Rapid Recolonisation of Agricultural Soil by Microarthropods After Steam Disinfestation

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ABSTRACT. Steam disinfestation of soil is attracting growing interest in intensive agriculture, because of the increasing demand of reduced use of fumigants. In this study, we assessed the effect of steam application on the microarthropod community, a fundamental component of soil environment. We conducted steam disinfestation treatments in experimental parcels, where we sampled for edaphic microarthropods in one date before and in four dates after the treatments. Our results showed that edaphic fauna quickly recolonised the disinfested soil, re-establishing dense and rich communities after 45 days. These results support the low environmental impact of this technique and then could be used for certification of the eco-biological sustainability of steam treatment in organic farming.

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INTRODUCTION

There is growing interest in low environmental impact methods in agriculture. This is especially true for intensive practices which, because of their characteristics (increased specialisation, monocultures with strong crop repetition, abundant yield of high-quality products on relatively small surface areas and in a short time), are at risk of attack by many pathogens.

In the past, soil-borne diseases and pests were mainly controlled by crop rotation, host plant resistance, biological control and especially fumigants. Although chemical control of natural enemies is comparatively simple and inexpensive, we normally want to protect natural enemies of pests so that the last decade has seen growing interest in low-impact methods. This is also due to demands by policy makers for reduced use of pesticides and consumer requests for residue-free foods. For example, the use of methyl bromide (CH_3Br), one of the most common fumigants, will soon be banned. The U.S. Environmental Protection Agency (EPA) has added methyl bromide to the Clean Air Act-Class 1 as an ozone-depleting substance and several European countries have announced a complete ban on this substance within a few years.

Steam disinfestation of soil is becoming very important in many developed countries as an alternative to methyl bromide. Indeed, steam sterilisation presents several obvious advantages, such as the lack of residues on the marketed product, the absence of environmental pollution, the speed of application and the reduced exposure of producer and applier to toxic pesticides. This disinfestation practice is useful to control plant pathogens, nematodes and weed seeds (Trevors, 1996), but there are no data about a possible long-term impact on the entire faunal community. Although factors such as costs, time requirements, access to power, fuel and water currently prevent the large-scale use of this technique, recent technological advances may improve the possibility of its widespread adoption (Dabbene et al., 2003).

Several studies have been devoted to the effects of steam sterilisation on physical and chemical characteristics of the soil (Lacatus et al., 1977), but less is known about its impact on the edaphic fauna. However, the fauna is a fundamental part of the soil environment. Edaphic communities are involved in many aspects of organic matter decompo-

sition, partial regulation of microbial activities, nutrient cycles and soil structure. They also play an important role in soil productivity and agricultural practices (Steen, 1983). Indeed, considerable attention has recently been given to soil biodiversity, especially to its role in ecosystem functions (Wolters, 2001).

In view of the high destructive potential of steam disinfestation, it would be interesting to evaluate its impact on soil microarthropods and to assess the resilience of their communities. Market demands and legal requirements have led to growing interest in production systems that promote and enhance the health of agricultural ecosystems. The availability of data confirming a low environmental impact of steam disinfestation could represent an important element in the certification of organic farming methods.

The aim of the present study was to assess the pattern of recolonisation of the soil by microarthropods in a 45-day period after steam sterilisation. We also evaluated whether or not the richness and diversity of the colonising community reach the values present before the treatment.

MATERIALS AND METHODS

Study Site and Sampling

The study was carried out in Boves (7°33' E, 44°19' N), NW-Italy. We conducted experiments in an open-field area, covered by a polyethylene tunnel, used for strawberry and vegetable production. Steam disinfestation treatments were carried out on two 4 × 10 m plots in two different periods: the first plot was steamed in summer (10 July 2002) and the second one in fall (2 October 2002). We collected soil samples at different times: before the sterilisation, 6 hours after sterilisation, 15 days, 30 days and 45 days after sterilisation. On each occasion, eight samples were collected with a soil sampler (diameter 7.5 cm; deep 10 cm; three replicates/sample). Microarthropods were extracted with Berlese-Tullgren funnels (Gorny and Grum, 1993) for 10 days. The taxonomic level of classification was always at least the same as in the Biological Soil Quality (B.S.Q.) index (Gardi et al., 2002).

We used four parameters to analyse the soil communities: N (number of microarthropods in the soil sample), S (number of taxa), the Shannon biodiversity index (Magurran, 1988) and the B.S.Q. index. The last index ranges from 0 (no taxa present) to 200 (maximum number of taxa present) and is based on a life-form approach: life-forms include groups

of microarthropods with the same convergent morphological features, and life-forms more sensitive to soil quality are given a higher score (Parisi, 2001; Gardi et al., 2002).

Richness accumulation curves, generated with EstimateS 6.0 software (Colwell, 1997), were used to estimate the cumulative taxa number for all samples collected in the two sampling periods.

The preference of individual taxa for a particular period was evaluated using indicator species analysis computed by the INDVAL 2.0 software (Dufrêne, 1998). Indicator analysis is a randomisation-based test that compares the relative abundance and relative frequency of occurrence of taxa to find indicator species assemblages characterizing groups of samples. A taxon's affinity for a sampling group is expressed as a percentage.

Steam Sterilisation Method

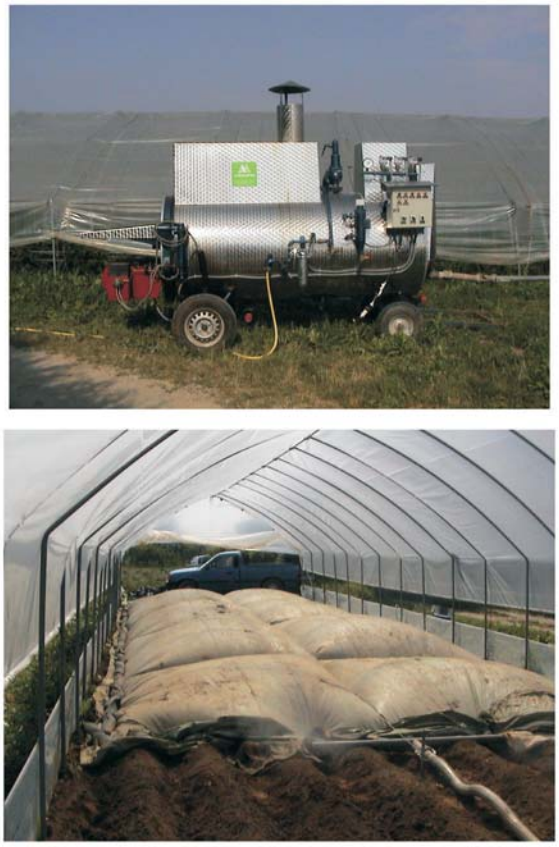
The soil was heated by sheet steaming. We covered the soil with a thermo-resistant sheet sealed at the edges and steam was blown under the sheet so that it penetrated into the soil. Steam was blown under the sheet by two parallel pipes placed in the trenches between ridges. Each pipe was connected to a valve by which air could be injected through a Venturi inlet.

The MÖSCHLE S500 boiler produced about 550 kg/h of steam with a fuel consumption of 36 kg of gasoline per hour. During each treatment (usually 2-3 hours per plot), the boiler output was directly connected to the pipes through an on-off valve. The data presented in this paper were collected after a 2-hour treatment in a plot with a 9.7% initial soil moisture (this value was computed by averaging five soil samples collected at 10 cm depth). A photograph taken during the treatment is shown in Fig. 1. To assess soil temperatures, thin cylindrical probes equipped with thermocouple sensors were placed at seven depths (15, 40, 65, 90, 115, 140 and 165 mm) at several points on the plots during steam disinfestation. Measurements were taken at 5-second intervals using National Instruments FP2000 and Advantech 5510 Dataloggers. The temperatures measured at the different depths are plotted in Fig. 2.

RESULTS

No active microarthropods were detected immediately after vaporisation, but thereafter there was rapid recolonisation of the soil (Fig. 3), with an increase in density (number of animals/volume unit), richness

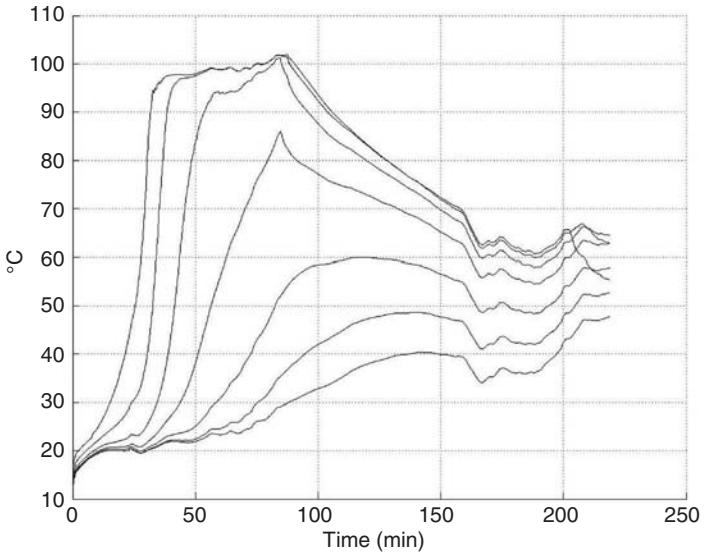
FIGURE 1. Picture of the steam sterilisation apparatus utilized in this study.



(number of taxa/volume unit) and biodiversity (Shannon and B.S.Q. indexes). The pedofaunal communities were completely re-established within six weeks after eradication: there were no significant differences in the parameters between the day before sterilisation and 45 days after the treatment (Table 1).

Taxa accumulation curves of summer and fall samples are reported in Fig. 4. Even if the richness of the edaphic community was slightly higher in fall, there was no significant difference in the values between the summer and fall treatments.

FIGURE 2. Soil temperatures measured during the treatment. From the top to the bottom the temperature trend at depth of 15, 40, 65, 90, 115, 140 and 165 mm.



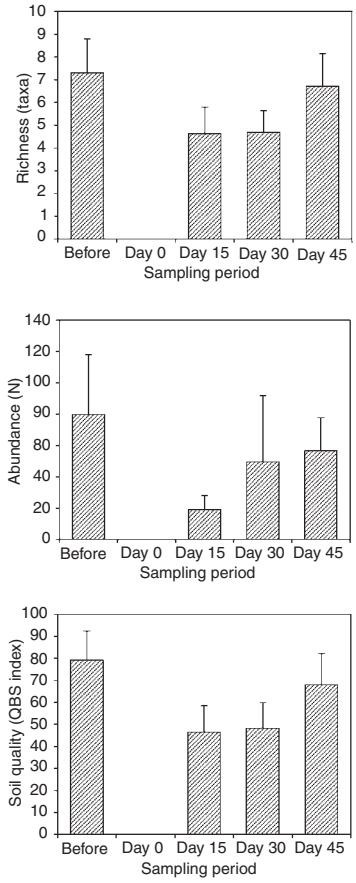
Considering in detail the four sampling dates separately, the summer and fall communities did nor statistically differ in the density of the invertebrate assemblages, nor in the B.S.Q. values), nor in the Shannon index values and the taxonomic richness (ANOVAs at different dates, all P = n.s.).

Analysing the taxonomical composition of edaphic communities in the different dates of the recolonisation process, the Indicator Species Analysis identified precocious and late colonisers. Some taxa promptly reappear in the treated area, such as non-Oribatida mites, larvae of some Coleoptera families (mostly Carabidae, Staphilinidae and Tenebrionidae) and Collembola Entomobriomorha. Other taxa appear only after some time, such as Oribatida mites, Psocoptera and Pauropoda (Table 2).

DISCUSSION

The purpose of soil sterilisation in intensive agriculture is to destroy pathogens without significantly altering the chemical and physical

FIGURE 3. Community richness, abundance, and soil quality index of samples collected before steam sterilisation, and 0, 15, 30, 45 days after the soil sterilisation treatment.



characteristics of the soil (Trevors, 1996). The low impact on the environment could be a good reason to use this technique instead of traditional chemical sterilisation methods, i.e., the low-impact profile would probably be appreciated by the general public.

Our results show that microarthropod communities are quickly re-established after depletion, and there are no significant seasonal differences in this process: in both summer and fall the colonisation rates were similar. Community resilience is an important topic in ecology be-

TABLE 1. Comparison of abundance (N), richness (S), B.S.Q. value and diversity (Shannon H'), before vs. 45 days after sterilisation (mean ± SD, ANOVA tests).

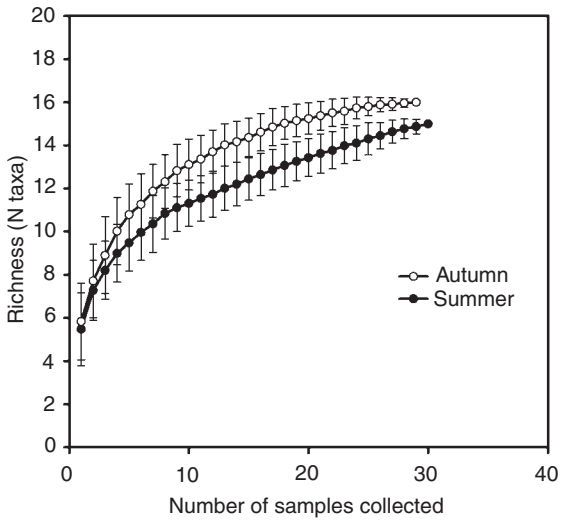
		Date		STATISTICS		
Season	Parameter	Before	After 45 days	F value	P	
Summer	Abundance (N)	93.0 ± 73.6	60.6 ± 21.1	0.485	0.50	n.s.
	Richness (S)	6.50 ± 1.38	7.00 ± 1.07	0.655	0.43	n.s.
	B.S.Q. Index	75.8 ± 11.6	68.0 ± 11.9	1.229	0.28	n.s.
	Shannon Index	1.15 ± 0.11	1.21 ± 0.14	0.797	0.39	n.s.
Fall	Abundance (N)	97.0 ± 39.7	60.0 ± 14.1	3.349	0.10	n.s.
	Richness (S)	8.50 ± 0.57	6.33 ± 1.86	4.550	0.06	n.s.
	B.S.Q. Index	84.2 ± 16.1	68.0 ± 18.0	1.958	0.19	n.s.
	Shannon Index	1.47 ± 0.20	1.33 ± 0.31	0.834	0.38	n.s.

TABLE 2. Indicator values of most representative early and late recolonist taxa.

TAXA	Indicator Value
Early recolonist	
Coleoptera (larvae)	55.45
Non-oridatida mites	40.55
Entomobriomorpha	24.20
Late recolonist	
Oridatida Mites	35.56
Psocoptera	33.31
Pauropoda	20.37

cause of its pure and applied implications. The re-establishment of a community after disturbance is a complex process involving various structural and functional properties, e.g., number of taxa, total number of individuals, species composition and relative abundance. Environmental alterations can deplete or destroy a biocoenosis, but recolonisation usually begins as soon as normal conditions are restored.

FIGURE 4. Taxa accumulation curves of microarthropods collected in summer and fall samples.



Many studies have investigated the recolonisation patterns of animal communities in marine (Palmer et al., 1996), freshwater (Fenoglio et al., 2002) or ground habitats (Hooks and Marshall, 2003), but there is little information about soils. Soil is also an under-represented medium in dispersal studies, especially with regard to truly edaphic fauna: investigations of the structure, abundance and distribution of soil faunal communities have shown that they are very diverse in taxa richness, highly spatially aggregated and exhibit a relatively low degree of trophic specialisation (O'Connell and Bolger, 1998). Since populations with high growth rates and communities with few trophic levels tend to be more resilient (Calow, 1999), we can hypothesize that soil microarthropods communities can quickly be re-established. However, despite several studies (Bengtsson et al., 2002), our knowledge of pedofaunal (re)colonisation mechanisms is very poor. Some studies have investigated aspects of dispersal related to particular groups in particular conditions, such as mites (Streit et al., 1985) or Collembola (Sjögren, 1997), or have focused on particular aspects of the soil environment, such as pH (Hagvar and Abrahamsen, 1980). Furthermore, information about dispersal movements among pedofaunal elements comes mainly from observations in artificial substrates (Bengtsson et al., 2002).

Our study shows that the recolonisation process is very rapid, in terms of both the density and diversity of organisms. The rapid re-establishment of diverse and rich edaphic communities is a key factor in determining the environmental and agricultural suitability of the steam vaporisation technique: the soil fauna is essential to efficient nutrient cycling, organic matter turnover, maintenance of soil physical structure, processes of primary production and ecosystem carbon storage (Wall Freckman, 1997).

Our study underlines the great resilience of pedofaunal communities and raises several points of practical interest.

- Microarthropods can quickly recolonise soil plots after steam disinfestation. The high resilience of these communities is a key factor in maximizing the biological activity and preserving the high functionality of the soil (Wolters, 2001).
- Soil sterilisation is a common practice in intensive agriculture (e.g., horticulture) to destroy pathogens and noxious animals (Mulder, 1979). Steam disinfestation is a clean, effective and rapid method, and our results demonstrate that it has a short-lasting environmental impact on soil faunal communities.
- Steam application could be considered a certified disinfestation treatment for organic farming. In the context of sustainable agriculture, it allows one to maintain long-term soil health without the introduction of contaminants into the environment and food.

Further studies will provide information useful to verify our results.

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