SG: share group (Vereijken, 1997; Vazzana *et al.*, 1997); SCIa: soil cover index annual; SCIc: soil cover index critic period (Vazzana *et al.*, 1997); OMARs: organic matter soil reserve; TNAR: total nitrogen annual reserve; PAR: phosphate available annual reserve; KAR: Potash exchangeable annual reserve (Vereijken, 1997; Vazzana *et al.*, 1997); C/N: carbon-nitrogen ratio (Vazzana *et al.*, 1997); NRRD: non renewable resources dependency; RE: re-use; OS: overall sustainability; IR: immediate removal; GT; Gross tot output from tot input; GS: Gross sold output from total external input (Tellarini & Caporali, 2000; Migliorini, 2006); OMDif: Humic balance (input-output); OMAB: Organic matter annual balance (input/output) (Vereijken, 1997; Migliorini, 1998); GNR: Gross tot output from non renewable external input (Tellarini & Caporali, 2000; Migliorini, 2006); ND: net drainage (Landi, 1999); Potential nitrate leaching (Vereijken, 1997; Vazzana e Raso 1997); GUS: Groundwater Ubiquity Score (Gustafson, 1993)

2 Hypothesis are verified by ANOVA and the average multiple comparisons are carried out by Bonferroni test at the level of probability, as follows: very significant $P < 0.01$ (**); significant $P < 0.05$ (*); non significant (n.s.).

3 Relative shortfall (discrepancy) of achieved (A) to desired (D) results

Table 1. *Sustainability and Agro-ecological Indicators list used to evaluate environmental and management system: Achieved results and relative shortfall in the experimental OldOrganic (OO), NewOrganic (NO) and Conventional (CO) agro-ecosystems of Montepaldi farm as average of 2003/2005 years*

Environmental and management system			Acronimy[1]	m.u.	Desired level (D)	Achieved result (A)[2]			Relative Shortfall (A-D)/D[3]		
						OO	NO	CO	OO	NO	CO
1. Landscape and Biodiversity			WA	% SAT	x > 10	34,64	34,64	34,64	0,00	0,00	0,00
			FA	n.	x = 1	1,00	1,00	1,00	0,00	0,00	0,00
			CFS	Ha	x > 1	1,30	1,30	1,30	0,00	0,00	0,00
			FLW	m/m	x > 4	5,20	5,20	5,20	0,00	0,00	0,00
			FD	n. ha-1	max	0,77	0,77	0,77	0,00	0,00	0,00
			EII	% SAU	x > 5	5,69	4,40	1,50	0,00	0,12	0,70
			EIRar	n.	x > 40	13,00	14,00	0,00	0,57	0,53	1,00
			EIDar (**)	n.	x > 2	2,44	2,06	0,00	0,00	0,00	1,00
			EIRhe	n.	x > 40	44,00	48,00	44,00	0,00	0,00	0,00
			EIDhe (**)	n.	x > 2	2,22	2,10	2,07	0,33	0,33	0,67
2. Crop rotation			CR	years	x ≥ 6	4	4	2	0,00	0,00	0,00
			SA	n.	x = 0	0	0	0	0,68	0,68	1,00
			SS	% tot. Sp	x ≤ 0,167	0,28	0,28	0,5	0,32	0,32	1,00
			SG	% tot. Gr	x ≤ 0,25	0,33	0,33	0,5	0,00	0,00	0,00
			SCIa	% months	x > 50	74,44	74,44	52,29	0,00	0,00	0,23
			SCIc	% months	x > 60	82,92	82,92	46,25	0,33	0,33	0,67
3. Soil			OMARs (n.s.)	%	x ≥ 2,5	1,63	1,65	1,51	0,35	0,34	0,40
			TNAR (n.s.)	‰	x > 1,5	1,19	1,21	1,08	0,21	0,19	0,28
			PAR (n.s.)	Ppm	35 < x < 25	61,75	83,67	69,95	0,76	1,00	1,00
			KAR (n.s.)	Ppm	150 < x < 200	128,16	143,27	137,53	0,15	0,04	0,08
			C/N (n.s.)	n.	9 < x < 12	8,03	8,06	8,34	0,11	0,10	0,07
4. Farm efficiency	Macro elements efficiency	Nitrogen (N)	NRRD (**)	kg/kg	min	0,00b	0,00b	0,63a	0,00	0,00	0,63
			RE (n.s.)	kg/kg	max	0,12	0,11	0,00	0,01	0,08	1,00
			OS (**)	kg/kg	max	1,00a	1,00a	0,37b	0,00	0,00	0,63
			IR (n.s.)	kg/kg	min	0,84	0,84	1,00	0,00	0,00	0,19
			GT (**)	kg/kg	max	0,76a	0,66a	0,37b	0,01	0,13	0,52
			GS (**)	kg/kg	0,8 < x < 1,0	0,72a	0,62a	0,37b	0,10	0,22	0,54
		Phosphate (P2O5)	NRRD (**)	kg/kg	min	0,00a	0,00a	0,98b	0,00	0,00	0,98
			RE (n.s.)	kg/kg	max	0,33	0,36	0,00	0,08	0,00	1,00
			OS (**)	kg/kg	max	1,00a	1,00a	0,02b	0,00	0,00	0,98
			IR (n.s.)	kg/kg	min	0,82	0,77	1,00	0,06	0,01	0,30
			GT (*)	kg/kg	max	2,46a	1,76ab	0,20b	0,00	0,29	0,92
			GS (n.s.)	kg/kg	1,0 < x < 1,2	4,51	4,17	0,20	1,00	1,00	0,83
		Potash (K2O)	NRRD	kg/kg	min	0,00	0,00	0,00	0,00	0,00	0,00
			RE (n.s.)	kg/kg	max	0,62	0,60	0,00	0,01	0,04	1,00
			OS	kg/kg	max	1,00	1,00	1,00	0,00	0,00	0,00
			IR (n.s.)	kg/kg	min	0,56	0,57	1,00	0,01	0,02	0,79
			GT (**)	kg/kg	max	2,15a	1,88a	30,51b	0,93	0,94	0,00
			GS (n.s.)	kg/kg	0,8 < x < 1,2	17,80	17,07	30,51	1,00	1,00	1,00
	S.O. Efficiency		OMDif	Kg/ha	x > 0	-675,59	-664,26	-659,37	1,00	1,00	1,00
			OMAB (n.s.)	kg/kg	x > 1	0,43	0,43	0,40	0,57	0,57	0,60
	Energetic efficiency		NRRD (**)	Mj/Mj	min	0,70b	0,71b	0,90a	0,00	0,02	0,29
			RE (n.s.)	Mj/Mj	max	0,12	0,10	0,00	0,01	0,13	1,00
			OS (**)	Mj/Mj	max	0,30a	0,29a	0,10b	0,00	0,04	0,68
			IR (*)	Mj/Mj	min	0,95b	0,96a	1,00a	0,00	0,01	0,05
			GT (*)	Mj/Mj	max	3,35a	2,79ab	2,03b	0,00	0,17	0,40
			GNR (*)	Mj/Mj	max	4,81a	3,93ab	2,24b	0,00	0,18	0,53
			GS (n.s.)	Mj/Mj	max	3,20	2,66	2,03	0,00	0,17	0,37
5. Environmental risk			ND	$m\ ha^{-1}$	x > 90	190	190	175	0,00	0,00	0,00
			PNL (n.s.)	kg	x < 70	74,80	113,80	166,80	0,07	0,63	1,00
			EEP	$kg\ ha^{-1}$	x < 1,8	0,00	0,0	2,50	0,00	0,00	0,39

applied on three micro agro-ecosystems (AES): (a) "Old Organic" area of 5.2 ha, divided into 4 fields, organic since 1991; (b) "New Organic" area of 5.2 ha, divided into 4 fields, organic since 2001; (c)"Conventional" area of 2.4 ha divided into 2 conventional fields.

Each field is 1.3 hectares (260 m × 50 m). The agro-ecosystem is surrounded by ecological infrastructures (hedge, natural and/or planted and/or spontaneous herbaceous strips). A four-year crop rotation was adopted in the organic agro-ecosystems (barley-green manure+corn-barley+clover-clover), whilst a biennial rotation (barley-corn) was adopted in the conventional agroecosystem. The present crop rotation is adapted to the typical land use and the farm typology of the pedo-climatic zone.

Results

In Table 1, both the values and the relative shortfall (discrepancies) of the Indicators are listed for each agro-ecosystem as a mean value for the years 2003/2005. The following may be concluded:
1. for the landscape and the biodiversity aspects, all the indicators are satisfactory, with the exception of the Ecological Infrastructures Arboreal Richness (EIR);
2. crop rotation indicators are below the desired level in all the systems, although the organic systems are closer to the desired values and superior to those of the conventional;
3. regarding soil fertility, both organic and conventional systems do not satisfy the optimal values for organic matter reserve (OMAR), total nitrogen reserve (tNAR), phosphate available reserve (PAR) and Potash exchangeable reserve (KAR). However, the Old Organic system shows lower discrepancies compared to New Organic and Conventional systems;
4. macro-elements (N, P, K) and energy efficiency is much higher in organic systems than in conventional, while all the systems have very high discrepancies for organic matter efficiency indicating poor organic matter management
5. environmental impact is negligible in the Old Organic, requires attention for the New Organic and of great concern for the conventional system.

Discussion

The analysis of the agro-ecosystem through the Sustainability and Agro-ecological Indicators demonstrates that a stockless farm, organically managed for many years, attains an optimal level of sustainability. The organic system is better than that of the conventional for all the indicators provided, with the exception of the soil indicators that showed remarkable resilience to change.

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