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СЕМИНАР И ОЗНАКОМИТЕЛЬНЫЕ ПОЕЗДКИ ПО ОБЕСПЕЧЕНИЮ СОХРАННОСТИ И УЛУЧШЕНИЮ ДРЕВОСТОЯ С ЦЕЛЬЮ ПОСТОЯННОГО ПОЛЬЗОВАНИЯ ЛЕСОМ

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CAN EARTHWORMS RESTORE DAMAGED FOREST SOILS ? POSSIBILITIES, PROBLEMS AND PROSPECTS

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ABSTRACT

A brief overview of the beneficial effects of earthworms on the soil physical and biogeochemical characteristics is given. The ecological demands of earthworms are next confronted with the specific properties of forest soils. The results show us ways to use earthworms for amelioration purposes in degraded forest soils. These possibilities are discussed and followed by some basic guidelines for a new ecotechnology based on earthworm biostimulation.

Key-words: earthworm biostimulation, forest soil, soil improvement, soil acidification, soil compaction.

1. INTRODUCTION

Altough the close relationship with the popular topic of forest decline, forest soil degradation isn't a recent issue. ULRICH (1981) situates the deterioration of the Middle and West-European mixed oak forest characterised by a mull humus and a soil pH > 5 (silicate buffer range) round about 5000 years ago, by the time that human population started settling, organising shifting agriculture, cattle breeding, all accompanied by biomass utilization in the forest. He even ascribes the migration of Germanic tribes in the centuries after Christ to soil acidification and a consequent decrease in fertility explained by aluminium toxicity.

In many cases, the homogeneisation and resinification of the forest, strongly developing during the industrial revolution has further increased the mineral weathering and lessivation of base cations (BONNEAU & al 1979, SOHET & al 1988).
Scientists and forest managers early this century like Müller, Erdmann, Hasselkamp and Wittich were already aware of these evolutions and tried to design ameliorative techniques of all kinds (VAN GOOR & al 1952, VAN DEN BURG 1986).
Since the eighties forest research became aware of the important ecosystem-external proton-loads penetrating the forest and mounting to 2 - 6.5 kmol $H^+ ha^{-1}.yr^{-1}$ (DEVRIES & BREEUWSMA 1985).
Acidified soils tend to have a low soil biological activity (MÜLLER 1889, WITTICH 1952, TOUTAIN 1981, KREUZER 1986) and are consequently characterised by the formation of raw humus, by unsufficient natural regeneration (RÖHRIG & al 1978) and superficial rooting. The absence of burrowing soil fauna causes an evolution from a

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loose pedogenous state to the sedimentogenous state. This loss of soil structure and macroporosity can also follow mechanical pressure on the forest soils due to heavy logging machinery (HILDEBRAND 1987). Anyway, there exists a closed link between degradation through compaction and acidification.

Our hypothesis is therefore that the stimulation of burrowing soil fauna, i.o. mainly earthworms, can contribute to the restoration of damaged forest soils both enhancing litter decomposition and unlocking the soil through bioturbation (figure 1).

2. POSSIBILITIES

2.1. Ecological categories

In order to get insight in the possibilities of soil restoration by earthworms, it is necessary to introduce the concept of ecological earthworm categories (BOUCHE 1972, 1977).

Among the earthworms, species are found with distinct niches. Three main categories can be distinguished on the basis of their morphology, distribution and way of living (Table 1). They are not to be considered as closed but as adaptive and evolutive poles with a certain number of intermediate species.

Table 1 : The concept of ecological earthworm categories (after BOUCHE 1972, 1977)

PROPERTY	CATEGORY		
	Epigeic	Anecic	Endogeic
Habitat	Litter	Soil	Soil
Food source	Litter	Litter	Soil
Channels	None	Vertical	Horizontal
Pigmentation	Red	Dark	None
Surviving strategy	Cocoons	Diapause	Quiescence
Acidotolerance	Important	None	Moderate

- Epigeic species : these generally small acidotolerant species are typical litter-dwellers in forests with moder and mor humus. Their ameliorating effect is rather limited (BOUCHE 1972).

- Anecic species are intensive burrowers. They represent more than 50 % of lombricid biomass in rich soils of the temperate climates where they play a primary role in the conservation of soil fertility (BOUCHE 1981). In most forest soils however they are absent (MUYS 1989 a).

- Endogeic species have thanks to their continuous intestinal transit of soil an additional bioturbation effect (SCHEU 1987). In rich forest soils they represent more than 50 % of lombricid biomass (MUYS 1987). Their activity is restricted to the first 30 cm of mineral soil.
- Epi-anecic species are evolutively epigeic but functionally anecic : deep burrowing but without diapause in summer and somewhat more acidotolerant (e.g. *Lumbricus terrestris*). They can be very important in forest soils with mull humus (MUYS 1989a).

2.2. Soil ameliorating effects of earthworms

The solar energy offered by plants under several forms of necromass (leaves, roots, exudates, ...) is partly used by the earthworms with consequences for the physical, chemical and biological soil characteristics. The importance of this earthworm functions has been described by several authors (DARWIN 1881, BOUCHE 1972, EDWARDS & LOFTY 1977, SYERS & SPRINGETT 1984, LEE 1985, CURRY 1988, LAVELLE 1988).

2.2.1. Physical effects (Figure 2)

Soil acidification causes desaggregation, clay lessivation and consequently pseudogleyfication, the hair roots escaping for more than 70 % from the mineral soil into the formed holorganic layer.

The physical effect of the earthworms on the contrary, consists in the increase of porosity and aggregation and leads to better aeration, better water economy and hence better rooting in the deeper soil horizons (SYERS & SPRINGETT 1983).

Aggregates are deposed on the soil surface as turricula (70 tonnes.ha^{-1}.yr^{-1} per 1000 kg earthworm fresh weight) and in the soil profile (230 tonnes) (BOUCHE & al. 1983). Epi-anecic and anecic channels can attain 2530 km.ha^{-1}. AL ADDAN & al (1988) and AL ADDAN (1990) found a positive correlation between water drainage and (anecic) earthworm biomass. The effectiveness of earthworms for the restoration of compacted forest soils was demonstrated in a limed beech stand where a significant negative correlation between earthworm biomass (epigeics and endogeics present) and compaction (penetrograph resistance) together with a positive correlation beween earthworm biomass and maximal depth of bioturbation was found (MUYS 1989b).

2.2.2. Biogeochemical effects

The importance of (epi-)anecic earthworms for litter decomposition was frequently prooved (NEF 1957, MALDAGUE 1970).
The humus particles formed in a mull through the symbiotic action of worms and intestinal Bacteria is more stable and long-living than raw humus (WITTICH 1952). The establishment of a mild mull humus is an effective anti-acidification process. It is attended with lower lessivation of mineral elements since its products of humification are insoluble : practically no aggressive substances meet the mineral soil (BONNEAU & al 1979).

Besides roots, anecic earthworms are almost the only actors of ascendent organo-mineral migrations in the soils of the temperate climatic zone which have a strong natural tendency to downwards migrations (BOUCHE 1981) : The 70 tonnes surface casting of a 1 tonne weighing *Nicodrilus velox* population in a beech forest (Vosges) originates for 20 % from litter, for 14.2 % from the A_1-horizon (avg. depth 7 cm), 9.3 % from the A_2-horizon (avg. depth 41 cm), 9.7 % from the B-horizon (avg. depth 140 cm) and 53.9 % from faeces, earlier deposed in one of these horizons, so that the mineral deposits originate after one or more gut transits for 54.7 % from the A_1-horizon, 35.8 % from the A_2 and 9.7 % from the B (BOUCHE & al 1983).

The earthworm channels, clothed with mucus and faeces are preferential ways for root development in deeper soil layers.
Different studies showed the higher availability of P and N for plant assimilation due to earthworm-activity (MANSELL & al 1981, MACKAY & al 1983, BOUCHE & al. 1987, HAMEED 1989).

2.2.3. Effects on forest productivity

The result of the foregoing earthworm effects on the forest soil are summarised in figure 3. It is an open question if all this beneficial effects give concrete form to increase in forest productivity. In agricultural and grassland soil, a lot of evidence has been assessed about production increases due to earthworms by comparing zones with and without earthworms (SYERS & SPRINGETT 1983, HOOGERKAMP 1987, STOCKDILL 1959 & 1982) (fig. 4).

Very little is known however about the influences on tree growth. VAN RHEE & NATHANS (1961) found an increased wood production in apple orchards after earthworm introduction. TOUTAIN (oral communication) found that an NPKCa fertilisation in the presence of anecic earthworms (TOUTAIN & al. 1988) increased the forest productivity with more than 50 %. There exist also indirect indications about the positive influence on tree growth : different authors mention the strong positive correlation between annual increment (m^3.ha^{-1}.yr^{-1}) and humus quality (ROGISTER 1978a, THILL & al 1988). Humus quality is mainly a function of pH and C/N-value which are strongly interrelated with the presence of earthworm functional categories (BOUCHE 1971, NORDSTRÖM & RUNDGREN 1974) and with earthworm abundance (SATCHELL 1955, MUYS 1989a). It must be noticed however that, to our opinion, optimal forest stability and vitality are more essential objectives than short-term production increases.

2.2.4. Effects on biological diversity

A lot of secundary tree species (genera *Fraxinus*, *Ulmus*, *Prunus*, *Carpinus*, *Tilia*, etc.) and many mesophilous forest herbs vanished out of the forest with increasing acidification, probably due to

Al^{3+} toxicity (ULRICH 1981).

Earthworm abundant mull forest soils on the contrary have a high diversity of woody and herbal plants. Moreover, GRANVAL & ALIAGA (1988) and GRANVAL (1990) published a survey of 190 European earthworm predators, among them badger (*Meles meles*), woodcock (*Scolopax rusticola*), wild boar (*Sus scrofa*), fox (*Vulpes vulpes*) and many other forest living species. He could proove that this predators concentrated on the forest sites with highest earthworm biomass (GRANVAL 1988a). This sites are consequently superior from the viewpoint of nature conservation and hunting (GRANVAL 1988b).

3. PROBLEMS

The question arises if the optimal ecological conditions for anecic and endogeic earthworms coincide with those for the main forest tree species. Therefore, we confronted the earthworm environmental demands with the ecograms for ash (*Fraxinus excelsior*) and beech (*Fagus sylvatica*) (ROGISTER 1978b). The coincidence with ash is perfect. Also for beech, earthworm soils give good growth altough the highest increments of beech are situated in acid mulls where earthworm activity is probably restricted. It is a fact that most ecomically important species (e.g. beech, spruce (*Picea abies*)) can grow in extremely acidified soils through their high Al^{3+} tolerance and that the water economy is a more restrictive factor for their growth than humus quality.

An inventory of earthworm activity in Flanders (Belgium) learned that most forest soils (under oak (*Quercus robur*), beech, pine (*Pinus sylvestris*)) only contain epigeic earthworm as a consequence of their pH(H_2O) below 4 in the A-horizon (MUYS 1989). The same research could demonstrate that the tree species itself is the most explicative factor of earthworm activity in the forests of this region, compared to climate and soil texture (MUYS & LUST 1990).

The ameliorating/degrading character of a tree species can be predicted for a certain soil type, mainly on basis of the C/N-value of the leaf litter (WITTICH 1961). This was affirmed by a species trial on former grassland where the earthworm communities differed after 20 years as a function of leaf species, e.g. under *Quercus palustris*, anecic and endogeic earthworms gradually disappeared and moder humus formation started (MUYS & al. 1990) (fig. 5).

In short, the natural soil development under a lot of important tree species is opposite to the conditions favcurable for earthworms.

4. PROSPECTS

The confrontation of the possibilities of soil restoration using earthworms with the problem of certain ecological incompatibilities between earthworms and forest soils does not necessarily lead to

restrictions in the feasability of this idea but rather to practical techniques, useful in all soils except extremely poor sceletic sandy soils where only organic sorption is possible (EBERT 1988) and where slow litter decomposition has probably to be considered as a saving strategy.

Liming and/or fertilising is a necessary compensation for the mineral losses due to human forest use during centuries and also a necessity for stimulating biological soil activity (WITTICH 1952, BEESE 1985, SCHAUERMANN 1985, TOUTAIN & al 1988). The composition of such a corrective fertilisation is dependent on the local leaf and soil analysis. In general, medium gifts must be preferred. Fastworking aggressive products as CaO are negative, because of a too fast mineralisation of litter and even humus resulting in lessivation and also because of damages to roots (BEESE 1985) and decomposing fauna (BUSCHINGER 1990).
It has been made clear, and this is of crucial importance, that liming/fertilising of a soil without endogeic or (epi)anecic species has a small, superficial (LANG & BEESE 1985) and anyway a shortterm effect compared to the same soil with earthworms present (MUYS 1989b). Moreover, it induces mineral and especially nitrate losses (WILHELMI 1988).

The realised vermimull will be more durable as the leaf litter of the trees is less refractory. The choice and mixing of tree species is therefore of great importance.

Soil tillage has to be considered as unfavourable. In combination with liming, it accelerates mineral losses (BEESE 1985). The increase of macroporosity is shortlived because it is an unstable situation in comparison with the pedogenous steady state (HILDEBRAND 1987). The more, it contains a direct (machinery) and an indirect compacting component : tillage is very negative for earthworms by destroying their channels, decreasing their food source, changing the soil microclimate and inducing excessive predation (GARCEAU & al. 1983, GRANVAL & al. 1990).
Only a superficial treatment (10 cm maximum) with a rotavator for example can be advantageous.

We are convinced that organised earthworm introduction is often the only way to realize bioturbation (BRUN & al.) because in most degraded forest soils the active species are totally absent: Intensive international study on this subject is therefore an absolute priority. Only few introduction experiments in forest soils are known uptill now (HUHTA 1977 with *Nicodrilus caliginosus* (endogeic), JUDAS & SCHAUERMANN 1989 with *Lumbricus terrestris* (epi-anecic) and other experiments on the run in France and Finland with *Nicodrilus velox* (anecic)).

The above described measures can only be succesful when taking place in an integrated concept of soil activation (GRANVAL 1989, MUYS & LUST 1990). For practical purposes we propose a diagnostic, utilising leaf and soil analysis and earthworm activity, permitting to choose an optimal ameliorating technique (fig. 6).

5. CONCLUSIONS

- Enumerous publications deal with the beneficial effects of earthworms on soil physical and biogeochemical properties, resulting in higher productivity, stability and diversity. It leads to the hypothesis that earthworms can help to improve acidified and compacted forest soils.

- West- and Middle-European forest soils have a low earthworm density due to the natural acidification process under the most important timber species, which is severely accelerated by human interference. In most of these forests active earthworm species (endogeic or anecic) are totally absent.

- Therefore, forest soil improvement must be an integrated concept of soil activation including choice and mixture of tree species, corrective liming and fertilising and earthworm (re-)introduction.

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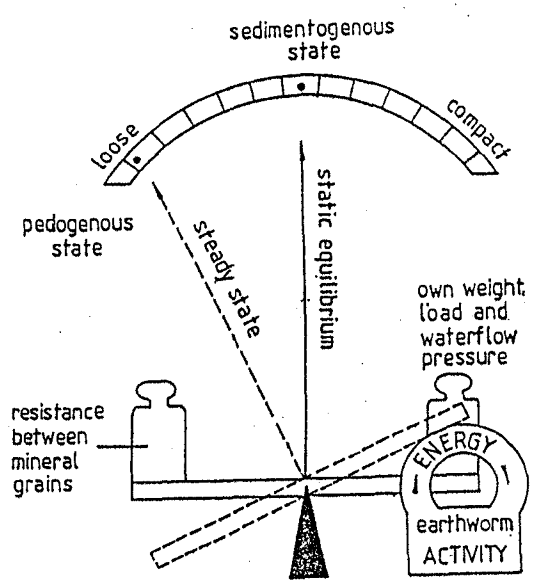

Figure 1 : Hypothesis of forest soil improvement through earthworm bioturbation (modified after HILDEBRAND 1987)

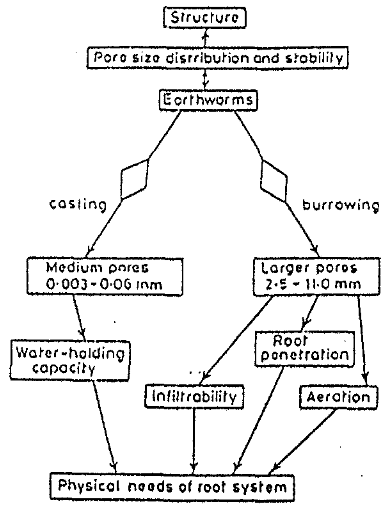

Figure 2 : Soil physical effects of earthworm activity (SYERS & SPRINGETT 1983).

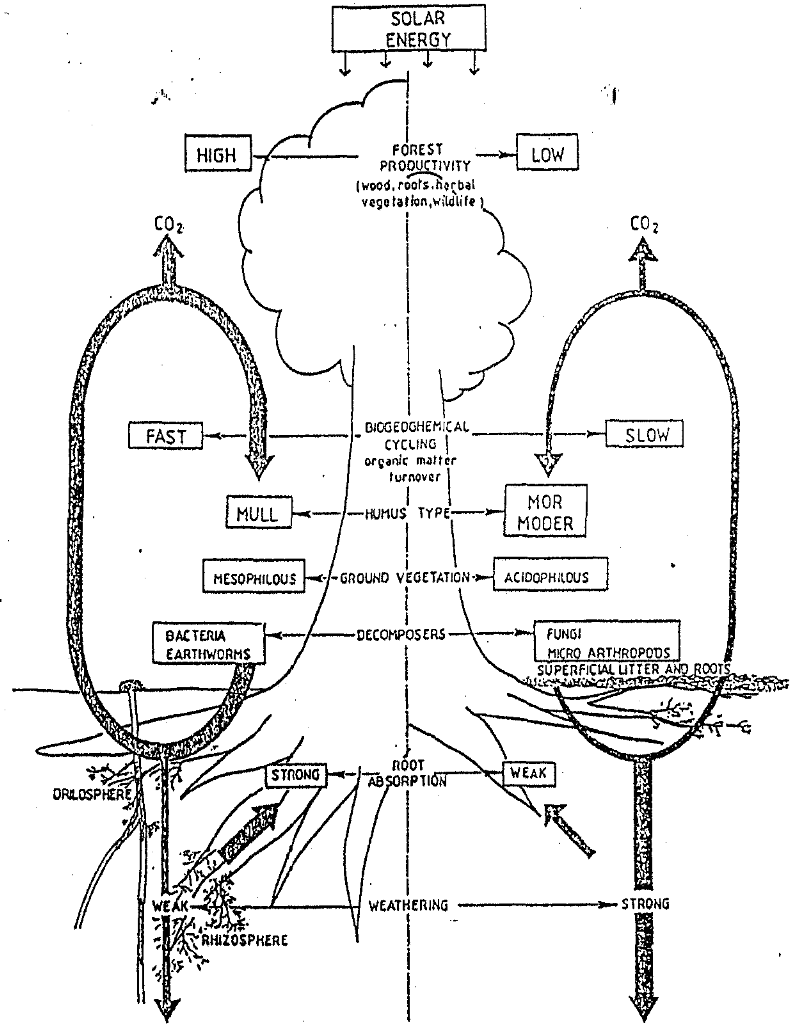

Figure 3 : Comparison of a forest ecosystem with (left) and without earthworms (right) (after TOUTAIN 1981 and LAVELLE).

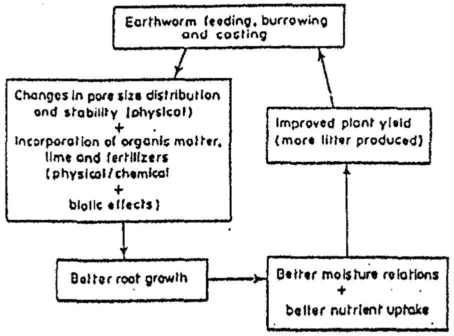

Figure 4 : Interrelationships between earthworm activity, soil properties and plant growth (SYERS & SPRINGETT 1983).

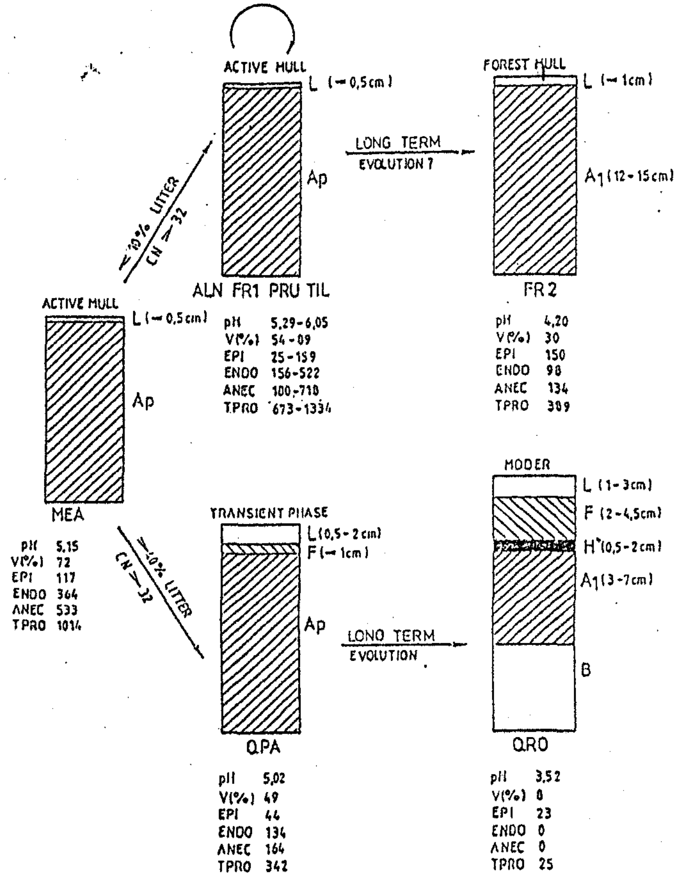

Figure 5 : Evolution of earthworm communities, humus type and soil properties after afforestation of a meadow with different tree species (MUYS & al. 1990). [legend : MEA=meadow; 20 year old stands : ALN=*Alnus glutinosa*, FR1=*Fraxinus excelsior*, PRU=*Prunus avium*, TIL=*Tilia platyphyllos* and QPA=*Quercus palustris*; 70 year old stands : FR2=*Fraxinus excelsior*, QRO=*Quercus robur*; V(%)=base cation saturation; earthworm biomass (kg.ha^{-1}) : EPI=epigeics, ENDO=endogeics, ANEC=anecics and TPRO=total biomass.

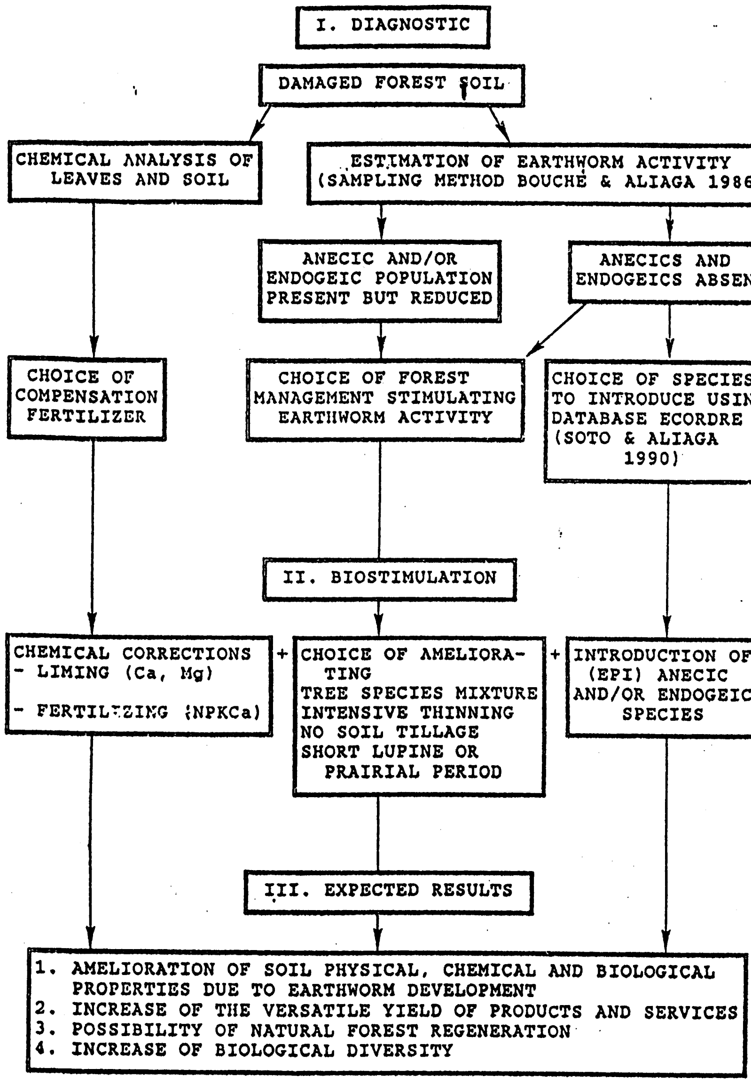

Figure 6 : Scheme of the integrated concept of soil activation.

STELLEN REGENWÜRMER GESCHÄDIGTE WALDBÖDEN WIEDER HER? MÖGLICHKEITEN, PROBLEME UND AUSSICHTEN

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Bodenzerstörung ist teilweise ein biologisches Problem und könnte möglicherweise mit biologischen Mitteln gelöst werden. Seit der Veröffentlichung von Charles Darwin über "Die Bildung von Humus durch Würmer" im Jahre 1881 wurden zahlreiche Aufsätze über die nützlichen Wirkungen von Regenwürmern auf die bodenphysikalischen, chemischen und biologischen Eigenschaften veröffentlicht. Regenwürmer entwässern und durchlüften den Boden, zersetzen organische Stoffe und mischen diese mit Mineralboden, fördern das Leben von Mikroben und die Nährstoffaufnahme von Pflanzen. Alle diese Ergebnisse wurden auf Wiesen und landwirtschaftlichen Flächen ermittelt. Es ist eine offene Frage, ob Regenwürmer für die Verbesserung geschädigter Waldböden nützlich sind.

Eigene Ergebnisse und eine Untersuchung der Literatur haben gezeigt, daß bei den Waldbeständen, bei denen Regenwürmer ausreichend vorkommen, die Streuzersetzung rascher erfolgt, der pH-Wert und die Basenkationensättigung höher sind, die Bodenverdichtung niedriger ist und mehr pflanzliche Biomasse vorhanden ist als bei Beständen ohne Regenwürmer. Spärliche Hinweise gibt es auf ihre nützlichen Auswirkungen auf die Holzproduktion.

Regenwürmer stellen jedoch hohe Ansprüche an ihre Umwelt: Die meisten humusbewohnenden und mineralbodenbewohnenden Arten, die für die biologische Bodenumwandlung und Mullhumusbildung unentbehrlich sind, fürchten Säure, obwohl die meisten Wälder mit wirtschaftlich bedeutsamen Baumarten extrem saure Böden haben, was teilweise auf ihre kaum schmackhafte Blattstreu zurückzuführen ist. Die optimalen ökologischen Bedingungen für die meisten Regenwurmarten weichen von denen der Hauptbaumarten ab.

Daher muß eine Verbesserung geschädigter Waldböden durch eine Änderung der ökologischen Bedingungen zugunsten von Regenwürmern erfolgen. Dies kann durch Mischung der Wirtschaftsbaumarten mit bodenverbessernden Baumarten sowie durch Kalkung/Düngung erreicht werden. Bodenbearbeitung ist zu vermeiden, weil sie die Regenwurmbestände vermindert. Diese Methoden werden jedoch nur erfolgreich sein, wenn Restbestände von humus- oder mineralbodenbewohnenden Regenwürmern noch vorhanden sind. Wenn nicht, ist es unbedingt notwendig, diese Methoden mit einer (Wieder)-Einführung von Regenwürmern zu verbinden. Säuretolerante Wurmarten, die möglicherweise für diese Arbeit nützlich sind, sind Lumbricus terrestris, Aporectodea caliginosa und Nicodrilus velox. Es ist dringend notwendig, unsere Kenntnisse über die Methodik der Regenwurmansiedlung in Wäldern zu verbessern.

AGROFORSTLICHE PRODUKTIONSSYSTEME FÜR BODENSCHÜTZENDE UND NACHHALTIGE PRODUKTION IN DEN TROPEN UND SUBTROPEN

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1. BODENSCHUTZ, NACHHALTIGKEIT, AGROFORSTWIRTSCHAFT

Ein gewisser Bodenabtrag durch Wasser und Wind ist vielerorts ein normalerweise natürlich begrenzter Vorgang. Durch unpflegliche Bodennutzung wird dagegen die Bodenerosion weltweit zu einem gefährlichen Prozeß der Bodenzerstörung (5, 6, 15).

Die Bedeutung der Bodenzerstörung in den Tropen und Subtropen ist eine Folge vielfach verfehlter Landnutzung und des steigenden Bedarfs an neuen Produktionsflächen für die Land- und Viehwirtschaft, meist auf Kosten der Wälder (8, 16, 17, 19, 21).

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