163

On Earthworms. A. M. Bonvicini Pagliai & P. Omodeo (eds.). Selected Symposia and Monographs U.Z.I., 2, Mucchi, Modena, 1987, pp. 465-484

D. CLUZEAU, M. LEBOUVIER, P. TRAHEN, M. B. BOUCHÉ,
C. BADOUR, A. PERRAUD

Relations between earthworms and agricultural practices in the vineyards of Champagne. Preliminary results

ABSTRACT

The specific and numerical richness in earthworms in grasslands is often opposite to the poorness of cultivated yields that have undergone intensive physical and chemical treatments. To study the qualitative and quantitative differences of the earthworm population in the vineyards of Champagne, soil samples of 1 square m have been taken with the formol method, followed by manual sorting *in situ* down to -0.20 m. The relationship between vineyarding and earthworms could be studied very accurately because the history of the plots was known and as reference environments (lawn, meadow, fallow land), close to the vineyards existed. Our results showed that the preparation of the plantations tends to reduce the abundance of earthworm populations. The non-cultivation of the vineyards and the massive use of organic wastes favour a restauration of earthworm communities. For this new environment, in relation to the reference plots the diversity and abundance are weaker, whereas the biomass is more important. In the vineyards, the anecic are dominant, the epigeic have almost completely disappeared, and the endogeic are rare. The comparative study between the tracks of land compacted by the passage of machines and compacted tracks under the vineplants revealed a significant difference in abundance. By taking into account the earthworms (as bio-indicators and taking into account the pedogenetical influence on the soil systems) there will be a more rational exploitation of the vineyard, without affecting the exploiters and neighbouring lands.

Key words: Earthworm, communities structure, agricultural practices.

1. Introduction

In the wine district of Champagne classical agricultural practices and the increasing use of tractors result in:

– mechanical and biological degradation of the soil

– gullying leading to skeletonization of the soils and to increase costs, for hand reclamation

– compaction of the soil, which, soon deprived of humus is unfavourable for the development of the vine.

Numerous studies have demonstrated these phenomena in different agrosystems (Gerard & Hay, 1979; Edwards, 1980; Reinecke & Visser, 1980; Edwards & Loflty, 1982; Edwards, 1983; Hennuy et al., 1985). While ploughing helps in the lutte against weeds, it destroyes the upper horizons of the soil where a large part of its biological activity is concentrated, whereas the absence of playing (non cultivation) seems to favour the restauration of the edaphic communities (Dunger, 1966; Atlavinyte, 1976; Hennuy et al., 1985), and also the accumulation of organic matter on the surface (Graff, 1969; Marshall, 1977; Andersen, 1980; Cottom & Curry, 1980; Edwards, 1983). The spread of non-cultivation of the whole wine - district associated with the use of organic waste (usually crushed household waste) should contribute to:

– reconstitute the natural organic profile
– economize on the working of the soil
– destroy weeds through the use of weed-killers that are non toxic for the vine,
– maintain and stimulate the activity of local soil
– maintain, with an organic cover on the surface a better humic profile of the soil and of the vine roots, favouring surface life thus limiting erosion (Graff, 1969; De Boodt et al., 1977).

However, the massive use of chemicals (herbicides, fungicides...) together with non-cultivation, can have negative impacts on earthwrom populations (Edwards & Thompson, 1973; Edwards, 1980; Atlavinyte, 1981; Bouché, 1984). The disappearance of the earthworms can have manifold repercussions on the environment:

– deep and disastrous modifications of the properties of the soil (Van Westering, 1972; Stewart & Scullion, 1984).
– a litter accumulation on the surface which could favour the development of parasites
– reduced resistence of the soils to phenomena of erosion through purling waters
– a risk of increase of the nitrogenous pollution of the surface- and phreatic-waters.

The evolution of agricultural practices (mechanisation, the use of chemicals, and the cost of the labour) has led to experiments aiming to understand the advantages and disadvantages. In this context we have studied the earthworm factor in order to clarify the essential roles of these invertebrates in the wine-growing agrosystem of the Champagne district and their reactions to the different human activities. Bosse (1966), Graff (1969) and Kuehle (1983) have studied earthworm populations in vineyards. The aim of this study was to define the techniques and methods that allow a global understanding of the way the earthworm populations react to vine cultivation. The second stage of the study requires precise knowledge of the impact of the main agricultural practices: therefore we must know:

– on the one hand the structure of the populations in the soil before the cultivation

– on the other hand, the history of the selected plots

In an ecosystem as strongly submitted to the action of man as the wine-district of Champagne there are very few undisturbed environments, at least within living memory, that can serve as a reference. Therefore, the presence of a reference environment in the vicinity (lawn, permanent meadow, fallow lands) should be a determining factor when selecting vineyard plots to inventory for comparative studies. With regards to the history of the plot, information on various points is needed, e.g.:

– initial nature of the soil

– the vegetable grouping that probably existed before the planting of vines

– the nature and intensity of levelling works and soil treatment before cultivation

– the number of vine generations and the age of the actual vine

– the nature of the type of vine and other wine-growing characteristics

– the agricultural practices after planting:

  – working of the soil or not (tools, frequency)

  – supply of fertilizers (nature, quantity, frequency)

  – chemical treatment (nature, quantity, frequency)

  – crushing or not of vine shoots

Knowledge of these factors should allow a better evaluation of the impact of the cultivation and of diverse agricultural practices on the dynamics of earthworm populations, in order to retain the practices that are likely to preserve, indeed to improve the fertility of these soils. The present study is a first approach to investigate the structure of the earthworm populations in the vineyard of Champagne. The number of plots and the number of samples studied are relatively limited. In a first approach, the use of methods for multi-factor analysis will allow us to better understand the possible interrelations between samples, earthworm species and physico-chemical characteristics.

2. Material and methods

2.1 *Study area*

In agreement with the specialists of the Interprofessional Committee of the wine of Champagne (CIVC), four plots have been selected as being characteristic for a great majority of the actual vineyards, as much for the agricultural practices as for the kind of soil, exposure, yield, ...

These are average vineyards, first or second generation, without particular problems of exploitation and submitted to current chemical treatments (Tab. I) The history was available for the plots of Champvoisy. In 1976 a whole slope was cleaned with the exception of a plot of fallow land, thus we had information as to the state previous to cultivation. Levelling, disinfection and the supply of basic organic matter were practically the same for all the plots. Some were planted in 1976, others in 1981. The first have received 3 supplies of exogenous organic matter (crushed household waste) the second 1 supply of organic waste. In addition, in 1984 there were plots without vines. Some received organic waste (plots without vines with organic matter: PWVWOM), others not (plots without either vine and organic matter: PWVOM). In both cases the soil was kept clean by passing a rotavator each year. All the plots receive the same chemical

TABLE I - *Characteristics of the different plots studied.*

Name of the Plot	Nature of the subsoil	Nature of soil	Number of studied cases	Nature of methods	Symbol	Number of samples	Chemical samples
Champvoisy (Ch)	chalk	soil brown calcareous	5	reference plot (fallow land)	A △	4 (a)	yes
				plot without vine with OM (PWVWOM)	B ○	3 (b)	yes
				Plot without vine without OM (PWVOM)	C ●	3 (b)	yes
				3-yrs old vine	D ○	4 (b)	yes
				10-yrs old vine	E ○	6 (b)	yes
Plumecoq (Pl)	chalk	«Redzine» brown calcareous	1	10-yrs old vine	G ○	8 (b)	yes
Oger (Og)	chalk	calcareous	2	10-yrs old vine (second generation)	I ○	6 (b)	yes
				reference plot (meadow hydromorphe)	J □	8 (a)	non
Mont Bernon (MtB)	chalk	soil brown calcareous	2	10-yrs old vine	M ○	1 (b)	non
			reference plot (old lawn)		N ◇	4 (a)	non

OM: organic matter (crushed and composted household, refuse)
(a) samples of 0.25 m^2 (b) samples of 1 m^2.

treatment from the moment the vines were laid. With the help of these various situations, we have tried to understand the evolution of earthworm populations in the vineyard in connection with:

- the impact of cultivation
- the age of the vineyard
- the population of the natural undisturbed environment.

2.2 *Method of studying the earthworms*

As the horizontal structure of the populations between the vinerows and the inter-rows could present distinctive features we have adopted a relatively important elementary surface. Thus, the sampling has been carried out with a 1 square m frame (unit of sampling in the vineyards, called «taking» between two vine-plants) sitting astride the inter-row (space pathway for machinery and where exogenous organic matter is deposited) and under the vinerow (undisturbed zone in the case of non-cultivation). This frame is divided into 4 squares of 1/4 m^2 (sample unit in the reference environments). In turn these are divided (temporarily) so that we have a total of 64 small squares of 12.5 cm each side (8 columns going from the inter-row under the vinerow and 8 lines going from one vineplant to the next) (Fig. 1). These are our smallest samples. We have combined the formol method and postformol manual sorting in situ down to -20 cm (Bouché, 1969). We have respected aspects of time and places to allow the comparison and the combination of the different results of each method. Manual sorting in situ is easier than digging-washing (limitation of transport of substratum). This has permitted us to take a greater number of samples, thus increasing the internal validity of our results. It is less precise than the method of Bouché (1969, 1984), but it completes, in our case, the results obtained through formol extraction (Tab. II). We

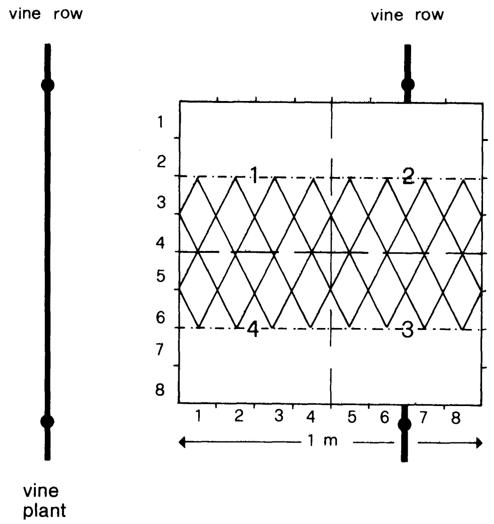


Fig. 1 - Position of the sampling frame of 1 m^2, in relation to the row by large squares (2 and 3) and to the interrow of the vineyard (by large squares 1 and 4) hatched: sampling frame used by Kuehle (1983).

TABLE II - *Relative structure of earthworm populations of 10-years old vineyards in Champvoisy and Plumecoq (E + C) and of reference environment (CA + N) taken with the help of two methods, taken separately, then globally (Total m^2 + standard error).*

	%Undet.	%Epigeic	%Anecic	%Endogeic	Total /m^2	%Adults	Control environment
Formol:	–	–	53,2	46,8	21,5 ± 4,5	20,8	
Hand sorting:	1,7	0,4	15,5	82,4	119,6 ± 28,6	24,7	(8 × 0,25 m^2)
Total abundance:	1,4	0,3	22,9	75,4	141,1 ± 28,8		23,5
Formol:	–	1,0	91,0	8,0	37,3 ± 5,5	26,0	
Hand sorting:	4,0	1,0	78,0	17,0	18,2 ± 3,6	37,0	
Total abundance:	1,0	1,0	86,0	12,0	55,4 ± 7,5	29,5	10-years old vineyards (11 × 1 m^2)

have, thus, taken 35 samples on 1 m^2 in 4 plots of vineyards and 3 «natural» reference environments. The environment of the latter was more homogeneous, thus the averages were calculated from 1/4 m^2 samples. The animals were fixed and preserved in a 4% formol solution. The biomass was measured with the fixed specimens, full digestive tract (fdt).

2.3 *Physico-chemical measurements*

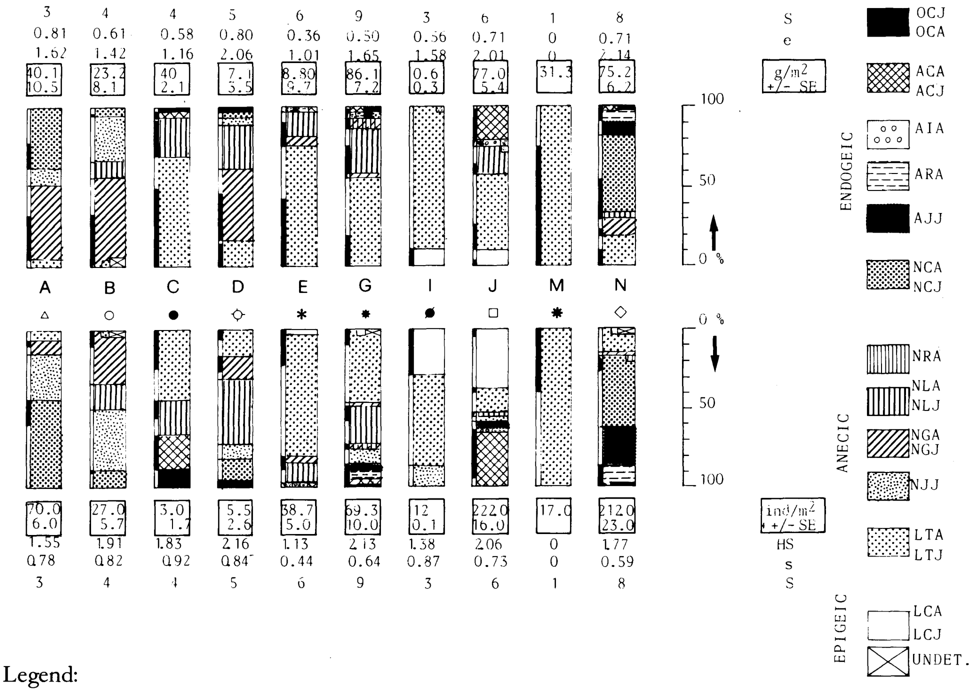
In the case of 31 samples (at least those of Mt Bernon and of the meadow of Oger), soil samples were taken at -20 cm for physico-chemical measurements (Fig. 7):

- Total organic carbon (A)
- total organic nitrogen (B)
- pH H_2O (C) and pH KCl (D)
- total (E) and active Ca (F)
- clay (G), fine (H) and coarse (I) silt, fine (J) and coarse (K) sand.

3. Results

The results demonstrate a wide variability of the abundance and the number of species (Tab. III). Thus, the total abundance tends to decrease from the reference environments to the vineyards, up to the disappearance of earthworms from a 10 years old vineyards (Tab. 1). It should be noted, however, that in general, the total abundance is more lower in younger vineyards (3 years old ones). In vineyards the effectives of certain species regress under the influence of various factors, some of which we shall try to specify. The number of species

TABLE III - *Specific composition, specific richness (S), diversity (index of Shannon HS), equitability (e), biomass (g/m^2) with standard error (SE), of earthworm populations in the various samples. Adults = lateral bar; Young = White lateral bar.*



Legend:

OCJ *Octoclasium cyaneum* (Sav., 1826); OCA Adult and young
ACA *Allolobophora chlorotica chlorotica* (Sav., 1826 *typica*; ACJ Adult and young;
AIA *Allolobophora icterica* (Sav., 1826) Adult
ARA *Allolobophora rosea rosea* (Sav., 1826) Adult
AJJ *Allolobophora icterica* and *rosea* young
NCA *Nicodrilus caliginosus caliginosus* (Sav., 1826)
NCJ Adult and young (*N.*c. *alternisetosus* in Plumecoq)
NRA *Nicodrilus longus ripicola* Adult
NLA *Nicodrilus longus longus* (Ude, 1886) NLJ Adult and young
NGA *Nicodrilus giardi* Adult
NGJ *N. terrestris terrestris* (Sav., 1886)
NJJ *Nicodrilus sp.* Anecic
LTA *Lumbricus terrestris* (L., 1758); Adult and young (Sav., 1826)
LTJ *L. herculeus* (Sav., 1826)
LCA *Lumbricus castaneus* (Sav., 1826)
LCJ *Adult and young + 2 UNDET. undetermined young*

(S) varies from one species (*Lumbricus terrestris*) in a 10 years old vine to nine in a permanent meadow. The integration of variation in abundance and number of species led us to conduct a comparative study on the diversity (index of Shannon and equitability). However, because of the poorness of some populations (3 years old vine (D), PWVOM (C), 10 years old vineyards of Mt Bernon (M) and Oger (I) in many cases, it was not possible to interpret these indexes.

3.1 *Impact of cultivation*

The comparison of the various plots of Champvoisy has allowed us to evaluate the impact of cultivation. The abundance (number/m^2), the biomass (g fdt/m^2) and the specific richness in the various plots have been calculated, in percentage, of a reference plot (lawn of Mt Bernon (N)). The comparison of the reference fallow land (A) with plots without vines and without organic waste (PWVOM: (C)) and with three years old vines (D) shows that the earthworm populations have significantly affected by breaking up, levelling and soil treatment (fungicides, organic wastes). The abundance passes from 70 individuals/m^2 in A, to 3-4 in C and D. In the plot cultivated with 10-years old vines (E and G) and in the plot without vines with organic waste (PWVWOM: (B)) there is a tendency towards a restauration of the earthworm populations, without, however, reaching the abundance level of the fallow land (Fig. 2).

We next performed a multi-factor analysis to investigate for relationship between the various samples from the same plot of Champvoisy and between the earthworm species. The data include the effectives (coded into 5 classes of abundance) of adult and young earthworms belonging to 6 species and two groups of undetermined species (young of *Allolobophora rosea rosea* and *A.icterica* (AJJ) and anecic young of *Nicodrilus* sp. (NJJ) for 15 samples in which were present earthworms (see legend Tab. III). In a first step this table of data was analyzed by correspondences analysis (CA). A clustering analysis related to the factorial co-ordinates derived from CA, completed the results, and allowed the re-grouping of points in the factorial plans. Fig. 2 is a graphical representation in the plan of the axes 1-2 of the points corresponding to the 15 samples and the 17 species of earthworms. The axis 1 opposes the samples of 10-years old vines to those from environment that have been little disturbed or not disturbed at all (A and B). The anecic species, such as *L. terrestris* and *Nicodrilus longus longus*, characterizing the 10-years old vineyards are confronted with young Nicodrilus giardi and *Nicodrilus caliginosus caliginosus* (endogeic species). The axis 2 confronts, but less markedly, the plots charactyerized by a weak density and the presence of rare species, with natural reference environments of a greater density. As the endogeic and epigeic species are rare in the vineyards, one or two individuals of these species are sufficient to distinguish a sample group (e.g. *A. rosea rosea*). In the vineyards where populations are restored, the populations are very unbalanced by the clear domination of anecic species both in abundance and biomass. However such vineyards are characterized by *L. terrestris* and by *N. longus longus*, whereas the sample of PWVOM (B) are characterized by *N. giardi* (and by *N. c. caliginosus* endogeic). When no addition of organic matter has been made (3-years young vineyards (D) and plots without vines PWVOM (C)), the populations remain at a very low level (both the endogeic and the anecic species).

3.2 *Impact of the passing of machinery*

3.2.1 Objective

The vegetable zonation of a wine district entails the existence of a more or less compact track formed by the repeated passage of machinery (inter-row track) and of an undisturbed track beneath the vine-row. This creates preferential hydrosystems where the water flows away more or less quickly according to the slope.

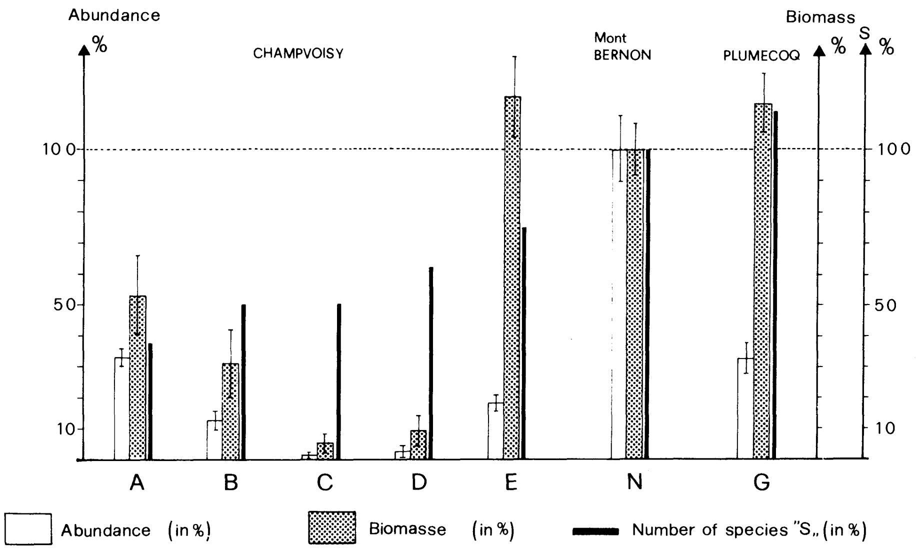


Fig. 2 - Variation of abundance, biomass and species number of the different plots, in relation to the reference environment (meadow of Mt. Bernon) (with standard error) (see significance of the different samples in Tab. I).

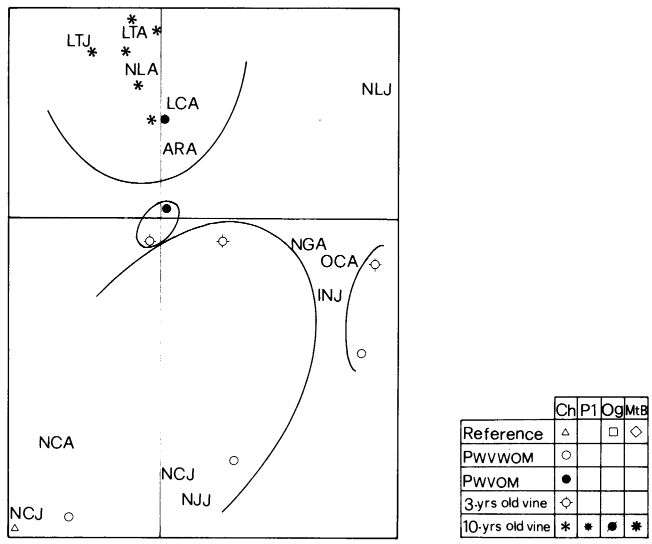


Fig. 3 - Order of valid samples and of earthworm species in the factorial plane 1-2 (Champvoisy only) For earthworm symbols see legend Tab. III.

The spread of organic matter on the inter-row track may constitute, depending on its nature, an excellent mulching thereby limiting the effects of erosion (Graff, 1969; De Boodt et al., 1977). In addition, this organic matter is a potential food source for the earthworms (Dunger, 1966; Graff, 1969).

The presence of earthworms in the inter-row tracks could, simply through the existence of a network of burrows, increase the drainage of water. We have compared the earthworm populations of the inter-row (large square 1 and 4) with those under the vines (large square 2 and 3). Moreover, the initial grid pattern of 64 small squares allow the study of the populations obtained by the formol method alone, by going from the inter-row track to under the vine-row (Fig. 1).

3.2.2 Results

As expected, in a natural environment the two zones have almost the same abundance, which is normal in a relatively homogeneous environment. On the contrary, in the vineyards, both at Plumecoq and at Champovoisy, 2/3 of the animals were captured under the vine-row (undisturbed zone) (Fig. 4). The

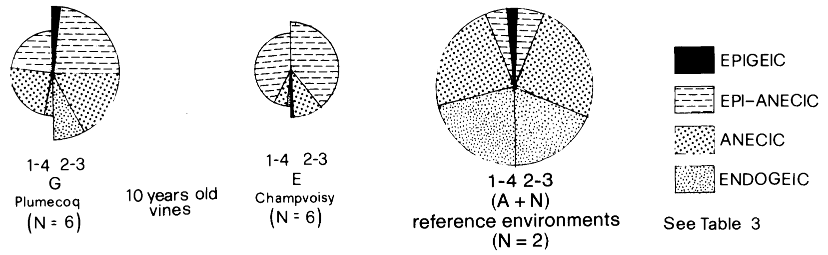


Fig. 4 - Comparison of total abundance between the large squares under the row (2-3) and those on the interrow (1-4). The surface is in proportion to the number of individuals.

whole structure, according to ecological categories (Bouché, 1977) is not greatly modified there, although the rarer species are not represented in the inter-row track: *N. l. longus* at Champvoisy, *N. c. alternisetosus, N. giardi* and *Octolasium cyaneum*, at Plumecoq.

The number of species and the abundance (formol) are lowest along the ruts left by the wheels of machinery, they increase going towards the vine row (Fig. 5).

The percentage variation of adults does not seem to be related to this horizontal structure of the population. These results show that in future studies, on earthworms in a wine growing district, samples may be taken solely from under the vine-row, since all the species are present there. However the rare species will be overestimated. No convincing evidence could up to be given for

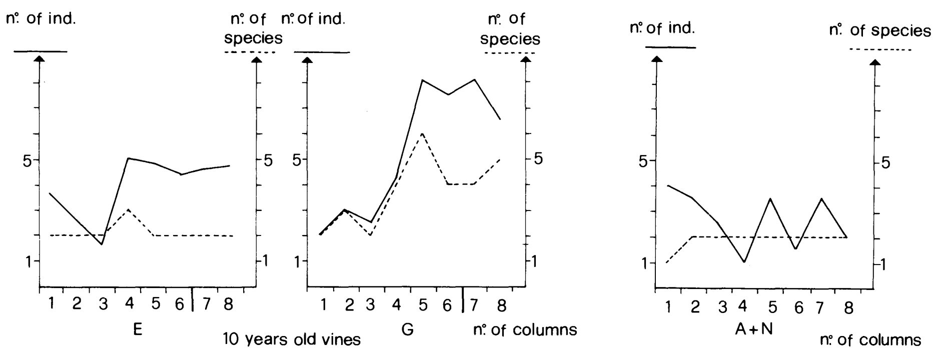


Fig. 5 - Variation of the abundance and number of species (by formol method only), passing from interrow to below the row, in the case of vineyards (E + G). Comparison with reference environment (A + N) (see Fig. 1).

the influence of the vine-plant on the distribution of the populations (line by line). On the other hand, a study of the influence of the organic matter on earthworm populations and of the influence of the earthworms on the water circulation in the soil (limitation of erosion) requires sampling over 1 m^2 (or over 1/2 m^2: idem Kuehle, 1983, see Fig. 1).

3.3 *Distribution of earthworms in the four plots*

We have attempted to establish whether the study of the earthworm populations could reveal differences among the plots investigated (compared to the study of role of physico-chemical factors alone). We repeated the same correspondences analysis, followed by a cluster analysis, with:

– on one hand, 7 adults and young earthworm species, 3 species with adults only, 2 undetermined groups at specific level (AJJ and NJJ) and one class of undetermined individuals at generic level (UND) (see legend Tab. III). (abundance treated in classes) with 31 valid samples

– on the other hand, 11 physico-chemical variables divided into categories in order to obtain a complete disjuctive table (Fenelon, 1981), thus containing 50 qualitative variables, with 27 valid samples (the first 2 factorial axes extracted 43% of the total variance).

The examination of the contribution of the various variables to the definition of the factorial axes (Fig. 6) shows that:

– axis 1 confronts samples taken in rich «natural» environments (lawn, fallow land and plots without vines with organic matter – PWVWOM –) characterized by adult and young *N.c. caliginosus* and by young *N. giardi*, with samples taken from 10-years old vineyards (Plumecoq and Champvoisy) characterized by adult and young *N.l. longus* and by adult and young *L. terrestris*.

– axis 2 confronts more or less rich samples (hydromorphous grassland, lawn), characterized by the endogeic species (*Allolobophora chlorotica chlorotica, A. icterica* and *A.r. rosea*) and epigeic species (*Lumbricus castaneus*) with environments affected by man, the earthworm populations of which, restored or not, are mainly characterized by the anecic species.

Thus, the perturbation of the environment (clearing and cultivation) entails the regression of epigeic and endogeic populations to the benefit of the anecic ones. Nevertheless, according to what happens to the plot after clearing, there may be a direct or indirect exclusion of one species by another (*L. terrestris/N. giardi*).

In this correspondence analysis study, the various samples from 10-years old vineyards, which possess a well developed population, form a homogeneous group, regardless of the plot of origin, except in the case of sample from the

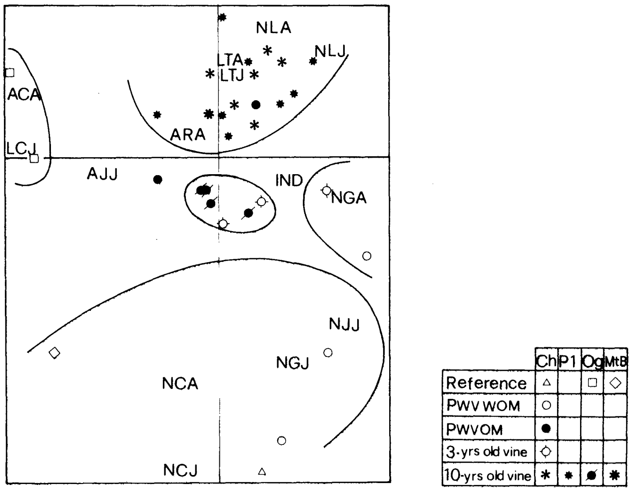


Fig. 6 - Order of the totality of valid samples and of earthworm species, in the factorial plan 1-2 (For earthworm symbols see legend Tab. III).

10-years old vineyard of Oger (I), which the samples are completely distinct. When we take into account the biomass data, we find again the principal features of the preceding scheme.

A second analysis, based on physico-chemical variables (Fig. 7) revealed two distinct areas, corresponding to geophysically distant plots: Champvoisy and Plumecoq-Oger. The pH KCl and the total rate of Calcium are higher in the plots of Plumecoq-Oger than in the plots of Champvoisy. On the other hand, the amount of clay is lower. Axis 2 lightly differentiates Plumecoq and Oger, but the influencing factors cannot be determined.

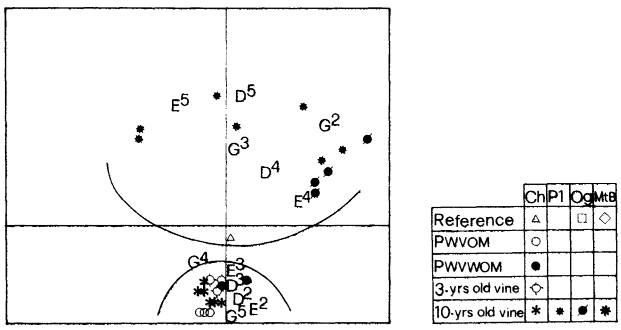


Fig. 7 - Order of all the samples and of the physico-chemical variables in the factorial plane 1-2 (only are given the variables that present a gradient correlated to one of the axes).

The same kind of analysis, focusing only on the samples from Champvoisy clearly separated the fallow land, which has more organic carbon and higher proportions of fine and coarse sand, than the other plots (dense gramineous system on undisturbed soil).

The observed differences between Champvoisy and Plumecoq-Oger could be due to the «historical characteristics» of these soils. The brown «rendzines» of Oger and Plumecoq, on the chalky colluviums, quickly come in contact with the chalk (hence the higher amount of calcium), whereas the brown soils of Champvoisy are more or less clay-calcareous, depending on the importance of the ablations of the clay colluviums of the Tertiary.

The physico-chemical variables divided the samples into two groups, whereas the biological variables (Specific abundance of earthworms) revealed 4 groups depending on the use of the plots and the characteristics deriving from that:

- little disturbed reference environments (lawn:N, fallow land:A), associated to disturbed environments that have received organic waste (PWVWOM:B)
- the 10-years old vineyards of Champvoisy and Plumecoq (G)
- the 10-years old vineyards of Oger (I)
- the hygrophyl meadow (J).

Moreover, with regard to the 10-years old vineyards, these biological variables group together plots that were distinct based on pedological variables (Champvoisy - Plumecoq), whereas they separate plots that were pedologically similar (Plumecoq/Oger).

4. General discussion

This study clarified the distribution of earthworm populations in some plots of the wine-growing district of Champagne.

We have shown that the implantation of vineyards (levelling at the time of clearing, soil treatments) greatly reduces the abundance of earthworm populations. This confirms previous reports (Edwards, 1980; Hennuy, et al., 1985).

In such almost sterilized soils, the migration of worms from deeper levels or neighbouring territories, as well as the survival of certain species in the form of cocoons, help to restore the populations (Blankwaardt & Van der Drift, 1961). Nevertheless, food being the main limiting factor for earthworm populations (Edwards & Lofty, 1982), the repeated and massive supply of organic matter (crushed household waste) accelerates the general process of progressive restoration of populations (Bosse, 1966; Graff, 1969; Andersen, 1980; Edwards, 1980). The vineyards should have a different selective effect according to the earthworm populations: this would be due to various components of the agrosystem (non-cultivation and keeping the bare soil through frequent and diverse chemical treatments, ...). In the vineyards, 10 years after planting, and also in generally disturbed environments, the populations are dominated by the anecic (with a more or less marked decrease of the endogeic and epigeic species). In non-cultivated soils, the earthworm populations are always more important than in the same mechanically worked soil (Graff, 1969; Edwards & Lofty, 1982; Gerard & Hay, 1979; Barnes & Ellis, 1982). The anecic species favoured by non-cultivation, which does not destroy the network of burrows, allowing the exploitation of the litter, except during dry periods (Edwards & Lofty, 1978; Henny et al., 1985), limiting also predation by birds that follow the plough (Cuendet, 1983). Although 2/3 of the population lives under the non-compact zone, the repeated passage of machinery does not to stop a certain colonization of the compact soil of the inter-row track. Once the vines are laid, the frequent application of various weed killers disturbs the stock of some populations; if the weed killers in normal quantities have little effect on the worms, the fungicides, on the contrary, based on copper or other fumigants, currently used in the vineyards, are «geodrilocides» (Duddington, 1961; Bouché & Fayolle, 1981; Edwards, 1983).

In some 10-years old vineyards there was no restoration of the earthworm communities (samples from vineyards of Oger). The fact that the vineyard was a second generation, having, therefore, received numerous applications of copper-based fungicides, explains perhaps this situation. The ecology of the worms and the way of spreading the pesticides are also important:

– *L. terrestris* which lives more on the surface than *N.c. caliginosus*, and feeds above all directly on fresh litter, accumulate more of the pesticides that have spread on the leaves, whereas the opposite is the case when they are incorporated in the soil (Davis, 1971).

– The small species, such as *N.c. caliginosus, A. rosea* and *A.c. chlorotica* are more sensitive to the various chemical treatments than are the anecic such as *L. terrestris* and *N.l. longus* (Van Rhee & Nathans, 1961).

Moreover, chemicals can have an important impact on the rate of reproduction of each species (Lofs-Holmin, 1982). Thus in the studied plots, *N.c. caliginosus* and *N. giardi* are perhpas more sensitive than *L. terrestris* and *N.l. longus*, as *N. giardi* had practically disappeared from some vineyards and *N.c. caliginosus* from all the vineyards.

The limitation of the plant production to only vine-stock, while keeping the soil bare by the repeated use of weed killers, results in a decrease of the small saprophage species (epigeic and endogeic), that are more sensitive to the various chemicals, particularly since they live close to the surface. The disappearance of a trophic interspecific competition could favour the development of the anecic populations with moreover benefit from the pluriannual deposits of litter.

In a disturbed environment, such as a field, where living conditions are more constraining than in a natural environment, competition among certain anecic species can occur. Edwards & Lofty (1981) have demonstrated a negative correlation between the abundance of *N.l. longus* and *L. terrestris*. In the samples taken in the vineyards of Champvoisy the number of *N.l. longus* varies very little between the 3-years old (2-4 ind/m^2 and the 10-years old vineyards (5-8 ind/m^2), whereas the number of *L. terrestris* passed from approximately 1-2 to 30 ind/m^2. In the case of these vineyards, where the trophic factor is no longer limiting, the important development of the *L. terrestris* populations could reflect the possibilities of such an environment not mechanically disturbed (advantage of non-cultivation). The relative stagnation of the effectives of *N.l. longus* is perhaps not the result of an interspecific trophic competition, but rather the result of a factor limiting only this anecic species (e.g. greater sensitivity to chemical treatment). This could favour more the development of *L. terrestris* populations.

Among the disturbed environments without vines (B) and those with vines (D and E) *N. giardi* disappears in favour of *N.l. longus*. Bouché (1972) shows the existence of an ecological exclusion (ecological vicariance) among certain species that occupy the same function in the same area such as between *N.l. longus* and *N. giardi*.

We have made a comparison between our results and those of Kuehle (1983) (obtained in german vineyards), based only on qualitative data, being different the sampling methods. He found a decrease of abundance, passing from an undisturbed environment to vineyards, but the earthworm populations of the vineyards are even less diversified than the majority of those observed in the sample of the wine-district of Champagne. Kuehle often found only two species in the vineyard: *L. terrestris*, which is dominant such as in Champagne and *A.c. chlorotica viridis*, which is, on the contrary, quite rare in our samples. This species is favoured by a reducing environment (Bouché, 1972) such as that generated through the ditching of little evolved organic waste in the soil; thus, this species could be an indicator of an agricultural practice. It is, therefore, not surprising that it is not found in our samples, because in the area studied by us, the organic waste is deposited there on the surface of the soil. Kuehle has also observed in a vineyard plot, the presence of *N.c. caliginosus* and of *A.r. rosea*, but he does not advance any explanation for this difference (in our study, the tendence of this species to be eliminated by cultivation of vines is shown).

The multifactorial analysis of earthworm populations allows to separate in space historically and structurally different plots, but also apparently identical plots. The biotic parameters of the environments, such as earthworms, can be used as bioindicators (Bouché, 1981; Kuehle, 1983) of the impact of man on the environment, in an assessment of the whole wine-district. They bring to light problems that are not revealed by classic studies (pedologic, oenologic and wine growing).

5. Conclusions

The impact of wine growing on earthworm communities should evaluated on different levels. Vine cultivation induces, through mechanical and chemical treatments, an important degradation of earthworm populations. After the vines are laid, the populations tend to reconstitute themselves, especially when organic waste (sources of nourishment) are massively and regularly supplied, either by culture or by man. However, there is no return to the original population: the populations of some species seem to be clearly placed at a disadvantage through the agricultural practices of vineyards, whereas others benefit from this situation (directly or indirectly). The communities are, therefore, very unbalanced, in favour of the anecic species. These populations, which are certainly simplified, but of a high biomass, have a relevant agro-pedogenetical impact (Bouché et al., 1983) in maintaining the fertility of the soil and in the recycling the biogenic elements, which could be lost through drainage and made unacessible for the rhizosphere (Bouché et al., 1977). Taking into account the structure and the physical features of the soil they should integrate the «earthworm» compartment. The activity of such a community consisting mostly of anecics, compensates for his action the non-working of the soil. As in a meadow, 1 ton of earthworms per hectare stirs up 300 tons of earth in a year (Satchell, 1960; Bouché et al., 1983), and as the best vineyard populations reach one ton of earthworms per hectare, 80% of which are anecic, we can estimate the impact of earthworms in such agrosystems. (when they can prosper). According to preliminary estimates (Bouché, personal communication in accordance with M. Assad), the drainage of waters in the burrows of these anecics could reach 25 mm/hour, corresponding to a good rainfall, the consequences, as to water reserves and to limiting erosion, are very important.

On the other hand, the medium and long term impact of chemical treatments that coincide with the non-cultivation of the vineyards should also be taken in account. The earthworms thus regain the important place that they traditionally occupied in the pedofauna and which they lost in man-disturbed environments (Hennuy et al., 1985). Moreover, the use of earthworms as bioindicators of the use of the environments by man, reveals problems, unknown up to now. The second phase of these studies should aim at clarifying the causes of the problems.

These studies should allow:

– On the one hand, to study more precisely the biology and the correlations of the various species in a perennial agrosystem, as well as the relation: earthworm – cultivation practices – plot history.

– On the other hand, to specify and to show the importance of this anecic population, in the medium-term management of a permanent agrosystem regarding:

i. the physical properties of the soil (increase of structural stability and porosity)

ii. the chemical properties (self-maintenance of the system through the earthworms, degrading the litter).

iii. the phytosanitary point of view (rapid burying of the litter would limit the winter inoculums).

Thanks to informations from professionals and to a seven-years multidisciplinary project, taking into account the earthworms would permit a more reasonable exploitation of the resources of the environment without damaging the vineyards, the exploiter of the adjacent lands. This is necessary for the medium and long term management of an agrosystem such as the wine-district of Champagne.

REFERENCES

Andersen C., 1980 – The influence of farmyard manure and slurry on the earthworms population in arable soil. In: D. L. Dindal ed «Soil biology as related to land use practices». C. R. VIIème coll. int. zool. sol, Syracuse, N. Y., Ed. EPA Washington, EPA-560/13-80-038, 687-701.

Atlavinyte O., 1976 – 14. The effect of land reclamation and field management on the change in specific composition and densities of Lumbricidae. Pol. ecol. stud., *2*, 147-152.

Atlavinyte O., 1981 – The effects of pesticides on Regeneration of earthworms and their Survival. In «Workshop on the role of earthworms in the stabilization of organic residues». (Ed. M. Appelhof), Proc. (Kalamazoo (Breech Leaf Press)) *1*, 151.

Barnes B. T., Ellis F. B., 1982 – The effects of different methods of cultivation and direct drilling, and of contrasting methods of straw disposal on populations of earthworms. J. soil sci., *30*, 669-679.

Blankwaardt H. F. M., Van der Drift J., 1961 – Effet de la stérilisation du sol sur les vers de terre dans les serres chauffées. Meded. dir. tuind. *24*, 490-496.

Bosse I., 1966 – Wiederbelebung biologisch verarmter Weinbergsboden, dargestellt am Beispiel des Regenwurmbesatzes. Progress in soil zool. (Ed. Graff), 341-352.

Bouché M. B., 1972 – Lombriciens de France. Ecologie et systématique. Ed. INRA, Ann. zool. - écol. anim., numéro spécial, *7/2*, 1-671.

Bouché M. B., 1977 – Stratégies lombriciennes. In U. Lohm et T. Persson «Soil organisms as components of ecosystems». In: Proc. VIth int. coll. soil zool.; Ecol. bull. (Stockholm), *25*, 157-163.

Bouché M. B., 1984 – Faune et flore telluriques: leur contribution à la fertilité du sol. Acta 1984. «Faune et flore auxilliaires en agriculture». Journée d'études et d'informations. 4-5 Mai 1983, Paris, 105-117.

Bouché M. B., Loquet M., Bhatnagar T., Rouelle J., 1977 – Essai d'estimation de l'influence écologique des lombriciens sur les micro-organismes. Pedobiologia, *17*, 400-417.

Bouché M. B., 1981 – Développement et lombriciens: biostimulisation des sols et bio-indications. C. R. jour. scien. écol. et dévelop., 19-20 sept. 1979, Ed. CNRS, 127-133 et C. R. Afie, Grenoble, 281-295.

Bouché M. B., Fayolle L., 1981 – Effets des fongicides sur quelques éléments de la pédofaune: conséquences économiques. C. R. 3éme coll. «Effets non intentionnels des fongicides», Paris. In Ed. soc. fr. phyt.-phytoph., 107-121.

Bouché M. B., Rafidison Z., Toutain F., 1983 – Etude de l'alimentation et du brassage pédo-intestinal du lombricien *Nicodrilus velox* (Annelida, Lumbricidae) par l'analyse élémentaire. Rev. écol. biol. sol, *20*, 49-75.

Bouché M. B., Gardner R. H., 1984 – Earthworm functions. VIII - Population estimation techniques. Rev. ecol. biol. sol, *21*, 37-63.

Cottom D. C., Curry J. P., 1980 – The effects of cattle and pig slurry fertilizers on earthworms (Oligochaeta, Lumbricidae) in grassland managed for silage production. Pedobiologia, *20*, 181-188.

Cuendet G., 1983 – Predation on earthworms by the Black-headed gull (*Larus ridibundus* L.). In: J. E. Satchell (Ed.) «Earthworms ecology from Darwin to vermiculture» Chapman et Hall. 415-424.

Davis B. N. K., 1971 – Laboratory studies on the uptake of dieldrin and D.D.T. by earthworms. Soil biol. biochem., *3*, 221-223.

De Boodt M., Gabriels D., Lenvain J., 1977 – Mulching as protection against erosion. Soil org. mat. studies, I.A. E.A., *1*, 117-121.

Duddington C. L., 1961 – The soil as an environment for animal life. (C. R. Symposium Norwich, 1er Sept. 1961). Nature (Lond.) *192*, 315-317.

Dunger W., 1966 – Die Entwicklung der Makro- et Megafauna in rekultivierten Haldenböden. Progres in soil zool. (Graff ed.), 341- 352.

Edwards C. A., 1980 – Interactions between agricultural practice and earthworm. In D. L. Dindal ed «Soil biology as related to land use practices». C. R. VIIème coll. int. zool. sol, Syracuse, N. Y., Ed. EPA Washington, EPA-560/13-80-038, 687-701.

Edwards C. A., 1983 – Earthworm ecology in cultivated soils. In J. E. Satchell (Ed.) «Earthworms ecology from Darwin - to vermiculture» Chapman Hall, London, 123-137.

Edwards C. A., Thompson A. R., 1973 – Pesticides and the soil fauna. Resid. rev., *45*, 1-79.

Edwards C. A., Lofty J. R., 1978 – The influence of Arthropodes and earthworms upon root growth of direct drilled cereals. J. appl. ecol., *15*, 789-795.

Edwards C. A., Lofty J. R., 1982 – The effect of direct drilling and minimal cultivation on earthworms populations. J. appl. ecol. *19*, 723-734.

Fenelon J. P., 1981 – Qu'est ce que l'analyse des données? Ed. Lefonen (Paris) 311 pp.

Gerard B. M., Hay R. K. M., 1979 – The effects on earthworms of ploughing, tiued cultivation, direct drilling and nitrogen in a barley monoculture system. J. agri. sci. Camb., *93*, 147-155.

Graff Von O., 1969 – Regenwurmtätigkeit im Ackerboden unter verschiedenem Bedeckungsmaterial, gemessen an der Losungsablage. Pedobiologia, *9*, 120-127.

Hennuy B., Van Ormelingen W., Gaspar C., Frankinet M., 1985 – Labour, demi-labour ou semis direct en continu: conséquences pédofauniques. (in press).

Kuehle J. C., 1983 – Die Bedeutung von Regenwürmern als Bioindikatoren - am Beispiel deutscher Weinbergsböden. Verhandl. Gesells. Oekolog. (Mainz 1981), *10*, 115-126.

Lofs-Holmin A., 1982 – Measuring cocoon producing of the earthworm *Allolobophora caliginosa* (Sav.), as a method of testing sublethal toxicity of pesticides. Swedish J. agric. res. *12*, 117-119.

Marshall V. G., 1977 – Effects of manures and fertilizers on soil fauna: a review. Commonwealth bureau of soils. 79 pp.

Reinecke A. J., Visser F. A., 1980 – The influence of agricultural land use practices on the population densities of *Allolobophora trapezoides* and *Eisenia rosea* (Oligochaeta) in southern Africa. In: D. L. Dindal ed. «Soil biology as related to land use practices». C. R. VIIème coll. int. zool. sol, Syracuse, N. Y., Ed. EPA Washington, EPA-560/13-80-038, 687-701.

Van Rhee J. A., Nathans S., 1961 – Observation on earthworm populations in orchard soils. Neth. H. agr. sci., *9*, 94-100.

Satchell J. E., 1960 – Earthworms and soil fertility. New Scientist, *7*, 79-81.

Stewart V. I., Scullion J., 1984 – Earthworm, soil structure and the rehabilitation of former opencast coal mining land. In: C. A. Edwards et al. «Int. Conference on Earthworm in waste and environmental amenagement. Jul., 84, Cambridge. (in press).

Van de Vesteringh W., 1972 – Deterioration of soil structure in worm free orchards soils. Pedobiologia, *12*, 6-15.

D. CLUZEAU, M. LEBOUVIER, P. TREHEN
Université Rennes I.
Station Biologique de Paimpont,
Laboratoire de Biologie du sol
F-35380 PLELAN LE GRAND FRANCE

M. B. BOUCHÉ
Laboratoire de Zooécologie du sol, CEPE.
CNRS/INRA,
BP 5051, F-34033 MONTPELLIER Cédex
FRANCE

C. BADOUR, A. PERRAUD
Département des services techniques,
Comité Interprofessionnel du Vin de Champagne.
BP 135. F-51204 EPERNAY + 1 Cédex
FRANCE