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Earthworm Species and Ecotoxicological Studies

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Abstract

Earthworms are an important food for vertebrates and have a major role in physical, chemical and biological processes in the soil. Laboratory studies on the toxicology of chemicals on earthworms are required to screen chemicals for any adverse affects of the chemicals on the earthworms and the ecological processes in which they are involved, before proceeding to more expensive field tests. The current morphological definitions of earthworm 'species' has resulted in the grouping of distinct non-interbreeding biological entities all together under the same name, e.g. Eisenia fetida complex and the Aporrectodea caliginosa complex. It is essential for laboratory tests that genetically homogeneous organisms are used such as biologically defined earthworm species, and/or that test animals are all derived from the same source. Although there is great taxonomic diversity among earthworms species, each can be characterised in terms of three ecological important categories, endoges, epigeics and aneciques.

The acute toxicity test must ensure intimate contact between the test chemical and earthworm by simulating natural soil but by using pure definable ingredients. Eisenia andrei (Bouché 1972) is recommended for this test.

The chronic toxicity tests should use a media that does not interfere with the interaction between the test chemical and the earthworm but allows cocoon production and growth to be assessed. A representative of each ecological category should be tested; endoge, Nicodrilus (= Aporrectodea) caliginosus caliginosus var paratypicus Bouché 1972; anecique, Nicodrilus (= Aporrectodea) caliginosus meridionalis Bouché 1972 ; epige, E. andrei. The last two species, which are more exposed to predators, are recommended for bioaccumulation studies.

To implement both the interpretation of the effect of chemical on earthworms and, through them, to agro-ecosystems and the acceptance of the use of chemicals, an initial analysis of the various steps to an integration of

In: P.W. Greig-Smith, H Becker, P.J. Edwards and F. Heimbach (eds) "Ecotoxicology of Earthworms". Intercept Ltd, 20-35 toxicological and ecological knowledges is given on the ground of the species field roles and the susceptibility to chemicals. The need, and the opportunity, today, to improve such an implementation is briefly discussed to demonstrate the absolute necessity to integrate researches to improve them and to serve practitioners.

Introduction

The increasing concern to provide a sound environmental assessment of chemicals requires that the interaction of chemicals and earthworms be taken into account. This was first realised after a general poisoning of the familiar american robin by way of their main food: earthworms.

While the study of earthworms was relatively underdeveloped, the ornithologists, among other environmentalists, focused attention to those tiny wriggly things as a key factor for wild life conservation. So, earthworms were one of the few organisms considered for ecotoxicological studies. Various acute toxicological tests were proposed and an easy-to-rear 'species': Eisenia fetida (Savigny) was chosen even though, this 'species' was known by some specialists as to be a species complex.

This first step – a pure artificial acute test – is a measure of the relative toxicity of chemicals. Obviously it does not provide sufficient information to predict the effect of a chemical applied in the field. So, an increasing effort has been made to improve field studies which are conducted on local earthworm communities of usually 3 to 10 species. The results from both laboratory and field studies can be grouped into three categories 1) acute toxicity tests (at first to establish an LC_{50} but providing other information at sublethal doses), 2) studies of chronic effects, 3) 'bioaccumulation estimations', i.e. chemical concentrations in earthworms, these earthworms being a vector in food chains (Figure 1).

All very well . . . but how to relate these results – gathered only for one (or a few) species in laboratories and for a few species in a few field conditions – to all earthworm communities, which hold thousands of species living in various soil, climate and management types? A method of interpretation and extrapolation of results is needed. Was it really necessary to spend so much effort to protect some birds?

In fact, birdwatchers were only looking at one role of earthworms, that of food for birds. Earthworms are a major component of the animal biomass of terrestrial ecosystems where they play several biological roles; as food for other organisms, interactions with plant roots and soil micro-organisms, chemical and physical functions which affect soil fertility and conservation. They are the main or occasional food of, 200 species of birds, mammals, amphibian and reptiles in France, plus many fish and invertebrates. They eat and crush an average of 300 Tonnes/ha of soil, mixing mineral layers and organic compounds to produce soil crumbs. The burrows they produce, provide channels through which soils respire. These channels also play a key role in infiltration of water allowing a mean through fall of 16 cm of water per hour (Al Addan *et al.*, 1991). Earthworms mediate many processes in the

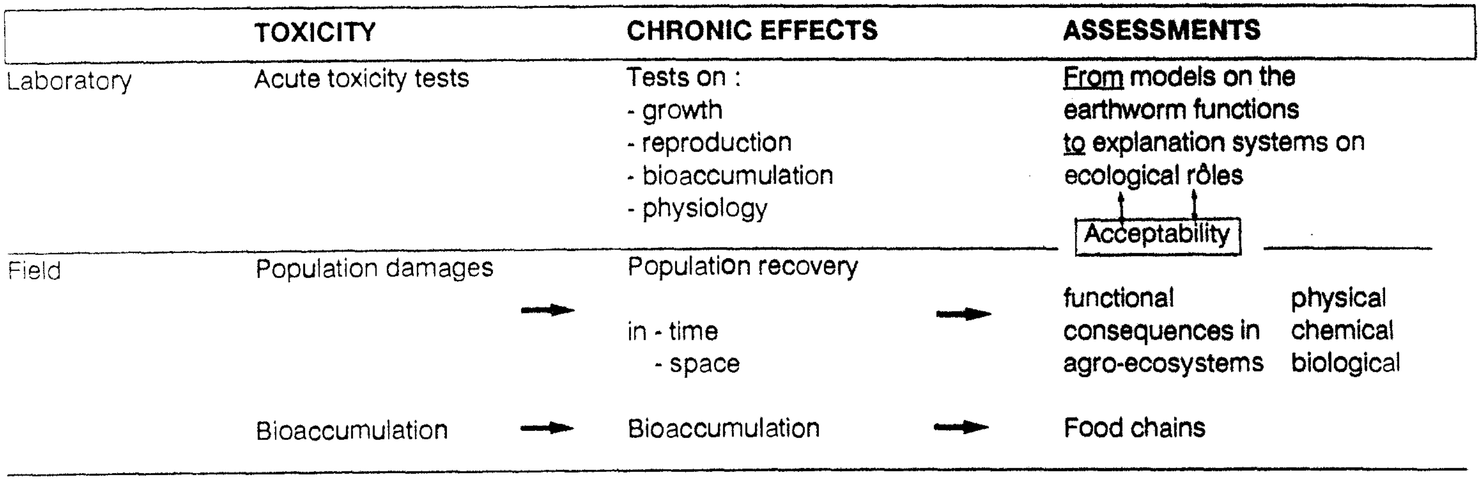

Figure 1. From the toxicity to the assessments. Contribution of both laboratory and field works to the appraisal of acceptable chemical effects.

nitrogen cycle. Direct effects include the huge gut transit (1200 kg N/ha/year) and excretion of small nitrogen molecules (ammonia, urea, microproteins: 400 kg N/ha/year) (Bouché *et al.*, in press), while their activities have indirect effects through changing soil microbial food conditions (Loquet *et al.*, 1977) and water logging.

So, we must thank birdwatchers who stimulated the protection of earthworms which in turn will contribute to better control of soil erosion, flooding, nitrate pollution and also an improvement of alternative methods such as minimum cultivation which need the earthworm task force as a substitute for most of the mechanical cultivation.

All earthworm species are not equally exposed to chemicals or are equally sensitive to them. However, in order to achieve a thorough environmental appraisal of chemicals in particular for the ecological processes involving earthworms, it is essential to realise that the effects of the chemicals on the environment is mediated through earthworm populations (Figure 2).

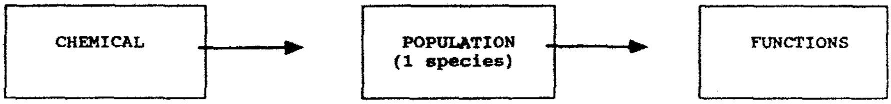

Figure 2. Relations between chemical input and ecosystemic function consequences.

The general validity of the model and its applicability depends on the functional position of the species of earthworms used in experiments, compared to the functional position of other earthworm species. This position depends, in turn, on the way of life (type of functioning) of the species, natural history and climate. There is an unavoidable need to extrapolate and integrate our knowledge from the few studies we have, both in toxicology and in functional ecology. Our ability to do this depends upon our skill to recognise species, and then to refer these entities to their roles. This in turn requires (i) our having a common concept of a species e.g. an entity composed of potentially interbreeding populations, (ii) our ability to distinguish between species and to recognise multispecies complexes.

Consequently, before we look which species to use in laboratory and field tests, a discussion of the functional position of a single species within the existing diversity is needed.

Functional position of species in their time-space diversity

PRESENT SPECIES AND TAXONOMY: THE STATE OF THE ART

The concept of a species as a group of potentially interbreeding populations can only be fully applied to a few groups of animals. For the rest, including earthworms, we have too few studies of the relevant properties.

There is a consensus by taxonomists on an earthworm classification based on those morphological characteristics which are preserved in museum specimens. However, earthworms bear relatively few morphological characters and it is therefore difficult to distinguish biologically defined species. On the other hand all stages of earthworms (gametes, eggs, juveniles and adults) have a very limited ability to move and therefore to mix their gene pools. Many other organisms e.g. ash trees are far more mobile due to their wind dispersed pollen and seeds. In other words we can suspect that taxonomists are being over-conservative in their concept of species and what is presently termed 'a species' based on morphology above could generally, if not always, be a mixture of true species.

For example, Eisenia fetida was recognized as heterogeneous since 1929 (Avel, 1929) and this fact, today well grounded, remains often ignored.

In this E. fetida complex, clearly Eisenia andrei is a good, relatively homogeneous, species while E. fetida is perhaps multispecific (Figure 3). E. andrei is a sibling species with at least one of the E. fetida 'species' (see Bouché *et al.*, 1988).

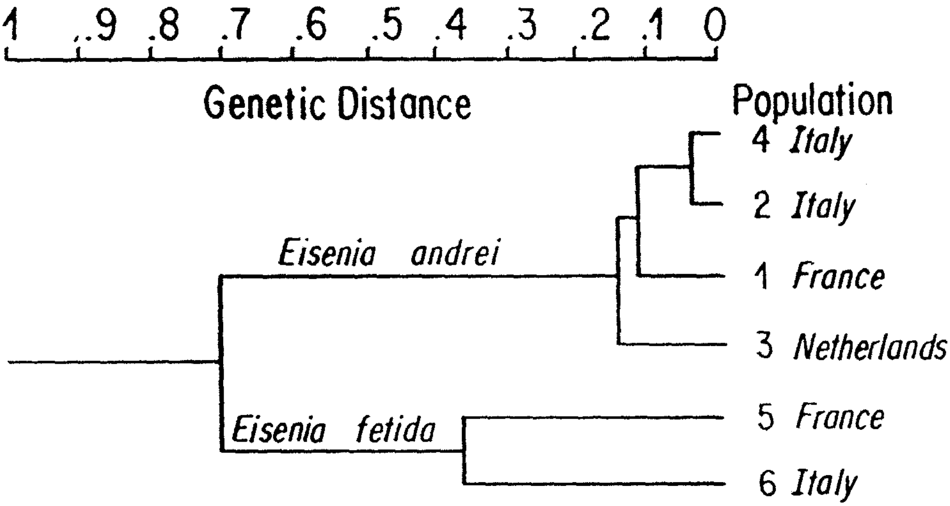

Figure 3. Genetic distances and diversity into the two sibling species of the Eisenia fetida complex (from Robotti, 1983).

An additional confusion here to non-taxonomists is which name to use for the genus. The question remains open as to whether A. caliginosa is a Nicodrilus (created by Bouché, 1972) or must be an Aporrectodea (having priority, created by Oerley in 1885) because we have no type and no original clear description of the species-type of the Aporrectodea genus. One 'species' (caliginosus) of this difficult-to-name genus is both very widespread around the world (Gates, 1972) and often plays a key ecological role.

About 50 species and subspecies of the genus have been described since 1826 when Savigny described Enterion caliginosa and Enterion terrestris. Taxonomists have recently been synonymising species based on preserved structures (see Easton, 1983) while an ecologist must recognise, or distinguish between entities with very different habits which live in the same field. For example Evans (1946) described A. nocturna, a big anécique species living in the same field in England as A. caliginosa, an endogé species but Easton (1983) synonymized these two totally different entities with no comment.

The A. caliginosa complex is multispecific, not totally described and the present 'specific' status of entities depends on taxonomists. However, this species complex is ecologically diverse and includes two definable entities, 'strains' that would be very suitable for laboratory tests on the chronic effects of chemicals (see below 'species and chronic tests') and should be relatively easy to rear. These two entities are A. caliginosa typica, an endogé and A. caliginosa meridionalis, a small anécique. In order to overcome problems with different interpretation of species definitions and genetic variation, well defined strains of each entity should be used.

THE HIGH SPATIAL AND TAXONOMIC DIVERSITY AND THE PRESENT VERSUS THE PAST

The colonization of terrestrial lands could be described since the primary era to the present (Bouché, 1983; Bouché, in press). The long lasting adaptation of earthworms to terrestrial conditions has led to an animal group with two main properties – 1) a very high biomass in many terrestrial soils, often earthworms are the major animal biomass in a soil, 2) a relatively poor ability to migrate with the consequence that selection of characters to suit the local environment is not diluted by the flow of genes between populations. With the result that some 'species' are mosaics of isolated populations.

The result is a key ecosystemic role and great taxonomic diversity. The great taxonomic diversity makes it very difficult to apply the results of laboratory or field experiments to all situations and we must even be cautious when applying them to the relatively few species that colonised areas of middle and northern Europe that were depopulated by the quaternary glaciations. As an example the 'well known' Lumbricus terrestris L. can be split in two non-interbreeding populations (two local 'species') in the same field (Figure 4).

Even though the taxonomic background is both complex and poorly known and field populations consist of mostly local subsets of 'species', we have fortunately a tool which gives us the chance to extrapolate the information on the faunal changes resulting from chemical uses between species, field and ecological consequences.

SPECIES PROPERTY CONVERGENCES AND ECOLOGICAL TYPES, OR HOW TO EXTRAPOLATE RESULTS BETWEEN COMMUNITIES VERSUS TIME-SPACE

Terrestrial ecosystems have several general functional features. Plants absorb most of their nutrient and water from the soil, and produce most of their

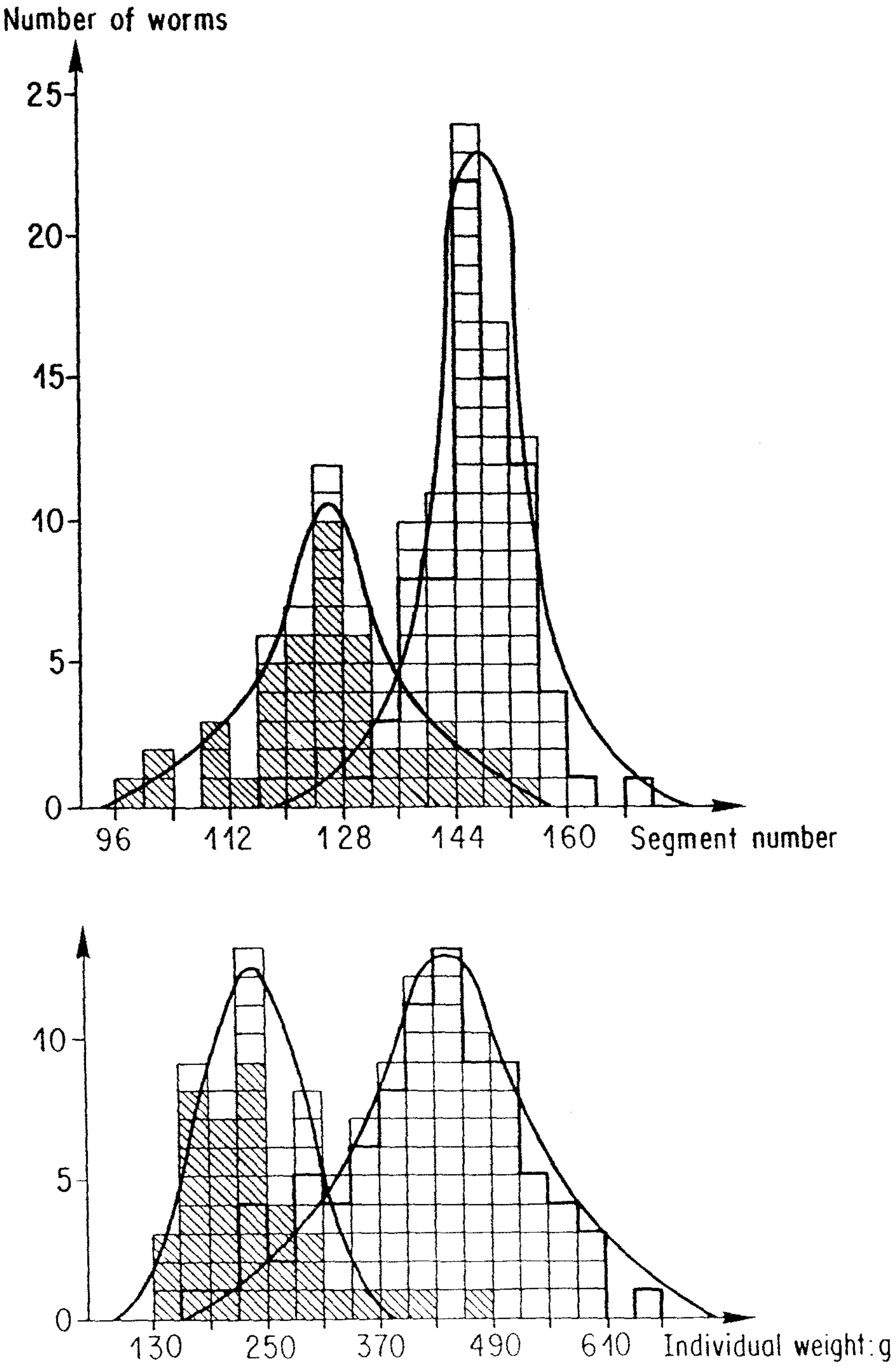

Figure 4. Observation of two distinct, most probably not interbreeding, amphimictic populations of the so-called Lumbricus terrestris L. (from Bouché, 1972). Is L. terrestris (at least) two species ?

(dead) tissues above ground. To resist herbivores, parasites and plants diseases, these tissues often include repellent factors such as alkaloids, resins, tannins, hard and poorly digestible tissues, spines.

The dead organic compounds from plants, directly or indirectly (faeces of decomposers or dead decomposers respectively), accumulate on the soil as litter. The decomposition of this litter depends on both the climate and the 'repellent quality' of its components. So that often, in bad seasons (dry or cold) or poor soils (where plants are repellent because more 'resistant') the litter is only slowly recycled and accumulates as an organic layer on the soil mineral horizon. This general pattern occurs more or less everywhere so that the various earthworm populations have evolved adaptations to enable them to recycle litter. This evolution has led to similar morpho-physiological characters in species of very different origins (family, genus) but converging on the same ecological roles and adaptations.

Three main ecological categories based on earthworm features (and not their milieu) were described (Bouché 1972) and could be recognized on the following features.

a) The endogés – or endogeics – are earthworms without skin pigmentation (i.e. flesh-tint more or less bloody or brown-earth by transparency) having an ecophysiological regulation of activity closely linked to soil conditions i.e. a resting stage or period of quiescence (hibernation or aestivation directly mediated by temperature and moisture). Great diversity of size, peripharyngial musculature, nephridial and circulatory adaptations occur in this group, depending of their sub-specialisation to feed on relatively organic rich food (polyhumics, carnivores) or poor food (oligohumics eating a lot of mineral soil), or living in well aerated or poorly aerated soils . . .

b) Epigeics – or epigés – are homochromically skin pigmented i.e. having a colour similar to their 'normal' milieu such as red-brown pigments in litter or sometimes green as in grasses because they are exposed to the selective presence of seeing predators. Often in the topsoil, they are destroyed by predation and physical factors as drought, frost or fire. They compensate these losses by high reproductive rate (r-selected: i.e. small size and a high number of hatchlings) associated with their rich organic food and by their 'resting' form as cocoons.

c) Anéciques – or anecics – are earthworms adapted to two milieus: they feed nightly at the soil surface on relatively fresh litter (where they later deposit their faeces) and they digest and regulate their physiology by precisely positioning themselves in soil gradients (1 to 6 m deep). They are subjected to night predators when they feed at the soil surface, their skin is darkly pigmented (brown-black or red-brown) especially the anterior and dorsal parts. Dragging their food into their burrows after an exploration of the available diet around these burrows (the tail remains in the burrow mouth), digging deep burrows to get of a greater choice of moisture and temperature in soil gradients, these earthworms open vertical channels in which they live most of the time (Bouché, 1987). To do that they are relatively large (7 cm to more than one meter in length), more strong musculature and a big gizzard able to mix the organic remains from litter with the mineral soil.

Under middle European conditions, the most stressful period for them is June when few plant residues remain as food, the short nights allow less time to eat, often there is drought and a high metabolic need because temperatures are high. These animals are typically adapted to these conditions by a specific resting stage: diapause. The diapause is mediated by photoperiod (Bouché, 1984; Saussey and Debout 1984) so that in June and mid-July they are resting irrespective of soil conditions. In the wetter and cooler parts of Europe an intermediate subcategory of earthworm – epianecics – occurs (i.e. Lumbricus terrestris, L. friendi, L. festivus, L. badensis, L. polyphemus . . .). This group differs from anecics by their lack of diapause. They always live in soils which remain moist.

The distribution of each of these ecological categories is determined by present soil and climate conditions and the recolonisation of areas following paleogeographic events (Bouché, 1983). Such historic, pedologic and climatic conditions must be carefully interpreted before results from ecotoxicological field tests can be generalised and applied in an European, or even worldwide context.

In other words laboratory tests are not directly relevant to field nor natural populations and field tests are not relevant to any time-space generalisation without a mechanism for extrapolation. The 'ecological categories' provide the mechanism which allows extrapolation both between species and between field populations. Let me demonstrate how to handle such concepts in practice.

Species and laboratory tests

SPECIES AND ACUTE TOXICITY SCREENING TESTS: ACCURACY AND REPRODUCIBILITY

Acute toxicity laboratory tests are an attempt to categorise chemicals into 3 groups; 'very toxic', 'non toxic' or 'intermediate toxicity'. The very toxic compounds must be discarded and the non toxic compounds could be accepted. While the chemicals of intermediate toxicity must be assessed by studies (chronic laboratory tests and field tests). Laboratory tests are just models, i.e. in any way they are substitute of true natural ecosystems where the chemical will be spread. To conclude to 'non toxic' or an absolute toxicity we accept that the relation earthworm/chemical is so obvious that the model could not be wrong versus real systems even if it is a harsh representation of these systems. We have absolutely no means to compare such models to the infinite number of ecosystem properties and all arguments to relate them to real soils are just arbitrary.

Nevertheless, the model must be reproducible to be accepted both as a useful tool and internationally. Three aspects of reproducibility are discussed.

1. An acute lab-test must ensure a close relation between the tested chemical and the earthworms, i.e. must eliminate interferences between this relation and the 'soil' as a substrate. A 'neutral' soil substrate is

required so that the 'soil' does not interfere with the interaction between the chemical and earthworm.

2. An acute lab-test must be reproducible, i.e. based on 'pure' (similar) components. All components ('soil' and ingredients, earthworm, and chemical) must be clearly defined. The more closely this is achieved, the greater the reproducibility. Even if only one component is not precise (as, for example, peat which varies with origin and with level in the same peat-bog) the reproducibility of a test may depend on it.
3. In order to satisfy points 1 and 2 above it is not possible to reproduce at all ecosystems, where soils are interacting with chemicals and where components are not pure and vary always in time-space. The so-called similarities of microcosms with filed conditions are just arbitrary opinions.

Further discussion about how to achieve neutrality of soil and reproducibility of the milieu and chemical in tests must be made elsewhere. A suitable species for an acute toxicity screening test must be easy to rear and be genetically homogenous. A species that fits these criteria is Eisenia andrei. It is genetically more homogenous than the E. fetida complex (see above 'Present species and taxonomy'). A further improvement would be to select a genetically controlled single strain of E. andrei which could be distributed to all laboratories.

SPECIES AND CHRONIC TOXICITY TESTS

Chronic tests are made to detect physiological disorders at sublethal doses which could occur in field. In addition to the criteria for lab tests described above, the milieu (environment) must include an earthworm food which will not interfere with the chemical tested. At present such a synthetic food is not available. The feeding behaviour of each of the three main ecological categories of worms can be affected by the type of food and the type of chemical.

Ideally a chronic test should include representatives of each ecological type of earthworm. E. andrei is a suitable epige. Endogeics and anecics are less easy to rear. However, suitable and definable, entities exist within the Nicodrilus caliginosus complex. I propose

1. to establish laboratory cultures of one strain of an endogé such as Nicodrilus caliginosus caliginosus var. paratypicus and one strain of a small typical anecic such as Nicodrilus caliginosus meridionalis,
2. to restrict toxicological laboratory tests to these strains of the selected entities, which include E. andrei, so that genetic consistency and homogeneity is maintained. These strains would be distributed to laboratories rearing live animals for tests,
3. to improve the definitions of the milieu for such tests: a similar milieu for epigé, endogé and anéciques: similar reproducible food: special care for photoperiodic reactions of the anecic strain ; easy to handle soil to follow chronic effects such as cocoon production or growth changes . . .

SPECIES AND BIOACCUMULATION TESTS

The conditions for studying the accumulation of chemicals in earthworms are very close of those described above. Nevertheless the need to kill the worms at intervals in order to follow the bioaccumulation pattern means that many more earthworms are required and therefore increased mass cultures. The greatest concern is to predict risks for birds and most mammals (exception moles, which eat endogeics) so these laboratory tests could be made with an epigé, (E. andrei) and anecic N. meridionalis. Again special care must be taken with food-chemical interactions which could affect both food selection in the milieu and changes in palatability.

Interpretation and acceptability

Having obtained results from laboratory and field tests both about acute and chronic demographic effects on populations and about chemical body burdens, and bearing in mind that earthworms are an important food source, what level of population disturbance and chemical burden can we accept?

Obviously, we cannot give an answer without taking in account:

1. The fact that chemical use is linked with other human activities (agriculture, industry, . . .). The protection of earthworms must be justified in comparison with other socio-economic factors.
2. The fact that environmentalists and more generally society, could not accept a decision without the demonstration of a good assessment, which uses state-of-the-art technology.
3. To make such an assessment we need to shift our primary interest from the relationship of the chemical and earthworm, to the integrated ecosystemic and economic role of earthworms. In other words toxicological and ecotoxicological studies are useless without a socio-economic and ecological evaluation.

This shift is possible only if we solve some problems caused by the weaknesses in our agro-ecological knowledge and of the absence of a really efficient integration between toxicology, earthworm ecology, agronomy, economics. Before discussing further the new possibility of forming our decisions using such an integration of information, I must point out one weakness in practice and the relations between species and acceptable perturbances.

SPECIES AND RESEARCHERS

While Europe has the highest concentration of earthworm specialists they are only the equivalent of one to three full time taxonomists on the whole continent. The various researchers with some skill in this matter are also involved in other activities and are not in a position to make a very classical work based on both comparative morphology and the use of modern techniques which are essential if we want to know on what species we work.

Not only does the general ecologist or toxicologist have no modern taxonomists available to help them but often there are no good text books on their local fauna. In consequence, researchers studying earthworms often use very doubtful or imprecise names for the 'species' on which they worked. The unreliable names used in reports and papers prevent a sound integration of knowledge to assist in the interpretation of the effect of chemicals on earthworms. We are now paying for a lack of earthworm researchers and the lack of general studies about the main animal component of our terrestrial ecosystems. We must fill this gap in our knowledge by assumptions!

SPECIES AND ACCEPTABLE PERTURBATIONS

Is a reduction of earthworm populations by 50% and the subsequent reduced population during the period of recovery, acceptable?

This simple and practical question includes three questions

1. What is the length of time required for the population of each species to recover to its original level?
2. Is the time for full recovery less than the time before other human action again reduces the population?
3. During the period(s) of reduced population is the decreased activities of the various earthworms in their physical, chemical and biological agro-ecosystemic roles acceptable?

Clearly to give a sound answer to the first question we need a demographic, an environmental and a functional appraisal.

DEMOGRAPHY AND SPECIES RECOVERY

There are cases where earthworm populations have substantially declined, in mining spoils or in moderately polluted soils for example. Heavy metals eliminate the susceptible genus Scherotheca in South France (Abdul Rida, com. pers.). Such situations are clearly unacceptable.

The acceptability of a partial and temporary poisoning depends on the time needed by a population to recover. We have at present no field studies to predict such a recovery but we can nevertheless build a predictive model based on the sparse knowledge we have from laboratory cultures and on the 'activity submodel' which relate the intensity of metabolism and the activity to three main driving factors: soil temperature and moisture, and photoperiod.

It is possible to make some generalisation on the rate of recovery of a species based on its size and the ecological functional type. The smaller the worm and more like an epige, the more likely a species is r-selected and has a high rate of reproduction and a short time from egg to maturity (2–5 months – depending on environmental factors). On the other hand the larger the worm and more it is K-selected, the slower the rate of population recover will be. Even though there are a large number of European earthworm species we can fortunately place those species in their ecological categories and apply our rare knowledge to both internal properties (genetical aptitude in the gradient of prolificacy: K to r) and on external regulations (physical environmental factors and food availability) based on their relative position in relation to the ecological categories. We need to build such an interspecific demographic model, to validate its predictability in the field and to use it.

SPECIES RECOVERY AND SUCCESSION OF POPULATION REDUCTIONS

To determine the acceptability of one population reduction resulting from the use of one pesticide we need to predict the time of recovery of the populations of earthworm communities and to place it in the context of other population reducing actions such as ploughing and other chemical uses during the year.

The frequency of such population reducing actions on earthworm is variable: very scarce in forests and permanent grasslands, these actions increase with the intensification in cropping (in orchards, in cereal crops, . . .). Acceptability of a chemical application depends on integrated assessment of the successive population reductions versus the ability of populations to recover.

SPECIES ROLES AND ACCEPTABILITY

When earthworm populations are reduced one or more times their ecological actions are reduced in proportion to their lower biomass.

The acceptability of reduced populations should not be fixed at an arbitrary level of decrease (such as 50%) but must result from an assessment of the various consequences of such a decrease for the ecosystem concerned. Examples of possible consequences to be assessed are:

(i) an appraisal of the loss of soil physical properties must be made in terms of a decrease in soil formation and stabilisation of granules, of water infiltration through- burrows, of increased risk of erosion,
(ii) an appraisal of the change in fates and movement of plant nutrients must be made as the balance of chemical elements in biomasses, necromasses, soil catchment and leaching, and seasonal synchronisation between compartments (as soil supply and plant needs).
(iii) biological consequences such as root distribution or microbial functions must be tackled. Especially, the consequence on earthworm predators (as fox, badger, woodcock, american robin, . . .) must be estimated both because the decrease of an important source of winter protein and because of the potential contamination of the remaining earthworms.

A new and integrated assessment is a prerequisite to general acceptance

INTEGRATED KNOWLEDGE AND ACCEPTABILITY

The use of chemicals on agro-ecosystems have been both an economical need and a blind action because the consequences of these uses are not fully predictable. Only some empirical properties have been observed while most, including all indirect effects were ignored.

Today this situation is changing dramatically both because we have a greater concern with a true agro-ecological assessment and mostly because we have recently gained the ability to do such a true assessment (Bouché, 1990). This change paves the way for linking preliminary laboratory tests, which discard or select useful chemicals, field tests, which measure the true chemical effects on populations and integrated assessments, which give a sound appraisal of the acceptability of a given population reduction versus the economic value of a given chemical use.

This integrated assessment needs the coordination of European research to aggregate all the available knowledge. This is possible thanks to two main tools, plus a conceptual transdisciplinary improvement.

1. Relational Data Bases, which are now reaching a new step (Distributed Relational Data Base), are computerised systems which manage all available data and automatically give access to the required data without the need of programming. The question only has to be asked. Thanks to these tools, facts (without pre-interpretations) will be available on the European scale.
2. Artificial Intelligence (A.I.) systems such as hypertexts, made possible for each specialist to produce the 'best' interpretation procedures; for example, to describe detailed models, to give their limits, their level of probability, their power to predict. Such A.I. systems could be organised in a matrix structure freely available to people and able to give a general interpretation and, if needed, to dig deeper to more detailed levels. All models on the effect of the chemical distribution technique, on earthworm exposure to the chemical in the field, on earthworm susceptibility versus chemical or solvent properties, on demographic population recovery, on effects of seasonal variation of temperature, moisture and light, on physical soil consequences, on transfer through food webs, . . . could be described by available specialists. These A.I. systems will be up-to-date and give state-of-the-art information. Improvement could be made every day on such systems. There is fossilization in papers.
3. These two tools need a very restricted number of transdisciplinary concepts which make it possible to handle the so-called complexity. These few concepts link data handling, interpretations, validations to field, . . . and could be easily translated between the various European languages. For example the 'use of pesticides' needs to be understood early by researchers developing new chemicals, by agronomists testing them and by regulatory advisers giving authorisations. In addition this knowledge must be available to practitioners or farmer advisers, to choose the 'best' available chemical based on the full facts. In such 'explained' situations there is greater acceptability because of the improved transparency from very specialised works to general uses. Because each specialist 'explains' their knowledge and makes it available, the use of these A.I. tools improves 1) the clarification of ideas, 2) the

availability of such ideas, 3) the transdisciplinary improvement of interpretation i.e. the synergy (for more details, see Bouché, 1990). The clarification eases translations between European languages and improves cooperation and availability to practitioners.

Last, but not least because of the vast number of European earthworm species, of the great variety of local conditions and of the increasing number of available chemicals it is essential to integrate our knowledge. The case is even more necessary when we consider the needs of the rest of the world. Only this integration paves the way to use both the various earthworm species for tests and the numerous chemicals in a sound, practical basis.

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