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Field experiments to accelerate succession and to improve *Quercus ilex* establishment with a renaturation technique (ReviTec®)

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ABSTRACT: Within a large area destroyed by fire (1991 and 1993) at Na Burguesa mountain near Calvià/Majorca (Spain), experimental sites were established at Bendinat in Nov. 1997 (300 m a.s.l., south-east exposition). ReviTec® was applied to accelerate succession and improve *Quercus ilex* establishment on these highly degraded sites. This eco-technology has been developed for the ecological restoration of degraded landscapes, for the stabilisation of erosion-prone sites and for the (re)vitalisation of undeveloped sediments. It is based on the understanding of ecological processes, like ecosystem development (succession) and ecological interactions (e.g., mycorrhiza). Due to its modularity, the technology is highly flexible in its application and may be linked to recycling technology.

The basic module of ReviTec® as applied in the experiments is a jute bag filled with amended substrate and biota. A couple of bags are composed to form a fertility island. The bags perfectly fulfilled erosion control functions, which are taken over by ruderal vegetation timely in the course of their decay. The islands serve as catchments and are habitat islands, which promote phyto-diversity and attract fauna. They serve as scatter plots. The results from a multitude of experiments with different treatments to plants and substrates confirm the importance of the right choice of substrate amendments and the positive influence of mycorrhiza for growth and survival of *Q.ilex*. Bioactivation in the sense of establishing a vital and sustainable initial biotic composition on the ReviTec® fertility islands is most important and offers a wide range of management perspectives.

1 INTRODUCTION

1.1 *The problem*

Plato: 'Attica (Athens) was no longer cultivated by true herdsmen, who made husbandry their business, and were lovers of honour, and of a noble nature. As a result Attica had become deforested, the soils depleted, and there are remaining only the bones of the wasted body –all the richer and softer parts of the soil having fallen away'.

In many parts of the world, man's exploitation of terrestrial resources overstressed the ecosystems' resilience, which becomes evident in the degradation of the soil. Ecosystem functions and resulting services, like soil stabilisation, nutrient cycling, filter function and carbon sequestration are challenged or even lost, leading to erosion, loss of soil fertility, polluted ground water and effects on global warming. The detrimental developments are aggravated by negative feed-back and global change, including agricultural practices and economy as well as climate change. In degraded ecosystems, one or more of Reichle's (Reichle et al. 1975) four attributes for ecosystem persistence are dysfunctional or even destroyed. They are: (1) autotrophic energy base, (2) nutrient cycling, (3) rate regulation and (4) energy and nutrient sink.

These facts have been recognised, e.g., by AGENDA 21, UNEP-EEA (2000) and UNCCD (1994), which propose a wide range of activities to address land degradation in general and desertification in particular. However, there is still some need for an understanding of the underlying causes and processes and for the development of adapted restoration tools in order to counteract or alleviate degradation.

In less severe cases of environmental deterioration, where soil cover is at least partially intact, afforestation may be attempted, mainly for economic reasons but also for its positive effects on mesoclimate, water household and erosion control (Aronson et al. 1993). However, an Ecosystem Approach (UNEP 2000) for soil development is not in the focus of such efforts, particularly when fast growing introduced (alien) species are planted. Such “approaches to ecosystem rehabilitation are extensions of traditional agronomic technologies” (Whisenant 1995). One of the problems arising from an underestimation of the ecosystem context is the asynchronous development of vegetation, soil biota and soil (Weidemann et al. 1982).

Fire is a characteristic environmental variable of Mediterranean environments; however, there are considerable increases particularly for Spain in numbers of fires and area affected (Hetier 1993). In combination with an increased anthropogenic pressure and climate change, fire may initiate under these conditions degradation processes. On the Mediterranean island Majorca (Spain), repeated fire destroyed an extended area (>1000 ha) of *Pinus halepensis* forest at the Na Burguesa mountain range in the municipality of Calvià/Majorca in 1991 and 1993. Here it was possible to establish an experimental site for the restoration of a self-sustaining site-specific ecosystem with the help of an eco-technology (ReviTec®), which is in line with the Ecosystem Approach of Convention on Biological Diversity (CBD): “The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. ... 2. An ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organisation, which encompass the essential structure, processes, functions and interactions among organisms and their environment. It recognises that humans, with their cultural diversity, are an integral component of many ecosystems. 3. This focus on structure, processes, functions and interactions is consistent with the definition of "ecosystem" provided in Article 2 of the Convention on Biological Diversity: 'Ecosystem' means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit“ (UNEP 2000, p. 104).

Our approach focuses on the reestablishment respectively on the support of the four attributes for ecosystem persistence mentioned above (Reichle et al. 1975), but also on ecosystem services like water holding capacity and soil stabilisation, and enhancement and “dynamic conservation” of site specific biodiversity. The establishment of an appropriate initial biotic composition and the artificial mycorrhization are most important tools to accelerate systems development and improve survival, e.g., of planted trees. The approach includes capacity building of stakeholders and may bring incentives to local SMEs.

Although economically not so rewarding due to its rather long reconstitution time of 70-80 years, succession leading to a *Quercus ilex* forest bears many advantages, including high biodiversity (Quézel et al. 1999). Barbéro et al. (1991) include the sclerophyllous oaks (*Q.ilex* and *Q.suber*) in a *modèle de résistance* with following features: adaptation to semi-developed soils, tolerance of drought up to six months, high interspecific competitive performance, compared to *P. halepensis* reduced inflammability, generally high adaptability due to high genetic variability. After fire, coppice shooting is essential; apart from zoochory, seed dispersal is low due to high weight of the oaks. As vegetation history reveals, sclerophyllous oak communities are highly adapted to human activity (Margaris 1981). The development of high soil stability (Cerda) contributes to resistance against perturbations. *Q. ilex* forest communities vary geographically considerably and may bear a high phyto-diversity (Zavala et al. 2000).

1.2 *The ReviTec® concept (http://www.revitec.de/)*

The ReviTec® eco-technology is a widely applicable tool for initiation and acceleration of succession, focussing on restoration and ecological management of biodiversity (Kesel et al. 1999). It relies on technological innovation and ecological knowledge, and allows for site specific natural processes of self-organisation which are to a great extent unforeseeable, coincidental and beyond specific management (Müller et al. 1997).

The modular design of ReviTec® covers three levels of scale and function. The basic module is a bag of degradable material, filled with ca. 30 litres of a substrate specifically amended with abiotic and biotic elements (bioactivation) for the establishment of ecosystem processes. A couple of bags are arranged to build a fertility island, with features as well of water and particle catchment as of scatter plot. The fertility islands are arranged within the landscape in specific patterns, which may be incorporated into the medium scale relief. Important on the landscape level is predominately their feature as scatter plots from which successional processes spread, but also as vegetated barriers against erosion, which in the long run will lead to living landscapes. It is intended to cover approximately 10% of a degraded terrain with fertility islands.

The technological innovation relates mainly to the bags and the substrate. The fabric protects the substrate from erosion. It may be selected in terms of degradability depending on the potential of biogenic soil stabilisation and on the erosion hazard. The substrate may be improved with additives, from quality compost to specific water and nutrient controlling substances. Eco-compatibility has to be ensured for all components.

The choice and management of biotic components for bioactivation of the substrate require ecological knowledge on potential autochthonous colonizers, their functions and their appearance in the course of natural succession (David et al. 1999). Plant saplings and seeds are considered as well as soil fauna and mycorrhiza for this introduced initial biotic composition. Particularly in the selection of saplings, special attention is paid to regional strains. The regional successional series and the respective successional mechanisms such as inhibition, tolerance and facilitation (Connell & Slatyer 1977; nurse plant concept: Castro et al. 2002) are important criteria for the configuration of the initial biotic composition. Unforeseeable and accidental events of colonisation are fostered by the micro-catchment function of the fertility islands and by favourable or selective properties of the substrate. The course of succession has to be observed with an extensive monitoring program to join in with management if required.

2 THE FIELD EXPERIMENT

2.1 *Site*

Within a large area destroyed by fire (1991 and 1993; > 1000 ha) at Na Burguesa mountain near Calvià/Majorca (Spain), the Bendinat site was established in Nov. 1997 (300 m a.s. l., south-east exposition, ca. 900 m²). The remains of the burnt forest were removed by the forestry services. The site is fenced against rabbits and goats (see also http://www.revitec.de/).

Average precipitation (Majorca Meteorological Services) is ca. 300 mm, however, the years of the period reported here (1997-2001) have been much drier with precipitation about half as normal or even less. Recently, in 2002 and 2003, the mean was reached, but data from this period are not yet considered in this report.

2.2 *Experimental set-up*

In all set-ups, used coffee-bags from jute were used. They were filled with 30 litres of a mixture from autochthonous red loam and organic materials. Fertility islands (plots) were composed of four or seven bags placed in non-shaded areas between coppicing shrub vegetation. Additionally, plots of one bag were placed in the shade of shrubs. Most of plots were surrounded and partly covered by small stones (white limestone) picked from the surrounding in order to enhance humidity capture. The islands were planted in the centre with one *Q. ilex* sapling. Additional arrangements included bioactivation of nursery substrate with forest soil, shading, and planting in prepared plant holes or into the bare soil. Little gardens ("huertas") with a couple of saplings are planted for hardening. Details are listed in 2.3 and in Table 1.

With the experimental set-up, the following questions are addressed:

- Influence of substrate on the development of vegetation: red loam (RL), mixtures of RL and compost (RL-CO), and paper compost (RL-PC), both in 3:1 volume equivalents.
- Effect of substrate amendments on the development of saplings: addition of almond shells (AS), AfriKelp® and paper pellets.
- Effect of bioactivation on the survival of *Q. ilex*.
- Effect of artificial mycorrhization of *Q. ilex* on survival and growth.
- Functionality of bags in terms of protection of substrate, effect on microclimate, micro-catchment and degradability.
- Effectiveness of fertility plots for succession and biodiversity.

Table 1: Variants tested in the experiments at the Bendinat site, including the corresponding survival rate for the first year, respectively, of *Q. ilex*.

	Constituents			Additives												
substrate	read loam	compost	paper compost	almond shells	Afrikelp	paper pellets	year of setup	no. of bags/plot	no. of saplings (n)	no. of sets (m)	bioactivated	mycorrhized	commercial nursery	own nursery	**survival rate**	variant (fig. 5)
	% volume proportion														**%**	
RL-CO	75	25	-	-	-	-	1997	7	43	23	-	-	X	-	**0**	Nursery 2
RL-CO	75	25	-	-	-	-	1998	7	7	7	-	-	X	-	**0**	Nursery 2
RL-CO	75	25	-	-	-	-	2000	7	18	18	-	-	-	X	**17**	Nursery 1
RL-CO	75	25	-	-	-	-	2001	7	18	3	X	X	-	X	**78**	Bag 1
RL-PC	75	-	25	-	-	-	1997	7	26	15	-	-	X	-	**8**	Nursery 2
RL-PC	75	-	25	-	-	-	1998	7	8	8	-	-	X	-	**0**	Nursery 2
RL-CO/PC	65	10	10	15	-	-	2000	4	2	2	X	-	-	X	**100**	Bag 2
RL-CO/PC	65	10	10	-	15	-	2000	4	5	5	-	-	-	X	**40**	Nursery 1
RL-CO/PC	60	10	10	10	10	-	2000	4	2	2	X	-	-	X	**50**	Bag 2
RL-CO/PC	60	10	10	10	10	-	2001	4	5	5	X	X	-	X	**100**	Bag 1
RL-CO/PC	70	15	15	-	-	-	2000	1	9	9	-	-	-	X	**33**	Nursery 1
RL-CO/PC	65	10	10	15	-	-	2000	1	6	6	X	-	-	X	**100**	Bag 2
RL-CO/PC	65	10	10	-	-	15	2000	1	9	9	X	-	-	X	**100**	Bag 2
RL-CO/PC	60	10	10	10	-	10	2000	1	6	6	X	-	-	X	**75**	Bag 2
RL-CO/PC	65	10	10	15	-	-	2001	1	9	9	X	X	-	X	**100**	Bag 1
Soil (RL)	100	-	-	-	-	-	2000	0	76	10	X	-	-	X	**46**	Soil
Soil (RL)	100	-	-	-	-	-	2001	0	52	4	X	-	-	X	**31**	Soil

The number of saplings may be higher than the number of sets, where 2 or more saplings were planted in one island (particularly the larger ones composed of seven bags).

2.3 *Material and methods*

Microclimate was measured with automatic data-loggers from Oct. 13-18 in 1999 (TESTO, Lenzkirch, Germany).

Substrate materials:

- Red loam (RL): from commercial excavations (Majorca);
- Compost: organic compost CO and paper-compost PC were shipped from UMWELTSCHUTZ NORD Ganderkesee (Germany) strictly for experimental purposes in Nov. 1997;
- Almond shells originate from an almond mill in Consell/Majorca;
- AfriKelp® was provided by TAURUS Ltd., Lüderitz (Namibia); it is made of dried giant brown algae from the Southern Atlantic.

Biotic resources:

- Plants: *Q. ilex* saplings and indigenous plants (nurse plants) were nursed commercially by a forestry nursery at Manut/Majorca and a nursery in Barcelona/Spain (both *nursery 2* in Table 1) and in the experimental nursery from our partner ECCOLOG, Calvià (*nursery 1* in Table 1). For nursing and direct seeding, acorns were collected from Majorca and Cordoba sites.
- Bioactivation: unspecific mycorrhization and introduction of other soil biota was achieved by adding small amounts from forest soil to the nursery substrate.
- Mycorrhization: Inocula of *Pisolithus*, *Paxillus* and Majorcan *Amanita* from our own cultures (UFT, Bremen) were applied in fall in the nursery of ECCOLOG for specific mycorrhization of *Q. ilex* saplings, which were raised from acorns the preceding winter/spring.

Standard soil analyses were performed in Nov. 1997, in Nov. 1998 and in May 2001: total carbon (Lichterfeld), total N (Kjeldahl), available phosphate (extraction with lactate), total Ca (ICP), soluble Mg (ICP in $CaCl_2$ eluate), soluble K (ICP in Ca-lactate), pH (H_2O).

The experiments have not been set up all at once, but have been refined according to experience. Plots with failing success were replanted. All activities were documented in detail. Plant vitality and survival were measured in at least one visit per year and allow a semi-quantitative evaluation. Data from visits in autumn of each year (1998-2002) are evaluated. Degree of mycorrhization was checked by harvesting some plants. Colonisation by epigeic invertebrate fauna was estimated on a general level. Soil samples for the assessment of mesofauna have been processed, but not yet evaluated.

3 RESULTS

3.1 *Microclimate*

The bags dampen the daily temperature amplitude considerably, although not so effectively as densely foliated shrubs (Fig. 1). Effects on dew condensation may be expected from such temperature differences.

The bags increase the habitat heterogeneity, thus providing shelter, e.g., as could be observed for arthropods such as woodlice or termites, the former important in decomposition and the latter as ecosystem engineers.

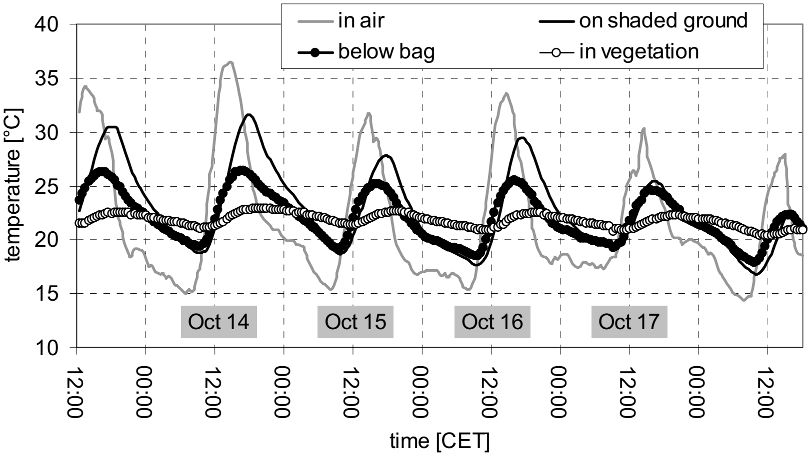

Figure 1. Temperature in air, on surface of bare soil, in grassy vegetation and below a bag, 13.-18.10.1999 (30 min. intervals).

3.2 *Substrate development*

Some pedological characteristics of the red loam, the composts and the mixtures are shown in Tab. 2, including data from other *Q. ilex* forests (Streller 2001, Canadell & Vilà 1992). As seen from the C-content, the red loam does not originate from deep excavations.

Table 2: Standard soil parameters for substrates; for comparison, data from the literature are included (*ca. values are recalculated estimates*).

	RL	CO	PC	RL-CO	RL-PC	F Maj	F Cat
C total [%]	2,2	28,2	14,0	ca. 7,5	ca. 5	3,9	2,7
N total [%]	0,1	2,1	0,5	0,6	0,2	0,2	0,2
C/N	15,7	13,2	26,4	ca. 17	ca. 30	19,0	13,3
P sol (lac) [mg/100g]	0,0	111,7	32,7	7,4	2,8	0,0	0,3
K soluble [mg/100g]	62,4	656,6	220,8	257,3	110,4	77,5	26,4
Mg soluble [mg/100g]	20,5	60,0	17,8	38,5	23,3	20,9	43,8
Ca total [%]	18,6	2,6	1,5	13,2	13,2	17,1	0,8

RL= red loam from excavation	RL-CO, RL-PC= mixtures (3:1 by volume; Nov 1997)
CO= organic compost (Nov 1997)	F Maj= forest soil from Majorca (Streller 2001)
PC= paper compost (Mov 1997)	F Cat= forest soil from Catalonia (Canadell & Vilà 1992)

The values for organic compost are in the ranges, which are known for communal compost; however, those of the paper compost are in all categories relatively low. C/N ratios provide good conditions for microbial activity in the organic compost mixture (RL-CO), but not in the case of the paper compost, where N immobilisation is expected when mixed with red loam (RL-PC). The P-input provided with the composts is bound in the mixtures to a large extent by the red loam, but still the available amounts are considerably higher compared to the natural substrates. Salt loads of

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the composts are very high, even when diluted in the mixtures. The low Ca-content of the compost is raised strongly in the mixtures. pH ranges around 7,5 for red loam and the mixtures. Compared to the findings in forest soil, most values are elevated, considerably for P and K, but also for C/N in the paper compost mixture (RL-PC). Although decreasing within three and a half years, C, N and P of the organic compost mixture (RL-CO) are still substantially higher than the red loam alone; this is less pronounced in the paper compost mixture (RL-PC). With the exception of P, all measured parameters seem to converge towards the red loam conditions, which are expected to be attained in the paper compost mixture much earlier than in the organic compost mixture.

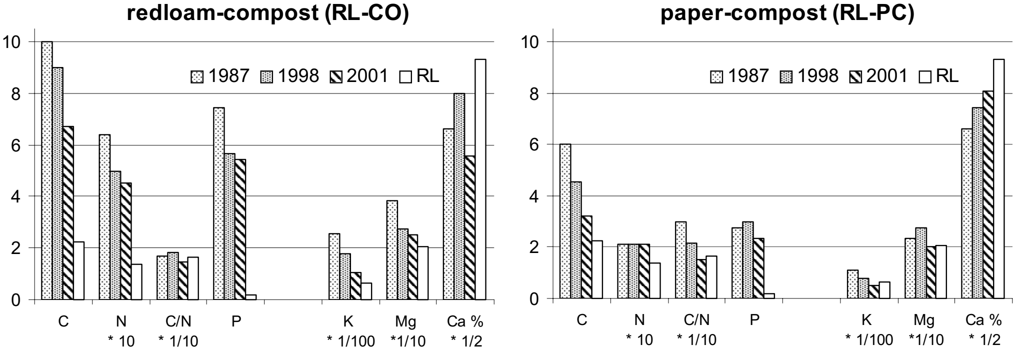

Figure 2. Development of soil parameters the two compost mixtures compared to red loam. Units of y-axis are for all categories of the x-axis (for exact definitions and dimensions of categories please refer to Table 1).

3.3 *Development of plant cover*

The development of plant cover reflects the influence of the compost and the differences in its quality, which became obvious in the pedological analyses (3.2). Organic compost (RL-CO) sustainably improves percentage of plant cover (Fig. 3), although the effect of the amendment is decreasing in the soil analyses (Fig. 2). Initially, protection against erosion was provided exclusively by the bags, a feature which is increasingly lost due to their decomposition. As a consequence of the improved development of cover, the plants take over a considerable proportion of the protection against erosion. The species contributing are most the grass *Piptatherum miliaceum* and the semi-shrub *Inula viscosa*.

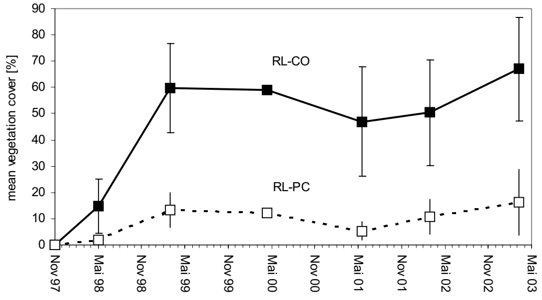

Figure 3: Development of vegetation cover on RL-CO plots (red loam organic compost mixture; n=.23) and on RL-PC-plots (red loam – paper compost mixture; n=15); error bars are standard deviations (May 2000: total estimate).

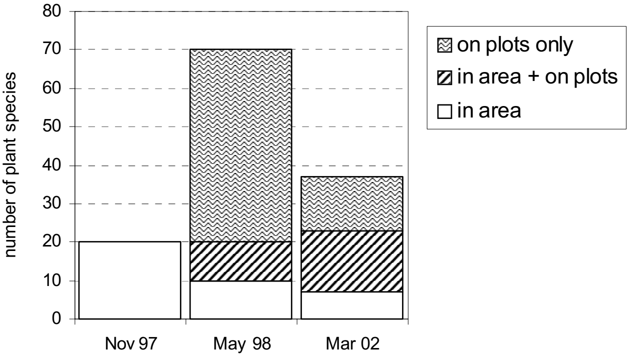

Figure 4: Plant diversity in the experimental area before starting with ReviTec® fertility islands (=plots), 5 months after installation and 4½ years later.

3.4 *Survival of Quercus ilex*

The survival rates of *Q.ilex* shown in Fig. 5 are derived from the data listed in Tab. 1 for the respective aggregated variants bag, nursery and soil; the indices 1 and 2 are explained in the legend to Fig. 5. The results point up the importance of bioactivation, which seems to be more relevant than specific mycorrhization, and the positive influence of the bags. This may be due to microclimate and erosion controlling effects particularly in the first phase of the establishment of the tree. A positive effect of mycorrhization may be observed, when the “soil” variant is compared to the un-mycorrhized “nursery” variants. The good performance of the saplings from ECCOLOG’s nursery may be due to the autochthonous origin of the acorns.

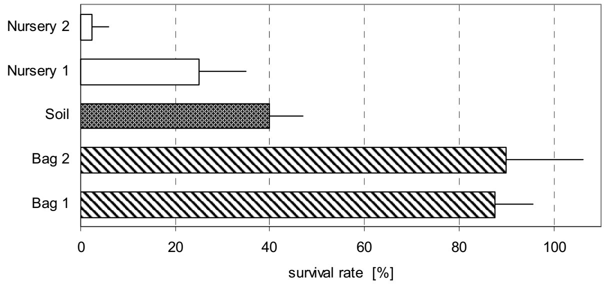

Figure 5: Rates of survival of first drought period of inoculated or non-inoculated *Quercus ilex* in bags with or without bioactivated substrate or in soil without bags (details in Table 1). Error bars indicate standard deviations. *Bag*: substrate bioactivated, 1=saplings mycorrhized (m=17), 2=saplings not mycorrhized (m=25); *Soil*: saplings planted directly in soil without bags, substrate not bioactivated (m=14); *Nursery*: saplings without mycorrhization, planted in bags without bioactivated substrate, 1= nursery ECCOLOG (m=32), 2= commercial nursery (m=53).

From Table 1 it can be seen that AfriKelp® alone seems not to improve the survival of the saplings, but performs excellent in combination with mycorrhiza. Also almond shells seem to have a positive effect on the survival of *Q. ilex*.

Specific experiments to test the effect of ecto-mycorrhizae have been set up in March 2002. Similarly, the preliminary results do not show positive effects of mycorrhization on survival, but on growth; however, it has to be borne in mind that drought stress was benignant in this recent period of investigation. In additional experiments, local shrubs and saplings of *Pinus halepensis* of two different ages from the forest nursery of Manut/Majorca where used. Most of the shrubs did not survive the first drought period and the survival rates of *Pinus* are around 50% on RL-CO and around 25% on RL-PC, confirming the minor quality of paper compost amendments for plant growth.

4 DISCUSSION

The experimental site at Bendinat offered a unique opportunity to test various hypotheses concerning the restoration of a degraded prone Mediterranean sites. With ReviTec®, the restoration process is deliberately influenced concerning abiotic factors as well as the biota and the ecological processes, it is embedded in an ecosystem perspective.

Compost amendments may have a positive effect, as could be shown with the improved development of vegetation cover by applying organic compost once at the start of succession. There is quite a potential in using high quality compost as improvement of soil conditions (Hartmann 2003). Of major importance for biactivating organic amendments may be a biological on-site ripening to allow for autochthonous colonisation by different kinds of biota and establishment of interactions.

Strictest control of ecotoxicological and epidemiological (human health, alien species) risks have to be ascertained. Because of considerable cost involved, this may be regarded as a draw back of any re-introduction of recycling products at a larger scale into nature. However, it should be stressed, that processing of safe composts should be economically feasible for modern high-tec composting plants and that it should be encouraged politically.

Soil amendments offer a wide field for experiments, from pedology to soil ecology (Roldán 1996). The main focus is the improvement of water holding capacity, in combination with water harvesting techniques. Also, as could be shown by the well-differentiated effects of the two composts, nutrient availability can be managed.

Substrate amendments do influence the survival rate of *Q.ilex*. The experiments indicate positive effects of almond shells and AfriKelp® in combination with mycorrhization. Almond shells and AfriKelp® considerably loosen the loamy soil and may thus enhance colonisation by soil fauna, as could be observed in the preference of these plots to termites and decomposer arthropods.

The positive effect on the survival of *Q.ilex* by bioactivating the substrate was clearly demonstrated. It may make artificial inoculation with ecto-mycorrhizae dispensable, but for many environmental conditions inoculation may be useful (Salamanca et al. 1992, Nardini et al. 2000). Recently, experiments have been conducted to inoculate with site specific fungi, specific for the early successional stage encountered in anti-degradation efforts. Roots were harvested, on which unspecified mycorrhization with ecto-mycorrhizae was well developed. For the artificial mycorrhization, basic research on the functioning of mycorrhiza in these systems is brought to application (e.g., Bücking and Heyser 2001, Bücking et al. 2003).

The bags are very suitable to carry material even to areas inaccessible by machinery. They may be placed according to small-scale topographic features. The jute fabric keeps its anti-erosion properties even in the beginning of the decay process of a couple of years; it promotes establishment of pioneer communities such as blue green algae and fungi, which is in line with the microclimatic effects observed. The fabric may have a water harvesting effect (rain, dew, fog) on this site not far away from the sea. This effect may be enhanced by the stones added to the fertility islands as a surrounding or partial cover.

The islands are catchments for particles and organisms, but also function as scatter plots. They increase phyto-diversity and seem to be attractive for insects and small mammals due to an enhanced offer of safe microhabitat structures (Urbanska 1997). As was shown, e.g., by Mando et al. (1999), termites may play a role as ecosystem engineers in improving water infiltration, reducing compaction and also influence nutrient cycling (Konaté and Linsenmair 2003). For predatory soil mites (Gamasina), ReviTec® - islands on an experiment in Bremen increased diversity of the site from 12 to 21 spp. (Bierschenk and Bierschenk in Koehler and Filser 2002). In the same investigation, higher moss species number and moss cover was found on the ReviTec® - islands compared to the surrounding (Böckmann and Winter in Koehler and Filser 2002). Also, the increase of edges may trigger the development of high biodiversity, similar to the situation in semi-open grasslands (David et al. 1999).

Effects of the plots on the larger scale of the site or even the landscape cannot be observed yet after six years. An experimental fenced control plot without the fertility islands is not available to come to conclusions in this respect.

5 CONCLUSION

ReviTec®, as it is embedded in an ecosystem approach and makes use of many aspects of succession and improvement of plant performance (particularly mycorrhization), can be adapted as soft eco-technology to specific needs of a degraded or degradation prone area. In this respect it relates to approaches such as, e.g., the West African Zai-technology (Fatondji et al. 2001). Succession could be accelerated on the experimental plots (improvement of development of vegetation cover) and *Q. ilex* survival was improved with organic amendments to the soil and bioactivation of the nursery substrate. Amendments as well as initial biota have to be selected carefully.

Research needs thus relate to the soil amendments, to the establishment of the “right” (adapted to the successional state, site specific) initial biotic community, to nursing plants that can cope with the harsh conditions of degradation prone or even degraded sites, and to the adaptation of ground survey techniques (e.g., ground radar) in order to select places with conditions suitable for planting. For detailed monitoring, near-earth remote sensing bears great potential. The long-term development on landscape scale have to be modelled with spatio-temporal explicit approaches.

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