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Advantages and possibilities of recultivating fallow land in accordance with natural succession

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SUMMARY - Reclamation of abandoned land often fails, because the special characteristics of the ecosystems are neglected. In some cases, recultivation by planting young trees is contradictory to natural development, which starts with pioneers invading the stand, followed by secondary settlers. As to respective investigations, the course of succession does not result in a sequence of concrete plant communities, but in sets of species which change slowly, both qualitatively and quantitatively. In order to mimic and to accelerate natural development, phytosociologically adequate seed mixtures were sown into virgin mine spoil, thus initiating a plant cover, improving the microclimate and soil development, and preventing erosion. Results are presented with respect to plant cover degree, vegetation structure and biomass production.

Key words: recultivation, raw soil, mine spoil, course of succession, pioneer vegetation, plant cover, stratification, biomass.

RESUME - "Avantages et possibillités de recultiver les jachères en accord avec la succession naturelle". La restauration des terres abandonnées échoue fréquemment car les caractéristiques spécifiques des écosystèmes ne sont pas envisagées. Parfois, la reprise agricole en plantant de jeunes arbres est contradictoire au développement naturel du lieu, qui s'amorce avec un envahissement dû aux plantes pionnières, suivi de la colonisation de plantes secondaires. La recherche sur ce phénomène nous indique que l'ordre de succession ne montre pas une séquence de communautés concrètes de plantes, mais des ensembles d'espèces qui évoluent lentement, aussi bien du point de vue qualitatif que quantitatif. Lors d'un essai d'imitation et d'accélération du développement naturel, des mélanges de semences adéquates du point de vue phytosociologique, furent semées dans un sol minier vierge, et une couverture végétale s'amorça, entraînant une amélioration du microclimat et du développement du sol, et réduisant l'érosion. Les résultats présentés se rapportent au degré de couverture végétale, à la structure de la végétation et à la production de biomasse.

Mots-clés: Restauration du sol, sol nu, terrain minier, ordre de succession, végétation pionnière, couverture végétale, stratification, biomasse.

Introduction

Every biologist, at least every botanist, knows that there is no habitat which is uncolonized by organisms, and almost no site condition which prevents plants from being settled. It is only their adaptation to the place to be colonized which is required. Phytosociologists are aware of communities which are characteristic for a certain site, but the system is based on past records, and there is evidence (Khun *et al.*, 1987) that at least some species compositions begin to alter according to environmental changes. This modification occurs particularly in the field layer. Up to now, most Europeans consider vegetation as a sure and stable unit, which of course, is not true. There is always some development, partly cyclical, partly directional, which can only be observed by monitoring. For biological conservation, succession, as an inherent feature of vegetation, must also be considered.

Present conditions for succession

In every case of abandoned land the process of natural succession will start, unless man interferes by recultivating according to his own ideas, usually creating plantations at high technical and financial expense. The speed of natural development depends on the state of the present vegetation:

(i) whether there is an existing plant cover or only bare soil with but a seedbank, or whether colonization is left exclusively to resources in the surrounding areas;

(ii) soil conditions; and

(iii) several factors which may be summarized as environmental circumstances.

However, today's problem concerns those plants establishing the following successional stages. Their diaspores are no longer sufficiently available, because industry and agriculture have expanded, not only claiming the whole area, but also extinguishing by chemical means those species which seem to reduce profit. In particular, ruderal biotopes which are the habitat of a number of pioneer plants have disappeared, and the same is true for those communities and species on the edge of natural forests, which probably act as the secondary settlers within succession. As proved by Jochimsen (1987), the deficiency of qualified propagules plays an important role in the colonization of abandoned land, and if there is also no seedbank, as in spoil heaps created by coal mining or other activities, and in those decontaminated soils which become biologically inactive by thermical cleaning, vegetation development takes a long time. In industrial countries, both events cause serious problems. In the past, and even today, foresters have tried to recultivate these substrata by planting trees and perhaps sowing some legumes and/or grasses. But reforestation of mine spoil will not succeed in establishing a natural ecosystem: a temperate forest is characterized not only by its tree layer but also by an understorey of herbs. The latter is always missing or will not persist, if recultivation starts with trees (Jochimsen, 1987; Pöser and Jochimsen, 1989). Therefore, it seems reasonable to initiate vegetation development by mimicking natural succession, using nature's own forces to restore the site. At the beginning of succession, pioneers characterized by their low demands with respect to site conditions, especially water and nutrient supply, invade the stand. These species must, therefore, be sown first.

Initial stage of succession

Most vegetation scientists consider the inital stage of succession as a random gathering of plants without any competition. However, that view is not quite correct. Our trials, which started in 1980, indicate that the processes of facilitation and inhibition are already working during the early stages of vegetation development. Altering the treatment of the substratum, even slightly, causes a change in the predominant species, even though the vegetation is not yet closed (see Fig. 4 Jochimsen 1987). Hence it follows that undeveloped soils also have their own particular species composition which fits best and, in the course of succession, meets the requirements of the following settlers. Of course, these processes cannot be detected by conventional phytosociological records which only represent the present cover. For this reason, with regard to pioneer communities, we use a different method evaluating the proportion of each species in relation to the existing vegetation (= 100%), and disregarding the total coverage (Jochimsen, 1986, 1987). Plants arrive and disappear as a result of selection. This process takes a long time to reach the optimum species composition. Therefore, it is not only necessary to mimic, but to accelerate, vegetation development contemporaneously, and in this respect it is the species composition we choose to sow which provides the success. For mine spoil the waste produced by coal mining and tipped in the landscape we were able to reduce the time usually needed to establish the initial community, which already includes some settlers belonging to the next stage, from approximately 10 years to 2 years (Fig. 1 to 3). Besides that it seems possible to influence further development by the same procedure.

Course of succession

Investigations of plant communities of different successional age which had developed naturally on older mine spoil heaps revealed some interesting features concerning one of the oldest debates in successional theory. According to Clements (1916), the stages of succession are definite: more or less isolated communities unfold and fade like a wave marked by an increasing and decreasing species number. However, no actual boundary was found. Analysing the behaviour of species belonging to ecologically defined groups (Ellenberg, 1979), we detected not only a migration of species, but also a change in their frequency, shown by their growing and decreasing values of constancy (Jochimsen, 1987 and unpublished). As Fig. 4 demonstrates, plants belonging to the species characteristic of later communities are immigrating into the stand but at low frequencies previous to their proper stage. The transition is smooth and continuous, and what is considered to be a community may, in fact, only represent the snapshot of a characteristic intersection between time axis and species composition in the course of the vegetation development. These findings may account for both Clement's (1916), Gleason's (1926) and diverging ideas, and reconcile those who either maintain that succession does not proceed in discernible stages or argue that there are close and definite associations between species during succession.

Therefore, in order to induce and accelerate succession, it seems reasonable and promising to sow secondary settlers, too, provided we know the correct species and the corresponding time. But it is not necessary to wait until a certain stage is reached. In most countries relevant phytosociological data will be available, from which suitable species sets can be identified, and the stage of

Fig. 1. Virgin mine spoil to be cultivated

Fig. 2. Mixtures of ruderal species *(Dauco-Melilotion)* sown into virgin mine spoil and treated with sand and fertilizer. First season after sowing (SD)

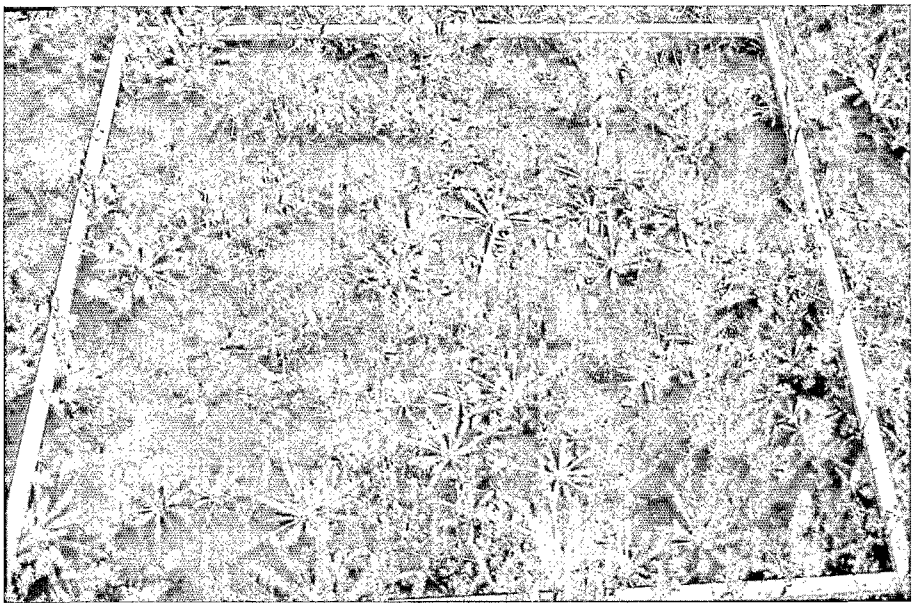

Fig. 3. Identical seed mixture as in Fig. 1 but virgin mine spoil covered with a layer of loamy sand (5 cm) and fertilized (ED)

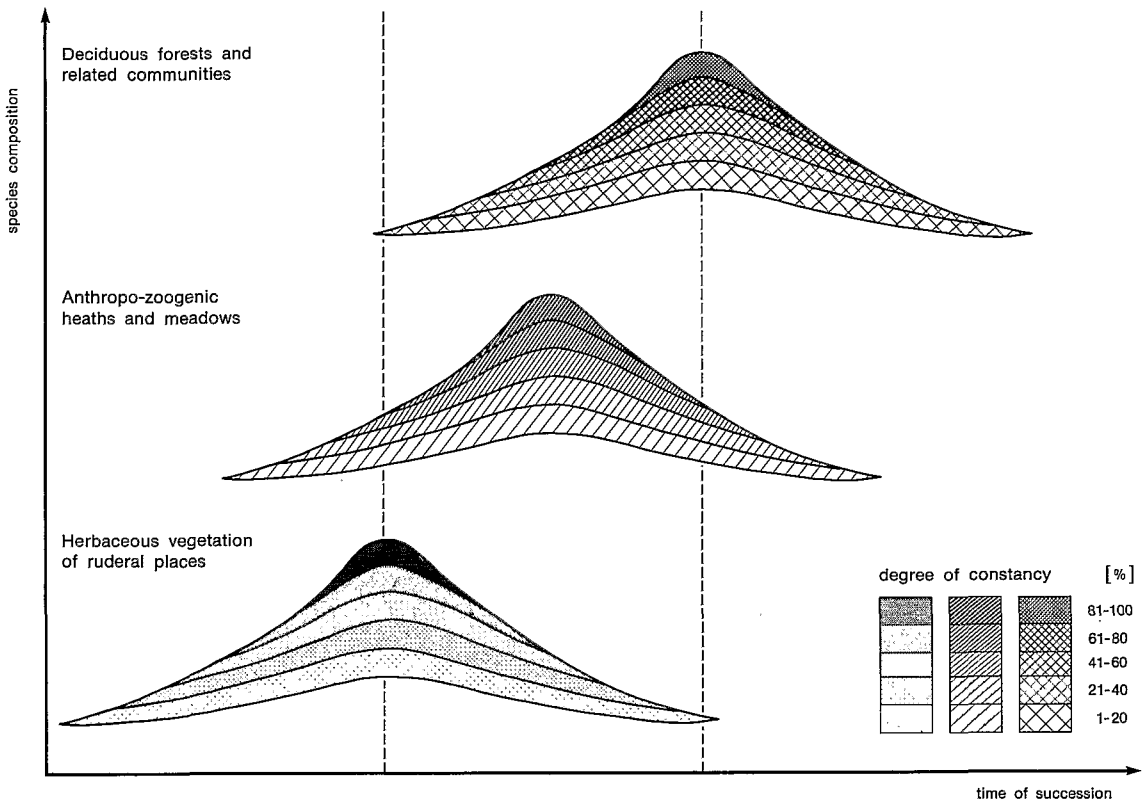

Fig. 4. Vegetation development on mine spoil course of succession

development may be determined by analysing the constancy of ecologically defined species groups in the present vegetation. This assumption of species migration may also affect our concept of conservation.

Advantages of recultivating according to natural succession

1. In the case of primary succession, e.g. on mine spoil or on decontaminated and biologically inactive substrata, but perhaps also in devasted Sahelian areas, which would pass through secondary succession, starting vegetation development by unassuming pioneers means a number of improvements considering nature conservation.

Growing biomass, above and below ground, prevents erosion and deflation respectively. While the leaves of plants act as a shelter against the destructive forces of rain and wind, the growing root system (Fig. 5) binds soil particles. (Trees planted in mine spoil generally develop horizontal roots which are less effective against the force of gravity).

"In phytosociology the degree of plant cover is commonly used as a measure for site conditions (Fig. 6). Sowing was done in autumn 1986, and it is obvious that fertilization accelerated the development to a nearly closed herb layer within short time. Already during the first growing season those plots treated with sand and fertilizer reached an average plant cover of 80%. In 1988, there was a small increase; in 1989, however, plant cover decreased slightly, probably because of the lacking precipitation and a strong subversive activity of mice. The influence of exposure consisted in supporting the plant growth microclimatically, that means, on the south facing slope by more beneficial temperatures in early spring, and on the northern side by keeping vegetation from dessication" (cited after Jochimsen, in press).

Above ground protection, however, not only depends on plant cover degree: the structure of the developing vegetation is also important. This becomes evident by comparing the Figures 7a and b, representing the vegetation developed on mine spoil during the first growing season after sowing. (Areas which had no artificial seed remained bare; see Fig. 1). Both test areas received an identical species composition of 49 ruderal plants produced in conformity with the phytosociological alliance *Dauco-Melilotion*, of which the annuals were extinct after one year. The areas only differed in the admixtures to the substratum. Fertilization (D) combined with the application of sand (S) (which improves water capacity the mine spoil and in one operation nutrient supply) proved effective for vegetation development (Fig. 7a) and produced a total cover of the soil surface, while using loamy sand for top soil (ED) and fertilizer was not as successful (Fig. 7b), because many bare patches remained. Figures 7c and 7d represent the situation 1 year later, and Figures 7e and 7f show the vegetation developed during the third growing season, demonstrating the quick change

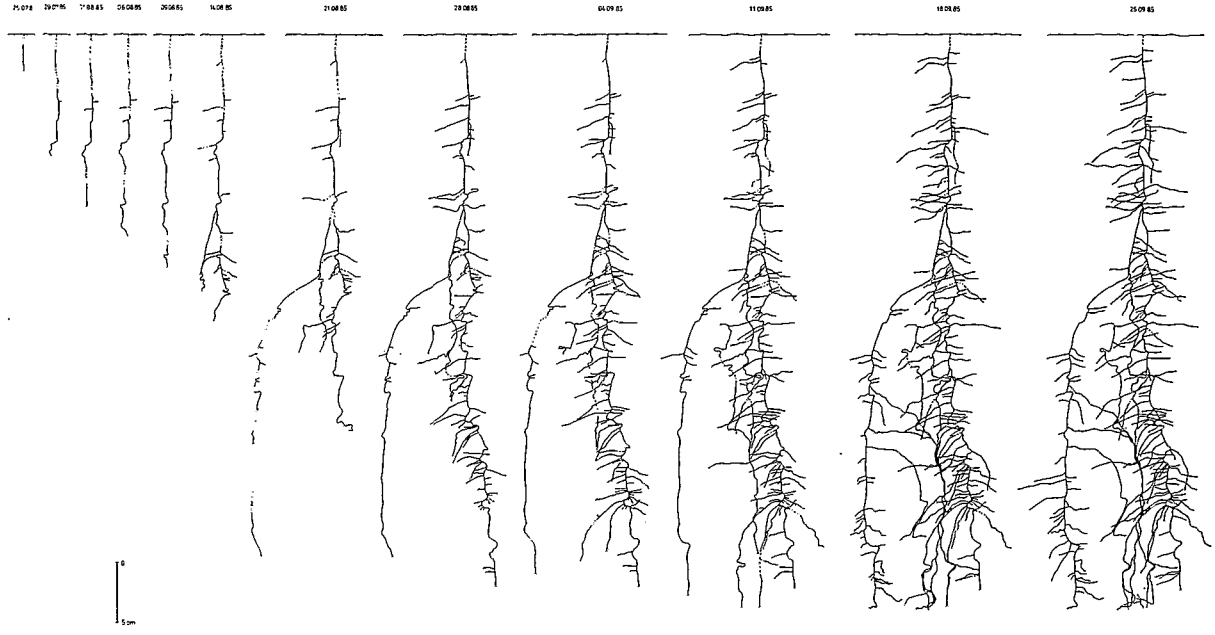

Fig. 5. Root development of the annual *Chenopodium album* within 2 months (mine spoil, SD). (From Bruns & Jochimsen, 1989)

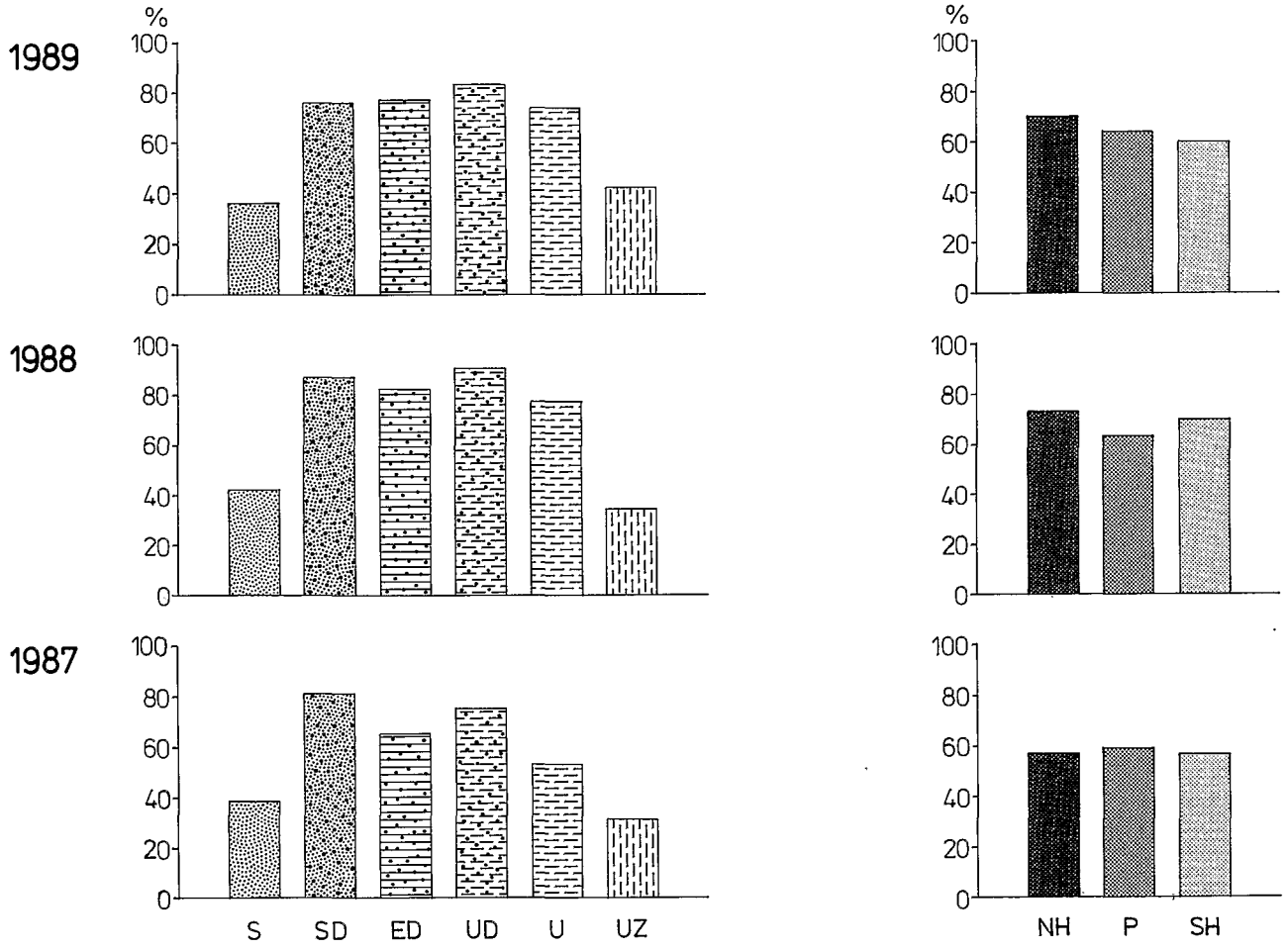

Fig. 6. Development of plant cover on mine spoil dependent on substrate variation and exposition in 1987-1989 (average percentage). (From Jochimsen, in press)

Fig. 7a

Fig. 7b

Fig. 7. Vegetation structure on mine spoil developed in the course of 3 growing seasons dependent on the kind of treatment (1987: SD = a; ED = b; 1988: SD = c; ED = d and 1989: SD = e; ED = f). (Partly from Janzen & Jochimsen, 1989).

A	*Artemisia*	Hp	*Hypericum perforatum*	Pl	*Plantago lanceolata*
Aa	*Artemisia absinthium*	I	*Isatis tinctoria*	R	*Reseda lutea*
Ae	*Arrhenatherum elatius*	L	*Linaria vulgaris*	Rc	*Rumex crispus*
Am	*Achillea millefolium*	M	*Melilotus alba or M. officinalis (seedlings are not distinguishable)*	Ro	*Reseda luteola*
B	*Bromus erectus*			S	*Sisymbrium officinale*
C	*Chenopodium album*	Ma	*Melilotus alba*	Si	*Silene vulgaris*
D	*Daucus carota*	Mo	*Melilotus officinalis*	T	*Tanacetum vulgare*
E	*Echium vulgare*	O	*Oenothera biennis*	V	*Verbascum densiflorum*
E/A	*Echium vulgare or Anchusa officinalis (seedlings are not distinguishable)*	Pc	*Poa compressa*		

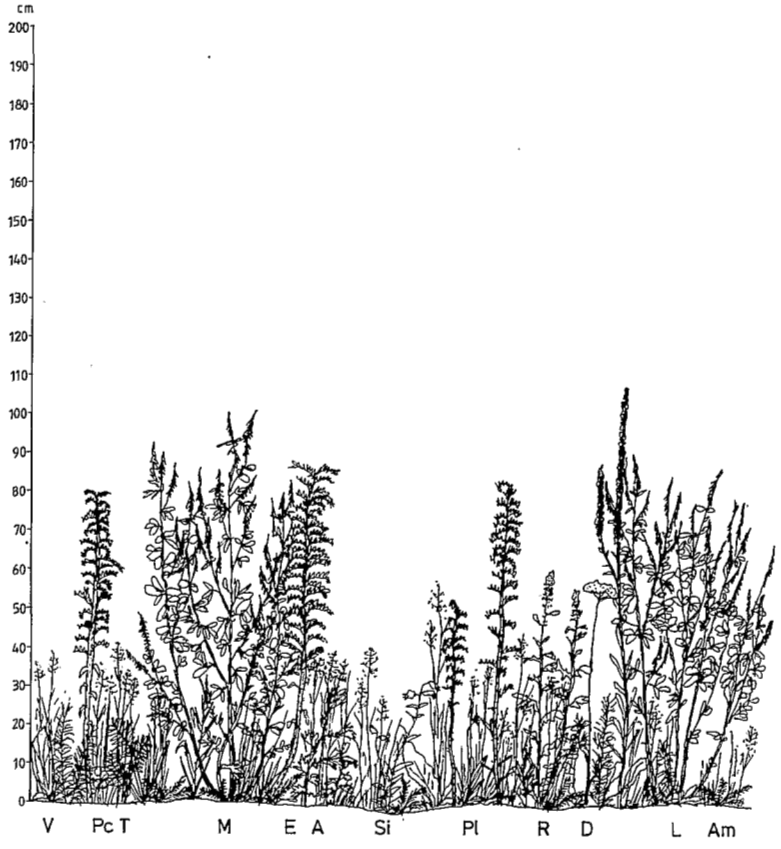
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Fig. 7c

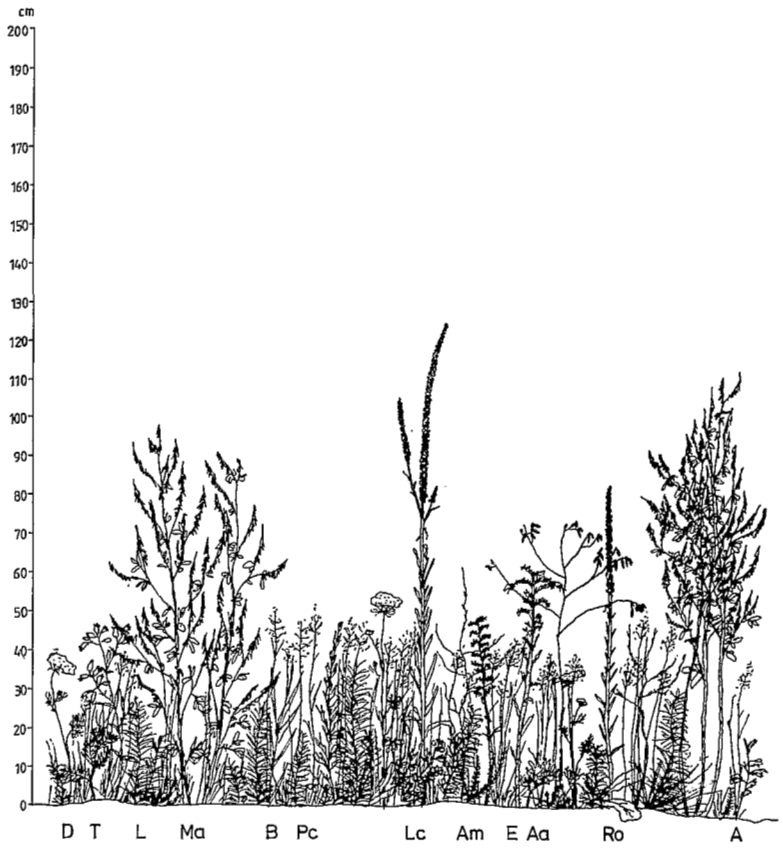
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Fig. 7d


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Fig. 7e


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Fig. 7f

in plant cover and stratification as well as in species composition.

In comparison to plant cover percentages the mean values for biomass production (Fig. 8) (standing crop was harvested) show much more variation particularly in reference to the vegetation period. Already in 1987, the vegetation on fertilized plots produced remarkable results. (Natural grasslands of the temperate region are estimated to have a biomass production of 500 g/m²/a). In 1988 this amount was multiplied more than three times not only because of the favourable weather conditions and proceeding vegetation developmment but also due to the life cycle of some biennial plants. Even the unusual drought (1989) was not able to reduce productivity to amounts less than in the beginning of the experiment. Of course, the vegetation suffered from water stress several times, but it recovered repeatedly, thus demonstrating the accommodation of the established plant community to the harsh site conditions.

From an ecological point of view, that means, in order to estimate the suitability of the created vegetation for restoration purposes, it was also important to know in which way and to which extent the various sown species contributed to the composition of the developing plant community. The diagrams (Fig. 9a to f) demonstrate the role of single species with respect to biomass, which is controlled by site conditions. The columns figure the absolute yield of the 5 most productive species, and the grey area indicates to what proportion they participate in the biomass production of the whole plot. There is no doubt that those stands in which only one or two species dominate, and that is especially true for the top soil plot (ED), may be less effective with respect to vegetation development and ecological functions. That means, for restoration purposes, vegetation structure must be considered, too." (Cited after Jochimsen, in press) (For further detail see Jochimsen and Janzen, in press).

Furthermore, increasing biomass production, of which coverage only gives a rough idea, stimulates soil devel-

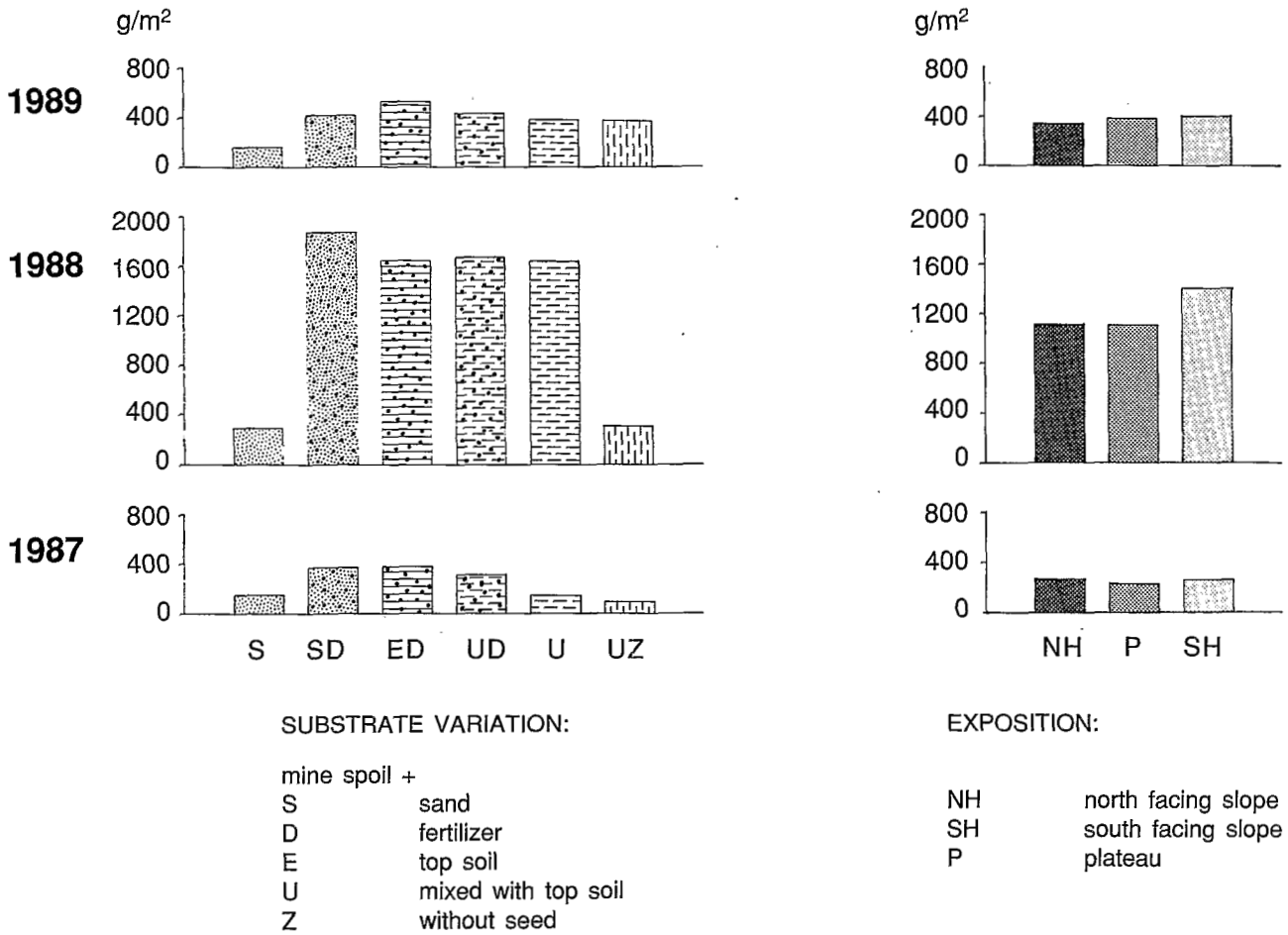

Fig. 8. Biomass production on mine spoil dependent on substrate variation and exposition in 1987-1989 (mean values). (From Jochimsen, in press).

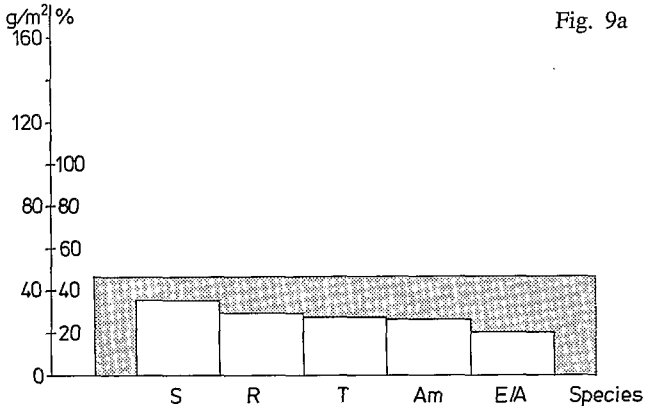

Fig. 9a

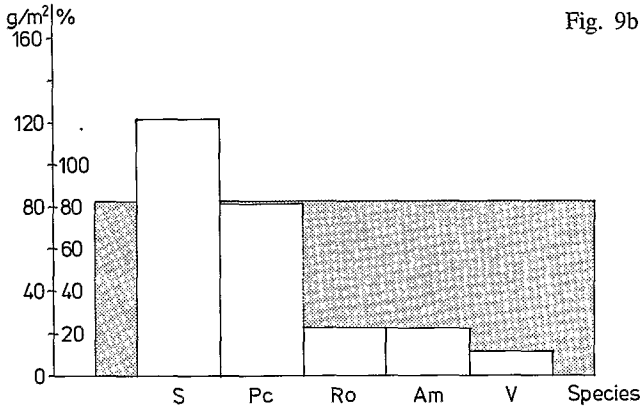

Fig. 9b

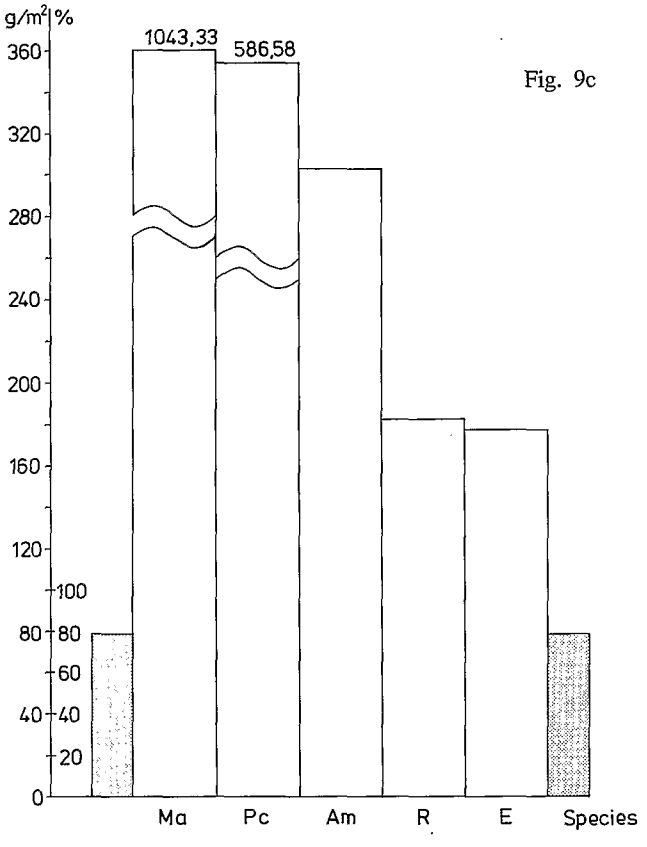

Fig. 9c

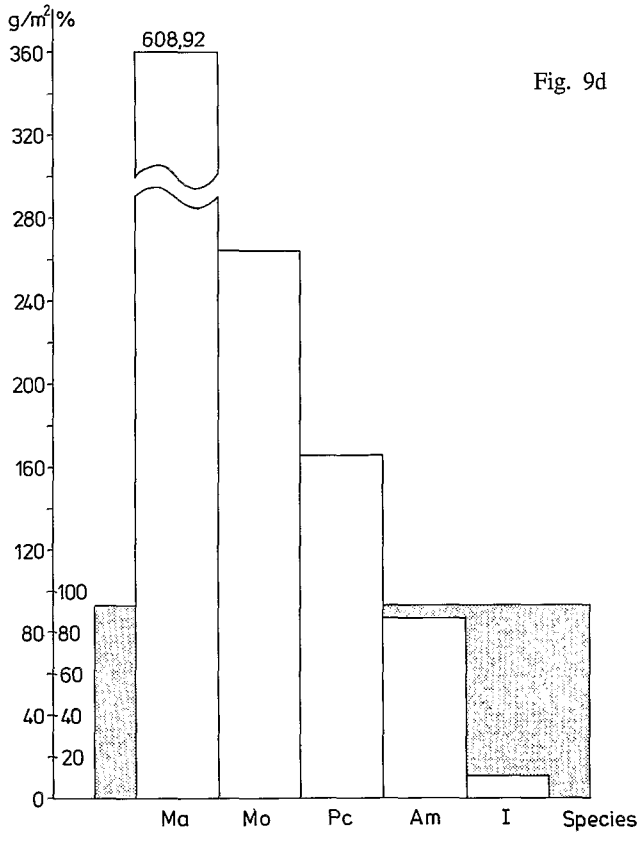

Fig. 9d

Fig. 9. The five most productive species and their contribution to the absolute yield of the whole plot dependent on growing season and kind of treatment (1987: SD = a; ED = b; 1988: SD = c; ED = d and 1989: SD = e; ED = f). (Partly from Jochimsen, in press)

A	*Artemisia*	Hp	*Hypericum perforatum*	Pl	*Plantago lanceolata*
Aa	*Artemisia absinthium*	I	*Isatis tinctoria*	R	*Reseda lutea*
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Am	*Achillea millefolium*	M	*Melilotus alba or M. officinalis (seedlings are not distinguishable)*	Ro	*Reseda luteola*
B	*Bromus erectus*			S	*Sisymbrium officinale*
C	*Chenopodium album*	Ma	*Melilotus alba*	Si	*Silene vulgaris*
D	*Daucus carota*	Mo	*Melilotus officinalis*	T	*Tanacetum vulgare*
E	*Echium vulgare*	O	*Oenothera biennis*	V	*Verbascum densiflorum*
E/A	*Echium vulgare or Anchusa officinalis (seedlings are not distinguishable)*	Pc	*Poa compressa*		

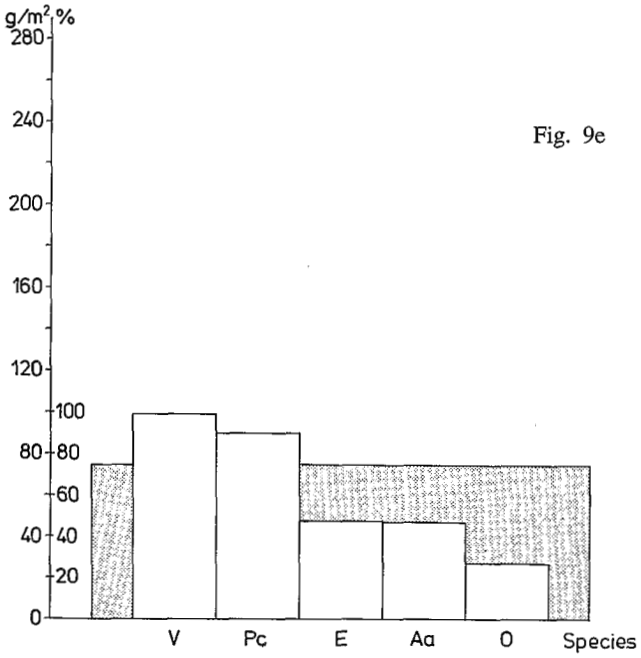

Fig. 9e

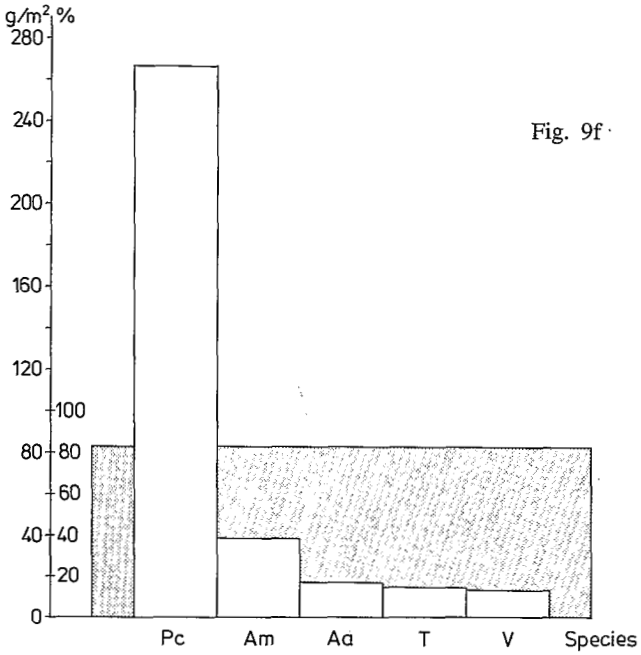

Fig. 9f

opment. Decomposing litter and the remains of small animals, particularly insects, which soon invade the stand, improve nutrient supply, thus improving production and supporting new colonizers. Humic acids arising from this process also play an important role in buffering the soil, so that the direct effect of acid rain is mitigated. This is a major point for abandoned land, which often lacks a closed plant cover, and in contrast to areas with at least a well developed herb layer, its soil will become acid easily.

Moreover, with increasing biomass production and plant density, microclimatic conditions improve enabling secondary settlers to invade the site. Our trials have shown that sowing species according to phytosociological principles results in creating an environment which is accepted by secondary settlers afterwards (Jochimsen, 1987).

As a result of all these improvements, succession progresses.

2. In secondary succession, however, the situation regarding nutrient conditions is not as severe as described above. However, there is a lack of propagules, because those plants naturally creating pioneer communities are removed in favour of agriculture, and industrial and urban settlements. Therefore, it seems appropriate to adopt the same method proposed for primary succession in order to create plant communities working like natural ecosystems. If it is necessary and desirable, succession may be accelerated by respective forms of management; otherwise, especially earlier phases serve as so-called compensation biotopes, providing a refuge to endangered species and communities. However, as European forests are heavily damaged, it will be reasonable to accelerate succession. In this context, abandoned farmland provides a suitable opportunity for the creation of new forests. There is another suggestion: why not reduce the export of energy to the atmosphere and diminish its temperature and CO_2 content by improving the earth's plant cover, on which they depend.

Conclusion

Because recultivation of raw soils requires massive investments, and, if done by foresters, mostly fails to establish a natural ecosystem with the advantages of both a steady state and easy maintenance, our procedure for reclamation follows the concept of natural vegetation development, starting with unassuming pioneers and, dependent on site conditions, finishing with woody species. In order to use nature's own forces, a species set was sought for colonizing virgin mine spoil (primary succession), considered to be hostile to plants. Investigations of older mine spoil heaps with a naturally developed vegetation revealed that the course of succession differs from commonly-held views. While the invasion and retreat of species occur steadily, communities appear to be characterized only by a certain distributional pattern of constancy. Hence it follows that, in order to mimic, initiate and accelerate natural vegetation development, the species set which has to be sown because of the

lack of propagules must consist not only of pioneers but also include secondary settlers. In the case of mine spoil, this assumption proved to be true, and it would appear to be applicable to every kind of abandoned land, if reclamation is desired in accordance with ecological principles. Furthermore, this kind of recultivation is cheap, especially because further development will occur unaided, although management can accelerate succession, e.g. by sowing diaspores of the following settlers, or arrest it at any point in its development in order to establish a persistent plant community.

Acknowledgements

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