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Invertebrates and nutrients in a Mediterranean vineyard mulched with subterranean clover (*Trifolium subterraneum* L.)

Maria Rosanna Favretto[1], **Maurizio Guido Paoletti**[1], **Fabio Caporali**[2], **Paolo Nannipieri**[3], **Antonio Onnis**[4], **and Paolo Emilio Tomei**[4]

[1] Department of Biology, University of Padova, Via Trieste 75, I-35100 Padova, Italy
[2] Department of Agronomy and [3] Agrochemistry, University of Tuscia, I-01100 Viterbo, Italy
[4] Department of Botany, University of Pisa, I-56100 Pisa, Italy

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Summary In the 25-year-old vineyard of a farm near the Maremma National Park (Central Italy), replicate plots were established with a mulch of *Trifolium subterraneum* L. or cultivation and two levels of fertilizer. The main objective of this research was to analyse responses by soil invertebrates and nutrients after introducing a herbaceous component into the system; the yield was also considered. The greater availability of organic substrate and the reduced cultivation as a result of green mulching increased the soil mesofauna biomass, especially detritivores. With time, a significant difference became evident between the populations of invertebrates present in the mulched plots and those in the cultivated plots. Over 2 years, most nutrients (Ca, K, P, and N) were significantly increased in the mulched plots compared to the cultivated plots. Grape yields were consistently higher in the bare plots. No significant differences were found in fertilizer effects.

Key words: Vineyard – Mulch – Subterranean clover – *Trifolium subterraneum* L. – Soil mesofauna – Soil nutrients

Periodic soil tillage, which tends to minimize water and nutritient competition between cultivated plants and weeds in orchards, is one of the most ancient soil management methods in viticulture, being mainly used in areas with low precipitation.

When the plant cover is removed, the bare soil is subject to phenomena such as the degradation of soil structure and consequent erosion, and a reduction in biota (bacteria, fungi, anellids, and arthropods) associated with a drastic reduction in the soil organic matter content (Dindal 1990; Seastedt 1984). In recent times, as a result of the tendency towards low-input agriculture and sustainable use of natural resources, no-tillage in association with living mulch has attracted increasing attention (Finch and Sharp 1981; Hargrove 1982).

Correspondence to: M.G. Paoletti

The application of a mulch has agronomic advantages including the control of weeds and erosion, an improvement in soil physical structure, and the biological fixation of atmospheric N when a leguminous plant is used (Finch and Sharp 1981; Hargrove 1982; Hargrove 1986; Power 1987). These effects increase the complexity of the agroecosystems and provide habitats and resources for a range of invertebrates (Altieri and Letourneau 1982; Altieri et al. 1985).

Living mulch trials and associated research on soil macrofauna and insects inhabiting the mulch vegetation have demonstrated an increase in pollen-feeding insects and significant abundance and efficiency of predators and parasitoids of pests following the use of cover crops (Altieri and Letourneau 1982; Altieri and Schmidt 1985; Altieri and Schmidt 1986; Buggs and Ellis 1988; Buggs and Dutcher 1989).

In a vineyard of a National Park area in Central Italy (Tuscany), an experimental trial with subterranean clover (*T. subterraneum* L.) as a mulch was established in order to evaluate fertility, biotic activity, and yield in comparison with traditional management. This reseeding leguminous plant has recently aroused interest because of its particular life-cycle; it has been used in several cropping systems (Morley 1961; McGuire 1985; Ilnicki and Vitolo 1986; Caporali et al. 1987; Enache and Ilnicki 1990). The choice of this plant for a mulch in the vineyard was based on agro-ecological factors. It is suitable for the hot–warm climate of the Mediterranean area and develops a dense cover, competing with weeds and preventing erosion (growing in periods of most abundant precipitation) and its vegetative cycle is asynchronous with that of the vine. This last factor is very important in the area studied, where precipitation is scarce (Fig. 1) and competition for water resources is a limiting factor for crops.

In agro-ecosystems, soil invertebrates are strongly influenced by soil management (Foissner 1987; Paoletti 1987; Dindal 1990; Stinner and House 1990). The presence of soil invertebrates is a useful measure of the disturbance induced by human activity (Crossley et al. 1989; Hendrix et al. 1990; Paoletti et al. 1991).

The main purpose of the present research was to compare the soil fauna in plots with and without mulch. Soil analyses were also conducted to evaluate possible changes due to the introduction of *T. subterraneum*.

Material and methods

The experiment was established in a 25-year-old vineyard in the Maremma National Park (Tuscany) with a mulch of subterranean clover (*T. subterraneum* L. cv. Mount Barker) which had been sown in November 1987.

Two contiguous mulched inter-row spaces were alternated with two tilled inter-row spaces. The trial was carried out as a Split-plot design, the main plots consisting of the mulched and cultivated treatments and the subplots of fertilized vs. unfertilized treatments. The fertilizer applied was Nitrophoska (Table 1). To control pests, S was applied at 20 kg ha^{-1} and copper sulphate at 5 kg ha^{-1}. The experiment was replicated three times. Each plot was 339 m^2 in area. The control plots were cultivated several times a year to prevent weeds growing.

Seasonal samplings for mesoinvertebrates were made from May 1988 to March 1990. A soil corer (diameter 7.5 cm) was used to sample the soil to a depth of about 11 cm. Three cores were taken from each of the 12 plots on each sampling date, giving a total of nine samples collected from each treatment (except for the mesofauna sampling on March 19, 1990, when only six samples were taken).

The soil was superficially (0.20 cm) sampled, air-dried, sieved (<2 mm), and analysed for its nutrient concentrations. Organic matter and total N were determined by the Walkey–Black procedure (Nelson and Sommers 1982) and the Kjeldhal method (Bremner 1965), respectively. The cation exchange capacity was determined after saturating the soil with Ba^{2+}, and exchangeable Ca^{2+}, K^+, and Na^+ were determined on the supernatants (Rhoades 1982). Total and available ($NaHCO_3$-soluble) P were determined as reported by Olsen and Sommers (1982).

The fauna was extracted with a modified Tullgren apparatus (Paoletti et al. 1991), and then preserved in ethanol. A stereomicroscope (50–100×) was used for identification. Cores taken on four of the sampling dates, which had been previously used for mesoinvertebrate extraction, were air-dried, sieved (<2 mm), and analysed for Ca, K, P, Na, N, C, and organic matter.

Data were analysed by two-way analysis of variance (STATPRO 1985).

Results

Soil

Some nutrients, in particular those in an assimilable form (Ca, Mg, K), were found in the greatest quantity in the bare soil plots (Tables 2, 3) 6 months after sowing the mulch (May 1988). At the next sampling (December 1988) only certain nutrients (Ca and P) differed significantly between the treatments (Table 2). The data from the last two analyses (respectively 24 and 28 months after establishment) clearly showed a significantly greater presence of nutrients, particularly total N and Ca, both assimilable and total, in the mulch plots. Over 2 years the increase in organic matter was about 1% in plots with subterranean clover and no fertilizer (Table 3). Fertilizer effects, apart from those in samples taken after 6 months, were restricted to assimilable P only; N and K apparently had no treatment effects.

Table 1. Rates of fertilizer application in some vineyard plots

Date	Nitrophoska ($t\ ha^{-1}$)	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)
November 7, 1987	0.6	90	54	90
November 16, 1988	0.5	75	45	75
February 14, 1990	0.6	90	54	90

Soil and invertebrates

Average invertebrate numbers generally varied with sample dates, reflecting changes in soil moisture (Fig. 1, Table 4). The lowest number of invertebrates was found in the dry, dead mulch plots (September 1988 and June 1989). Bare plots had the lowest faunal biomass (Table 4).

The absence of mulch and tillage resulted in a significant reduction in the mesoinvertebrate population (Ta-

Table 2. Analysis of variance results for element contents

	Mulching	Fertilizer	Interaction
May 3, 1988			
Total Ca	9.519 (+)	6.828 (+)	19.039
Assimilable Ca (CaO)	6.527 (−)		
Exchangeable K (K_2O)	50.068 (−)		
Total Na	4.613 (+)	11.798 (−)	
Total P	5.519 (−)	6.452 (+)	
Assimilable P (P_2O_5)		5.370 (+)	
Organic C (%)		7.730 (+)	
Organic matter (%)		7.730 (+)	
Total N (%)	28.398 (+)		
C:N	61.720 (−)	13.280 (+)	
Total Cu	7.910 (−)		4.609
Assimilable Cu	10.120 (−)		
Assimilable Pb	5.920 (+)		
pH	11.150 (−)		
December 8, 1988			
Assimilable Ca (CaO)	6.051 (+)		
Assimilable P (P_2O_5)	9.041 (−)	6.636 (+)	
pH	6.511 (+)		
November 30, 1989			
Total Ca	11.468 (+)		
Assimilable Ca (CaO)	15.739 (+)		
Exchangeable K (K_2O)	19.248 (+)		
Assimilable P (P_2O_5)		9.694 (+)	
Organic C (%)	24.998 (+)		5.202
Organic matter (%)	24.998 (+)		5.202
Total N%	27.015 (+)		
pH	11.043 (+)		6.368
March 19, 1990			
Total Ca	8.2493 (+)		
Assimilable Ca (CaO)	5.281 (+)		
Total P	7.930 (+)		
Assimilable P (P_2O_5)	18.488 (+)	10.512 (+)	
Organic C (%)	40.902 (+)		
Organic matter (%)	40.902 (+)		
Total N (%)	17.074 (+)		
C:N	5.147 (+)		
pH		13.647 (−)	12.729

The effect of the presence of *Trifolium subterraneum* of fertilizer produced an increase (+) or decrease (−) in the parameters measured. The analysis of heavy metals was carried out only for soil sampled in May, 1988

Statistically significant F values are given ($P<0.05 \rightarrow F=4.15$; $P<0.01 \rightarrow F=7.51$)

Table 3. Nutrient concentrations in soil

	Mulched, fertilized		Mulched, unfertilized		Bare, fertilized		Bare, unfertilized	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
May 5, 1988								
pH	5.10	0.09	5.10	0.05	5.44	0.24	5.48	0.27
Total Ca (ppm)	3030.00	168.00	2743.40	158.90	1810.50	577.60	2425.60	309.75
Assimilable Ca (ppm)	844.60	57.70	820.60	25.70	922.50	142.08	984.33	139.06
Total K (ppm)	9044.70	403.70	8001.20	298.40	8391.30	663.18	8420.44	966.50
Exchangeable K (ppm)	353.70	21.40	355.50	29.20	534.70	68.58	503.22	45.31
Total P	922.70	27.00	873.80	50.80	1070.30	130.15	915.11	90.51
Assimilable P (ppm)	113.00	2.20	104.00	16.04	126.80	22.35	109.44	15.59
Total Na (ppm)	490.30	12.70	532.80	12.00	461.50	40.82	506.77	33.28
Assimilable Na (ppm)	20.00	1.30	17.30	1.20	21.00	2.20	16.60	0.80
Total N (%)	0.96	0.05	1.16	0.34	0.69	0.10	0.69	0.06
Organic C (%)	0.92	0.04	0.78	0.08	0.95	0.18	0.83	0.11
C:N	9.71	0.42	7.30	0.75	13.61	1.08	14.45	6.94
Organic matter (%)	1.58	0.07	1.35	0.15	1.63	0.31	1.42	0.19
December 8, 1988								
pH	5.47	0.36	5.66	0.47	5.06	0.10	5.40	0.43
Total Ca (ppm)	1967.33	292.10	2068.55	562.17	1783.44	159.07	1786.60	213.54
Assimilable Ca (ppm)	679.55	98.79	734.00	155.50	607.00	74.54	619.88	81.02
Total K (ppm)	7907.10	1642.20	7968.55	686.30	7730.00	636.73	7578.00	1341.91
Exchangeable K (ppm)	552.66	102.56	497.55	90.46	481.33	55.53	465.44	30.93
Total P	1119.88	101.75	1061.44	141.21	1168.80	124.49	1162.33	88.48
Assimilable P (ppm)	109.33	21.88	93.77	15.94	129.77	19.66	112.11	14.49
Total Na (ppm)	367.33	69.48	418.55	106.62	368.11	50.35	372.40	61.06
Total N (%)	0.83	0.12	0.88	0.09	0.84	0.07	0.78	0.07
Organic C (%)	0.76	0.07	0.78	0.15	0.74	0.06	0.70	0.03
C:N	9.18	0.69	8.80	1.06	8.84	1.00	9.07	0.85
Organic matter (%)	1.31	0.12	1.35	0.27	1.28	0.11	1.21	0.06
November 30, 1989								
pH	5.39	0.26	5.66	0.20	5.34	0.13	5.27	0.14
Total C (ppm)	1405.89	209.41	1555.44	418.44	1219.78	160.98	1121.22	153.53
Assimilable Ca (ppm)	863.44	174.14	1044.33	373.98	647.11	125.73	640.11	98.66
Total K (ppm)	9651.00	1135.97	9860.67	927.29	9333.22	1334.72	9049.67	1491.46
Exchangeable K (ppm)	584.78	78.33	652.89	97.89	510.22	56.78	502.67	45.35
Total P	1129.78	179.80	1027.56	272.83	1085.56	208.10	1045.11	167.03
Assimilable P (ppm)	98.38	14.91	80.74	15.03	96.92	19.92	80.37	10.93
Total Na (ppm)	657.33	71.63	712.78	84.04	654.89	44.63	661.67	47.53
Assimilable Na (ppm)	28.35	4.04	30.62	5.33	27.61	6.15	26.25	2.98
Total N (%)	0.90	0.13	1.08	0.30	0.69	0.05	0.64	0.12
Organic C (%)	1.12	0.17	1.46	0.46	0.88	0.07	0.81	0.04
C:N	12.66	2.31	13.60	1.74	12.80	1.17	13.28	2.78
Organic matter (%)	1.93	0.29	2.52	0.80	1.52	0.13	1.40	0.08
March 19, 1990								
pH	5.17	0.15	5.62	0.21	5.31	0.15	5.31	0.18
Total Ca (ppm)	1110.56	179.14	1373.11	400.80	1045.67	119.66	970.33	71.07
Assimilable Ca (ppm)	870.56	87.66	1072.89	332.18	837.56	137.03	799.89	70.80
Total K (ppm)	9519.11	727.92	9709.33	515.46	9705.11	1085.06	10457.56	748.96
Exchangeable K (ppm)	572.00	71.32	570.00	66.24	636.22	127.04	530.33	40.73
Total P	1096.89	312.97	1075.44	88.25	975.78	158.82	825.44	89.23
Assimilable P (ppm)	112.53	23.27	89.61	14.90	81.63	28.07	55.56	16.56
Total Na (ppm)	757.56	74.55	810.89	89.51	777.33	59.90	824.00	72.47
Assimilable Na (ppm)	31.14	6.96	30.08	5.15	32.06	5.57	28.98	5.20
Total N (%)	1.00	0.20	1.17	0.25	0.80	0.17	0.83	0.09
Organic C (%)	1.22	0.17	1.36	0.33	0.84	0.12	0.82	0.10
C:N	12.41	1.75	11.77	2.05	10.95	2.64	10.03	1.33
Organic matter (%)	2.09	0.29	2.34	0.57	1.45	0.20	1.41	0.17

Means and SD, nine sample per subplot

Table 4. Principal taxa in each sample

		May 3, 1988		Sept. 17, 1988		Dec. 8, 1988		April 8, 1989		June 11, 1989		Nov. 30, 1989		March 19, 1990	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Oribatida	MF	0.66	0.81	1.66	4.37	8.33	10.36	9.66	7.70	44.33	65.51	11.22	11.16	24.88	38.43
	MFN	0.55	0.95	11.55	14.15	10.00	18.46	15.77	15.54	34.00	30.89	23.11	18.05	27.88	28.61
	BF	1.66	1.76	1.77	3.01	4.44	4.44	6.88	5.68	0.11	0.31	27.88	26.96	6.16	5.87
	BNF	2.22	1.61	0.66	1.05	4.33	6.32	3.77	3.25	0.33	0.66	22.77	23.26	5.00	2.38
Astigmata	MF	4.00	3.74	5.66	9.10	16.11	12.74	86.22	48.56	2.00	2.35	0.88	1.28	0.33	0.47
	MFN	8.00	4.52	6.77	8.72	19.22	16.08	88.77	59.11	3.44	4.66	0.77	0.78	0.88	0.99
	BF	27.88	25.97	1.88	3.24	7.55	9.96	14.44	15.10	0.11	0.31	0.00	0.00	4.00	3.82
	BNF	33.22	22.07	1.55	2.00	9.88	8.33	14.00	15.79	0.22	0.41	0.22	0.41	4.83	4.84
Prostigmata	MF	0.66	0.94	0.44	0.68	0.55	0.95	7.88	6.15	7.44	10.96	3.66	1.94	1.77	1.87
	MFN	1.00	1.24	0.00	0.00	1.88	2.84	5.55	4.62	2.00	3.74	1.88	3.03	3.22	2.39
	BF	0.11	0.34	1.66	3.09	2.11	1.96	0.33	0.66	6.88	4.53	1.22	2.77	4.83	3.48
	BNF	0.44	0.68	0.44	1.42	2.44	2.21	0.55	0.68	7.00	3.82	0.33	0.66	4.50	3.77
Uropodidae	MF	0.00	0.00	0.00	0.00	7.00	19.79	0.00	0.00	0.00	0.00	0.66	0.81	0.11	0.31
	MFN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	1.85	0.22	0.62
	BF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.31	0.00	0.00
	BNF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mesostigmata	MF	1.22	1.81	2.22	2.81	13.55	15.92	8.11	5.95	11.22	7.03	14.00	7.90	9.66	6.01
(Uropodidae	MFN	1.44	1.34	1.33	1.15	8.33	8.91	9.88	5.72	6.22	4.58	15.55	6.78	11.77	6.01
excluded)	BF	6.77	8.81	0.88	1.28	1.11	1.66	2.88	3.17	0.66	0.94	0.66	0.81	4.00	3.51
	BNF	2.77	3.96	0.44	0.83	0.44	0.95	2.22	1.93	0.22	0.62	0.55	0.68	5.16	3.71
Collembola	MF	9.88	5.44	0.22	0.41	41.77	25.76	10.11	7.92	1.11	1.44	143.00	72.44	91.11	52.20
	MFN	3.33	3.12	0.22	0.41	41.88	28.72	19.22	33.01	1.11	1.28	141.55	102.21	52.11	32.42
	BF	14.22	12.02	0.22	0.62	7.11	4.99	8.00	5.53	0.00	0.00	3.33	3.05	8.33	10.69
	BNF	4.77	2.89	0.11	0.31	3.88	3.57	1.00	1.24	0.00	0.00	1.55	1.34	7.50	6.07
Insect larvae	MF	7.33	4.42	0.44	0.68	2.11	1.72	3.55	2.83	2.55	2.62	4.22	3.11	16.11	14.46
	MFN	4.22	4.96	0.11	0.31	3.00	2.90	3.88	3.34	2.11	2.68	9.77	12.81	7.77	5.24
	BF	1.00	1.20	0.22	0.41	0.33	0.66	0.66	0.66	0.00	0.00	0.44	0.68	0.83	0.68
	BNF	0.11	0.31	0.00	0.00	0.11	0.31	0.11	0.31	0.00	0.00	0.11	0.31	0.66	0.74
Thysanoptera	MF	2.22	3.58	0.00	0.00	0.11	0.31	0.11	0.31	0.22	0.41	0.00	0.00	0.00	0.00
	MFN	2.66	2.74	0.00	0.00	0.44	0.68	0.33	0.66	0.22	0.41	0.44	1.25	0.00	0.00
	BF	0.00	0.00	0.00	0.00	0.11	0.31	0.00	0.00	0.11	0.31	0.00	0.00	0.00	0.00
	BNF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psocoptera	MF	0.00	0.00	0.55	0.95	0.00	0.00	0.44	0.95	45.44	27.60	0.00	0.00	0.00	0.00
	MFN	0.00	0.00	0.33	0.47	0.11	0.31	0.55	0.95	32.11	17.41	0.00	0.00	0.00	0.00
	BF	0.00	0.00	0.55	0.83	0.00	0.00	0.00	0.00	0.33	0.94	0.00	0.00	0.00	0.00
	BNF	0.00	0.00	0.33	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pauropoda	MF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	1.03	1.88	2.55
	MFN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.55	2.36	3.77	3.22
	BF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.66	0.33	0.74
	BNF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.41	0.33	0.47
Symphyla	MF	0.00	0.00	0.00	0.00	0.33	0.66	0.00	0.00	0.00	0.00	0.44	0.68	0.00	0.00
	MFN	0.00	0.00	0.00	0.00	0.22	0.41	0.11	0.31	0.00	0.00	0.55	0.95	0.00	0.00
	BF	0.00	0.00	0.00	0.00	0.11	0.31	0.55	0.95	0.00	0.00	0.22	0.41	0.00	0.00
	BNF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.37
Enchy-	MF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.95	1.00	0.94
traeidae	MFN	0.00	0.00	0.00	0.00	0.11	0.31	0.00	0.00	0.00	0.00	1.55	1.64	1.00	2.49
	BF	0.00	0.00	0.00	0.00	0.11	0.31	0.00	0.00	0.00	0.00	0.11	0.31	0.00	0.00
	BNF	0.00	0.00	0.00	0.00	0.11	0.31	0.11	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Other taxa	MF	1.00	0.81	1.00	0.94	1.56	2.06	3.66	2.49	2.33	2.10	4.11	3.41	3.00	1.33
	MFN	0.44	0.49	0.88	0.87	2.11	1.44	4.11	3.54	2.55	1.89	4.11	1.09	2.33	2.82
	BF	1.77	1.68	2.00	1.88	0.33	0.66	0.33	0.94	0.00	0.00	0.44	0.49	0.83	1.21
	BNF	0.66	0.81	1.55	2.49	0.66	1.24	0.22	0.41	3.88	7.26	0.33	0.66	1.50	1.50
Total	MF	27.08	7.37	12.20	12.45	91.44	42.44	129.77	55.18	116.66	60.29	183.55	69.33	149.88	54.64
invertebrates	MFN	21.88	11.62	21.20	12.41	87.33	37.03	148.22	66.85	83.77	45.66	202.00	117.63	111.00	37.12
	BF	53.00	28.46	9.29	7.89	23.33	16.43	34.11	24.21	8.22	5.78	34.77	25.73	29.66	18.17
	BNF	44.22	21.69	5.20	4.23	21.88	11.20	22.22	15.51	11.66	9.70	26.11	23.84	29.66	14.57

Nine samples were taken on each of the sampling dates, except in March when six samples were taken in both the bare plots. MF, mulched fertilized; MNF, mulched unfertilized; BF, bare fertilized; BNF, bare unfertilized

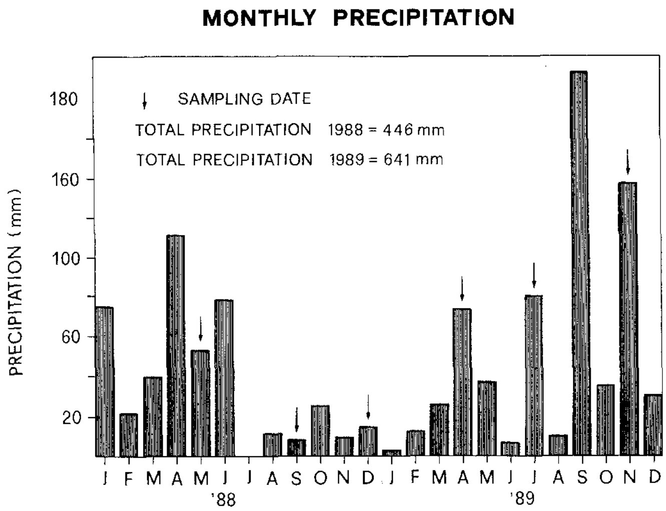

Fig. 1. Monthly precipitation in Maremma Park (Tuscany, Central Italy) during 1988 and 1989. ↓, sampling date; total precipitation: 1988, 446 mm; 1989, 641 mm

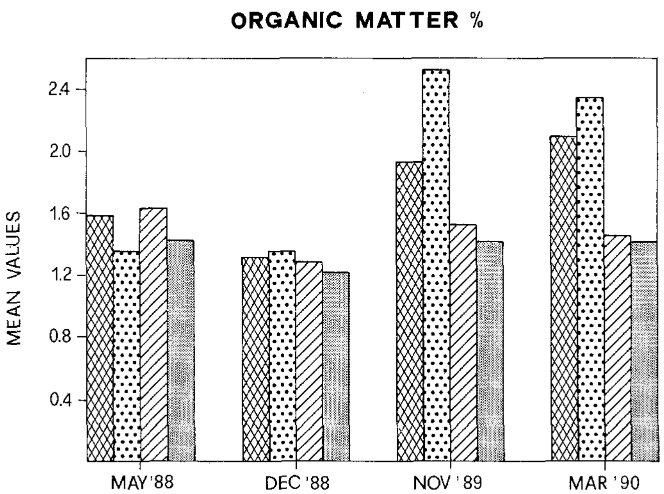

Fig. 2. Mean values of organic matter (%) in the various subplots; ▨, mulched plots with fertilizer; ▨, mulched plots without fertilizer; ▨, bare plots with fertilizer; ▨, bare plots without fertilizer

ble 5) of the microarthropods found in the cultivated plots, Collembola and Mesostigmata were found in the lowest numbers, but other groups also (Pauropoda, Psocoptera, some Coleoptera) were not abundant (Table 4).

Prostigmatid and Oribatid mites were relatively abundant in dry periods (June 1989; Table 4). However, fluctuations in the populations of Collembola and Oribatida in the mulched plots showed an opposite trend (Fig. 2, 3). The rapid numerical increase in Collembola, after subterranean mulch establishment, coincided with a less rapid development of oribatid mites, which are known to be influenced by K (Norton 1990). Numerous insect larvae (Table 4) were found in the mulched plots during the rainy season (spring). Most of them were Chironomid Diptera, but Hymenoptera, Carabidae, and Staphylinidae larvae were also present.

Mesostigmatid mites (Table 4) seemed to be the most numerous predators. Correlation indexes, which were statistically significant (Table 6), indicated that their presence was directly correlated with certain taxa of detritivorous organisms (Collembola and Oribatida).

Various taxonomic groups were present in different proportions in the mulched and bare plots (Figs 4–7). About 50% of the arthropods in the mulched plots were Collembola while in the cultivated plots about half were astigmatid mites (Fig. 4).

Table 6 shows correlation indexes (among the main taxa and soil nutrients). There was clearly a positive correlation between Oribatida, Mesostigmata, Collembola, and most of the nutrients, both total and assimilable, and organic matter. Only for total Ca was there a negative correlation with oribatid mites and Collembola. In contrast, there was a negative correlation between Astigmata and most of the nutrients and the organic matter, but a positive response to total Ca and assimilable K.

Table 5. Analysis of variance results for taxa

	Mulching	Fertilizer	Interaction
May 3, 1988			
Oribatida	7.783 (−)		
Astigmata	16.123 (−)		
Collembola		10.642 (+)	
Insect larvae	19.694 (+)		
Thysanoptera	9.375 (+)		
September 17, 1988			
Oribatida			4.213
Prostigmata	4.721 (−)		
December 8, 1988			
Astigmata	4.339 (+)		
Collembola	27.674 (+)		
Mesostigmata	9.820 (+)		
Staphylinidae	5.025 (+)	5.025 (−)	
Insect larvae	14.548 (+)		
April 8, 1989			
Oribatida	5.082 (+)		
Astigmata	27.137 (+)		
Prostigmata	20.967 (+)		
Mesostigmata	16.202 (+)		
June 11, 1989			
Oribatida	9.249 (+)		
Astigmata	7.563 (+)		
Mesostigmata	30.516 (+)		
Araneae	9.142 (+)		
Collembola	10.526 (+)		
Psocoptera	44.738 (+)		
Insect larvae	12.335 (+)		
November 30, 1989			
Astigmata	5.592 (+)		
Prostigmata	6.345 (+)		
Mesostigmata	53.919 (+)		
Collembola	40.020 (+)		
March 19, 1990			
Oribatida	5.082 (+)		
Astigmata	7.546 (−)		
Mesostigmata	10.887 (+)	4.473 (−)	
Collembola	24.158 (+)		

The effect of the presence of *Trifolium subterraneum* or fertilizer produced an increase (+) or decrease (−) of the presence of certain taxa Statistically significant F values are given ($P<0.05 \rightarrow F=4.15$; $P<0.01 \rightarrow F=7.51$)

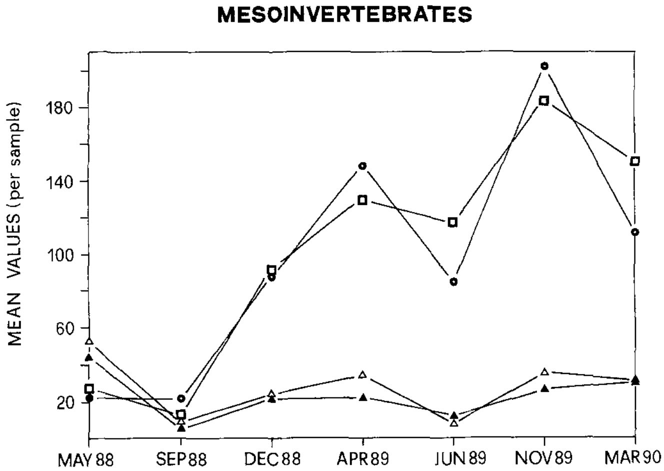

Fig. 3. Mean values of mesoinvertebrates on each sampling date; □, mulched plots with fertilizer; ○, mulched plots without fertilizer; △, bare plots with fertilizer; ▲, bare plots without fertilizer

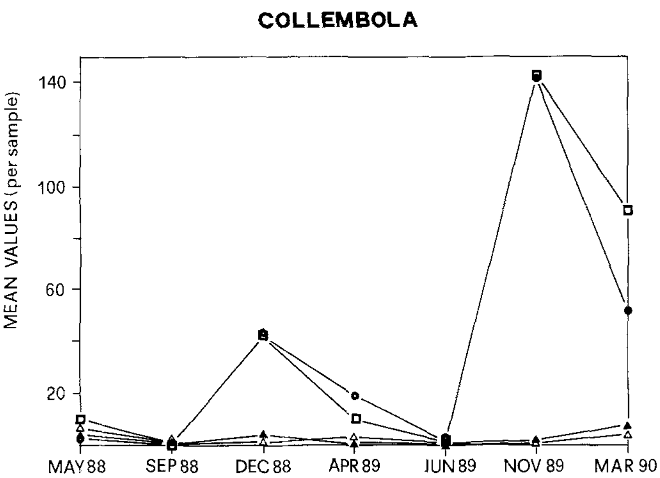

Fig. 4. Mean values of Collembola on each sampling date; for explanation of symbols, see Fig. 3

Table 6. Data from four soil analyses correlated with organisms extracted from the same samples with a Tullgren apparatus

		Correlation index
Oribatida	Total Na	0.3317
Oribatida	Assimilable Na	0.4124
Oribatida	Total Ca	−0.2439
Oribatida	Total K	0.4129
Oribatida	Exchangeable K	0.3166
Oribatida	Total P	0.2956
Oribatida	Organic matter	0.3069
Astigmata	Total Na	−0.4206
Astigmata	Assimilable Na	−0.4663
Astigmata	Total Ca	0.4208
Astigmata	Total K	−0.2865
Astigmata	Assimilable P	0.2778
Astigmata	Organic matter	−0.2190
Astigmata	Total N	−0.2343
Astigmata	Oribatida	−0.2190
Mesostigmata	Total Na	0.2902
Mesostigmata	Assimilable Na	0.2909
Mesostigmata	Assimilable Ca	0.4473
Mesostigmata	Total K	0.2080
Mesostigmata	Exchangeable K	0.4212
Mesostigamta	Total P	0.2896
Mesostigmata	Organic matter	0.6014
Mesostigmata	Total N	0.3959
Mesostigmata	pH	0.4324
Mesostigmata	Oribatida	0.2355
Collembola	Assimilable Na	0.2038
Collembola	Total Ca	−0.2339
Collembola	Exchangeable K	0.3224
Collembola	Total P	0.2245
Collembola	Organic matter	0.4432
Collembola	Total N	0.2577
Collembola	Mesostigmata	0.5932

Statistically significant correlation indexes are given ($P<0.05$; probability level, 0.1945)

Compared with other taxa, the relatively higher numbers of astigmatid mites in cultivated soil and their varying sensitivity to different soil nutrients make them useful biological indicators (Dindal et al. 1977) in studying the effects of agricultural management.

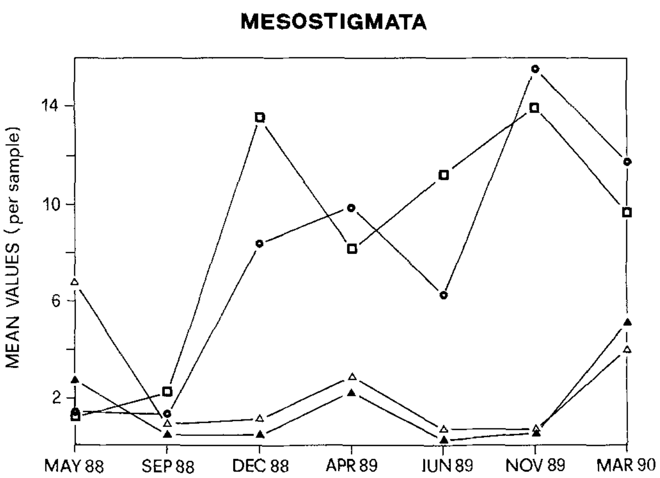

Fig. 5. Mean values of Mesostigmata on each sampling date; for explanation of symbols, see Fig. 3

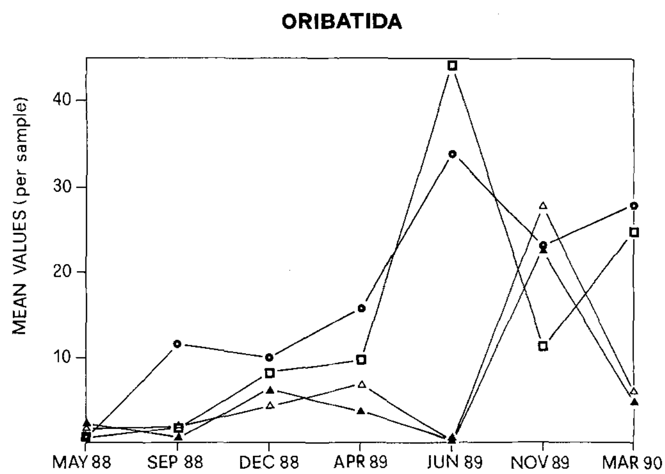

Fig. 6. Mean values of Oribatida on each sampling date; for explanation of symbols, see Fig. 3

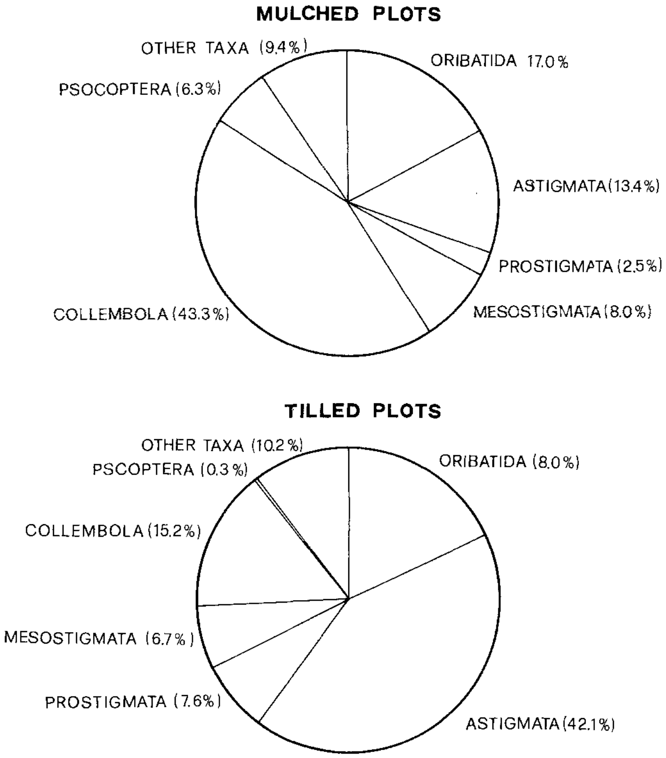

Fig. 7. Percentage composition of the principal invertebrate groups sampled in mulched and tilled vineyard plots

Discussion

The introduction of subterranean clover mulch resulted in a more complex ecosystem, which affected mesoinvertebrate populations and soil nutrient dynamics.

Lower initial mesoinvertebrates and nutrient values were observed in the mulched plots. During the first vegetative cycle (winter – spring 1988) the subterranean clover extracted some assimilable nutrients, but later, through the input of vegetable residues, there was an increase in organic matter and nutrient concentrations (Ca, P, C, N) in the soil (Table 2).

The maintenance of sufficient biological activity during the course of the year was made possible by the constant presence of vegetal matter, either living or dead mulch. While fertilization practice does not influence the invertebrate population (Table 5), the presence of the mulch and the consequent availability of organic matter supported mainly detritivorous populations. Soil invertebrate activity is linked with organic matter turnover and nutrient recycling, through interactions with the microbial population (Seastedt 1984; Moore et al. 1988); moreover, they constitute a conspicuous food base for poliphagous predators (Paoletti 1987; Stinner and House 1990).

The presence of mulch eliminates the need for frequent soil tillage in agroecosystems. Cultivation and the absence of mulch make the microclimate and the resource levels less favourable for soil mesofauna. The influence of arthropods in modifying the chemical and physical properties of soil should not be underestimated; the effects are both direct and indirect, occurring through microbial dissemination and organic matter comminution (Dindal 1990; Hendrix et al. 1990; Moore et al. 1988), and creating new areas for microbial colonization. Some soil organisms are bound to the edaphic environment for only part of their life-cycles, e.g., the larval stage. Soil disturbances therefore affect not only the detritus food web, but also the above-ground food webs.

Table 7. Grape yield and subterranean (subterr.) clover yield (kg ha^{-1}) of dry matter. The values refer to the average of three samples

	Mulched soils		Bare soils	
	Grape	Subterr. clover	Grape	Subterr. clover
Fertilized				
1988	1469	3097 S, A	2296	–
1989	451	1601 S	1246	–
1990	640	1695 S	1347	–
Unfertilized				
1988	1404	2667 S, A	2269	–
1989	526	1949 S	1194	–
1990	635	2052 S, A	1148	–

Averages of three samples. S, spring mowing; A, autumn mowing

Apart from the results discussed above, two other agronomic aspects were considered, yield and the presence of weeds. The vines grown in bare plots gave a much greater yield (Table 7). Although the life-cycles of the main crop and the subterranean clover only partly coincided, the spring period when the two plants shared nutritional and water resources was sufficient to create competition. The total biomass yielded by these plots (grapes alone or grapes + clover) was clearly greater in the presence of a vine – subterranean clover association. Moreover, the living mulch created a cover that controlled weeds and soil erosion.

On the one hand, the evaluation of plant association trials has provided positive results (fertility, soil mesofauna habitats, probably weed control); on the other hand, low productivity of vines may, in the area under examination, discourage further use of intercropping with subterranean clover. The present research appears to show that modifying a monocultural tilled system towards a plant association leads to substantial modification of the soil and the agro-ecosystem.

However, further research is needed to study the effect of mulching for longer experimental periods than those used in this work. In areas with a dry climate, like those in the Mediterranean, interventions that provide minimal dispersion of yield potential and of natural resources are required, so that a highly vulnerable system can be used rationally.

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References

Altieri MA, Letourneau DK (1982) Vegetation management and biological control in agroecosystems. Crop Prot 1:405–430

Altieri MA, Schmidt LL (1985) Cover crop manipulation in northern California orchards and vineyards: Effects on arthropod communities. Biol Agric Hortic 3:1–24

Altieri MA, Schmidt LL (1986) Cover crop effects on insect and spider populations in apple orchards. Calif Agric 40:15–17

Altieri MA, Wilson RC, Schmidt LL (1985) The effect of living mulches and weed cover on the dynamics of foliage- and soil-arthropod communities in the three crop systems. Crop Prot 4:201–213

Bremner JM (1965) Total nitrogen. In: Black CA (ed) Methods of soil analysis, vol 2. American Society of Agronomy, Madison, Wisconsin, pp 1149–1178

Buggs RL, Dutcher JD (1989) Warm-season cover crop for pecan orchards: Horticultural and entomological implication. Biol Agric Hortic 6:123–148

Buggs RL, Ellis RT (1988) Use of green manure crops to subsidize beneficial insects (a study in progress). In: Allen P, Van Dusen (eds) Global perspectives on agroecology and sustainable agricultural systems: Proceedings of the Sixth International Federation of Organic Agricultural Movements (1986), vol. 2. pp 553–557

Caporali F, Campiglia E, Paolini R (1987) L'inerbimento del noccioleto con *Trifolium subterraneum* L. nel territorio viterbese. Inf Agrar 1:57–60

Crossley DA Jr, Coleman DC, Hendrix PF (1989) The importance of the fauna in agricultural soils: Research approaches and prospectives. Agric Ecosyst Environ 27:47–55

Dindal DL (ed) (1990) Soil biology guide. John Wiley and Sons, New York

Dindal DL, Moreau P, Theoret L (1977) Effect of spray irrigation of municipal waste-water on soil invertebrate populations and the potential influences on physical factors of soil. Tech Rep Proj B-048-NY, Office of Water Research and Technology, US Department of Interior, Washington, DC

Enache AJ, Ilnicki RD (1990) Weed control by subterranean clover (*Trifolium subterraneum*) used as a living mulch. Weed Technol 4:534–538

Finch CU, Curtis Sharp W (1981) Cover crops in California orchards and vineyards. USDA, Soil Conservation Service, Davis, California

Foissner W (1987) Soil protozoa: Fundamental problems, ecological significance, adaptations in ciliates and testaceans, bioindicators and guide to the literature. Prog Protistol 2:69–212

Hargrove WL (ed) (1982) Proceedings of the minisymposium on legume cover crops for conservation tillage production systems, October 1981. Univ Georgia, Coll Agric Stn

Hargrove WL (1986) Winter legumes as nitrogen source for no-till grain sorghum. Agron J 78:70–74

Hendrix PF, Crossley DA Jr, Blair JM, Coleman DC (1990) Soil biota as components of sustainable agroecosystems. In: Edwards CA, Lal R, Madden P, Miller RH, House G (eds) Sustainable agricultural systems. Soil and Water Conservation Society, Washington DC, pp 637–654

Ilnicki RD, Vitolo DB (1986) The use of subterranean clover as a living mulch in corn. Proc Northeast Weed Sci Soc 40:36

McGuire WS (1985) Subterranean clover. In: Clover science and technology. Agron Monogr 25, Am Soc Agron, Madison, Wisconsin, pp 515–534

Moore JC, Walter DE, Hunt HW (1988) Arthropod regulation of micro- and mesobiota in below-ground detrital food webs. Annu Rev Entomol 33:419–439

Morley FHW (1961) Subterranean clover. Adv Agron 13:57–123

Nelson DW, Sommers LE (1982) Total carbon, organic carbon and organic matter. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis, part 2. Am Soc Agron, Madison, Wisconsin, pp 539–580

Norton RA (1990) Acarina: Oribatida. In: Dindal LD (ed) Soil biology guide. John Wiley and Sons, pp 779–803

Olsen SR, Sommers LE (1982) Phosphorus. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis, part 2. Am Soc Agron, Madison, Wisconsin, pp 403–430

Paoletti MG (1987) Soil tillage, soil predator dynamics, control of cultivated plant pests. In: Striganova BR (ed) Soil fauna and soil fertility. Moscow Nauka, pp 417–422

Paoletti MG, Favretto MR, Stinner BR, Purrington FF, Bater JE (1991) Invertebrates as bioindicators of soil use. Agric Ecosyst Environ 34:341–362

Power JF (ed) (1987) The role of legumes in conservation tillage systems. Proc Soil Conserv Soc 11

Rhoades JD (1982) Cation exchange capacity. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis, part 2. Am Soc Agron, Madison, Wisconsin, pp 149–165

Seastedt TR (1984) The role of microarthropods in decomposition and mineralization process. Annu Rev Entomol 29:25–46

STATPRO (1985) Penton Software Inc, New York

Stinner BR, House GJ (1990) Arthropods and other invertebrates in conservation-tillage agriculture. Annu Rev Entomol 35:299–318