THE USE OF ORGANIC AND MINERAL FERTILIZERS IN REFORESTATION AND IN REVITALIZATION OF DECLINING PROTECTIVE FORESTS IN THE ALPS

G. Glatzel[1], K. Haselwandter[3], K. Katzensteiner[1],
H. Sterba[2] and J. Weißbacher[1]

[1]Institute of Forest Ecology
[2] Institute of Forest Yield Science
Universitaet fuer Bodenkultur
Peter Jordanstr. 82
A-1190 Vienna, AUSTRIA

[3]Institute of Microbiology
University of Innsbruck
Sternwartestr. 15
A-6020 Innsbruck, AUSTRIA

Abstract. BIOSOL[1] and BACTOSOL[1], organic fertilizers based on residue from commercial antibiotic production, were tested as an alternative to mineral fertilizers in reforestation and in revitalization of Norway spruce stands (Picea abies) affected by forest decline. Due to its slow release of N and its stimulation of root growth, the organic fertilizer was superior to mineral fertilizer in enhancing growth of spruce planted in nutrient poor soil with low nutrient retention capacity, especially when combined with magnesium carbonate fertilizer. In mature stands, basal area increment responded positively and significantly to both mineral fertilizer and BIOSOL. So far no pronounced effects of fertilizer treatment on seed production and viability were observed. Fertilization in the moderate amounts employed had no adverse effects on microbial activity in the soil and mycorrhizal status and thus seems to be a safe method to increase tree vigor without dramatically changing site parameters.

1. Introduction

The decline of protective forests is considered a major threat to human settlements and activities in the Austrian Alps. Many protective forests show poor age structure as a consequence of heavy grazing by livestock, browsing by game and poor management. Frequently tree vigor is severely decreased due to mineral nutrient depletion and erosion of organomass and due to disease, namely root and stem rot, facilitated by root injuries from livestock trampling. Air pollution aggravates the situation, leading to accelerated decline of many stands. At present, poor seed crops and poor seed viability as well as poor seedbed conditions impair natural regeneration. A means to temporarily restore the vitality of old stands and to carry them through the regeneration period are, therefore, much sought after. Planting is necessary to reforest abandoned alpine pastures and to close gaps where natural regeneration has failed. On nutrient depleted soils mineral deficiencies are a common cause of poor establishment and slow growth of the planted trees. Experiments by Glatzel (1976) have shown that mineral

[1] BIOSOL and BACTOSOL are registered trademarks of Biochemie Ges.m.b.H., Kundl, Austria.

Water, Air, and Soil Pollution **54**: 567–576, 1990/91.

fertilization can significantly improve growth and survival of Norway spruce (*Picea abies*) planted near the alpine timberline. Many foresters, however, are still reluctant to use fertilizers in subalpine forests because overdosing can decrease hardiness and because soluble fertilizers are easily leached from poor soils.

In order to test whether slow release fertilizers are less susceptible to overdosing and leaching, organic fertilizers were compared with conventional mineral fertilizer in afforestation experiments and in revitalization experiments of old stands. In pot experiments BIOSOL fertilizer had shown positive effects on root growth of Norway spruce (*Picea abies*) (Glatzel and Fuchs, 1986).

2. Reforestation Experiment Gressensteinalm

2.1 Methods and materials

The Gressensteinalm experimental area is an abandoned pasture on a steep SW-slope in the Kutzbüheler Alps in Tyrol at 1800 m elevation. The geological substrate for soil formation is moraine material from quartzphyllite. Soils are acidic semipodzols and podzols (pH 3.7 in $CaCl_2$). The cation exchange capacity of the mineral soil is very low. Mean annual precipitation is in excess of 1500 mm. *Vaccinium myrtillus* and *Rhododendron ferrugineum* are the predominant woody species at this site. Old tree stumps and clumps of Norway spruce (*Picea abies*) up to an elevation of 2100 m show that reforestation of this site could be possible.

In the Gressenstein experiment the organic slow-release fertilizer BACTOSOL (see Table I for composition) and a commercial 12(N)-10(P_2O_5)-18(K_2O) chloride free fertilizer were tested. Crude MAGNESITE additions to buffer soil acidity were tested in combination with the organic and the mineral NPK-fertilizer. In June 1986, 432 3 yr old spruce seedlings were planted and randomly assigned to 11 treatments with 36 replications each (Table II). The fertilizer and the crude MAGNESITE powder were top dressed to individual trees. Organic fertilizer was applied immediately after planting, mineral fertilizer was applied 6 wk later. Fertilization was repeated at the end of June 1988 with a double amount of fertilizer.

2.2 Results

2.2.1 *Survival*. Although the dosage of mineral fertilizer was lower than the amount recommended by the producer, 50% of the plants treated with mineral fertilizer died until 1988. The combined treatment of mineral fertilizer with crude MAGNESITE showed also a 45% loss of plants, whereas the loss of seedlings fertilized with BACTOSOL was lower than 5%. Nearly all unfertilized plants survived. This result shows that overdosage of mineral fertilizer in high elevation of reforestation is a serious risk, whereas the use of organic fertilizers with slow release of nutrients is safe.

2.2.2 *Plant nutrition*. The nutritional status of the plants can be compared to values given by Hüttl (1986) for optimal and minimal nutrient levels. Figure 1 shows the foliar nutrient contents in fall of 1988. All fertilized seedlings had higher N levels than unfertilized ones.

Table I

Composition of the organic fertilizers BACTOSOL and BIOSOL (as used; both products have been improved since)

Parameter	Content (%) BACTOSOL	BIOSOL
Organic matter	60	70
Organically bound N	4 - 6	5 - 6
Soluble N	< 0.3	< 0.3
P (as P_2O_5)	3 - 5	1 - 2
K (as K_2O)	3 - 5	3 - 4
Mg (as MgO)	1.5 - 2.5	0.5 - 2.5
Ca (as CaO)	6 - 9	3 - 5
Antibiotic activity	below detection limit	

Table II

Treatments of the reforestation experiment "Gressenstein Alm" (doses in g per plant)

Nutrient/	Year	Control	Mineral Fertilizer*	BACTOSOL* (dosage level 1-4) 1	2	3	4
Total	86	--	30	30	60	100	150
	88	--	60	60	120	200	300
N	86	--	3.6	1.5	3.0	5.0	7.5
	88	--	7.2	3.0	6.0	10.0	15.0
P_2O_5	86	--	3.0	1.2	2.4	4.0	6.0
	88	--	6.0	2.4	4.8	8.0	12.0
K_2O	86	--	5.4	1.2	2.4	4.0	6.0
	88	--	10.8	2.4	4.8	8.0	12.0
CaO	86	--	3.3	2.3	4.5	7.5	11.3
	88	--	6.6	4.5	9.0	15.0	22.5
MgO	86	--	0.2	0.7	1.2	2.0	3.1
	88	--	0.3	1.2	2.4	4.0	6.0

* without and with 100g (1986) and 200g (1988) crude MAGNESITE

MAGNESITE treatment appears to stimulate N uptake, especially in the mineral fertilizer treatment. Potassium content is optimal only in the combined mineral fertilizer plus MAGNESITE treatment at the second dosage level of BACTOSOL. Critical dilution of Mg at high BACTOSOL dosage levels might be a problem even with MAGNESITE addition. The foliar nutrient levels of unfertilized plants, but also of mineral fertilized plants without MAGNESITE, indicate that nutrient deficiency and low base saturation of the soil are limiting factors for tree growth at this site. Optimum dosage levels for balanced plant nutrition seem to be 60 g BACTOSOL plus 100 g crude MAGNESITE per plant in the year of planting and 120 g BACTOSOL plus 200 g crude MAGNESITE 2 yr later.

2.2.3 *Growth and vigor*. One visible criterion for plant vigor is needle color. The color was judged on a five level scale (1 = dark green, 5 = yellow). Needle color was mainly correlated with N content at this experimental site. BACTOSOL fertilized plants showed dark green needles, especially at high dosage level, whereas unfertilized and mineral fertilized plants were of yellow color. The difference was statistically significant (Duncan-test, P = 5%).

For seedlings in high elevations, sturdiness is important. BACTOSOL fertilized plants have 45 branches per plants and thus significantly more branches than unfertilized (35) and mineral fertilized (33) plants. Branching index, the ratio of number of branches to shoot-length, is highest in BACTOSOL treatments (1.58) and combined BACTOSOL-MAGNESITE treatments (1.55). Unfertilized (1.33) and mineral fertilized plants (1.11) have a much lower index.

Both plant height and stem diameter below the lowest branches (Figures 2 and 3) were positively affected by fertilization. A higher dosage of 60 to 100 g BACTOSOL was able to increase ratio plant height to stem diameter (between 3.3 and 3.4) whereas the ratio is much wider in unfertilized plants (4.2).

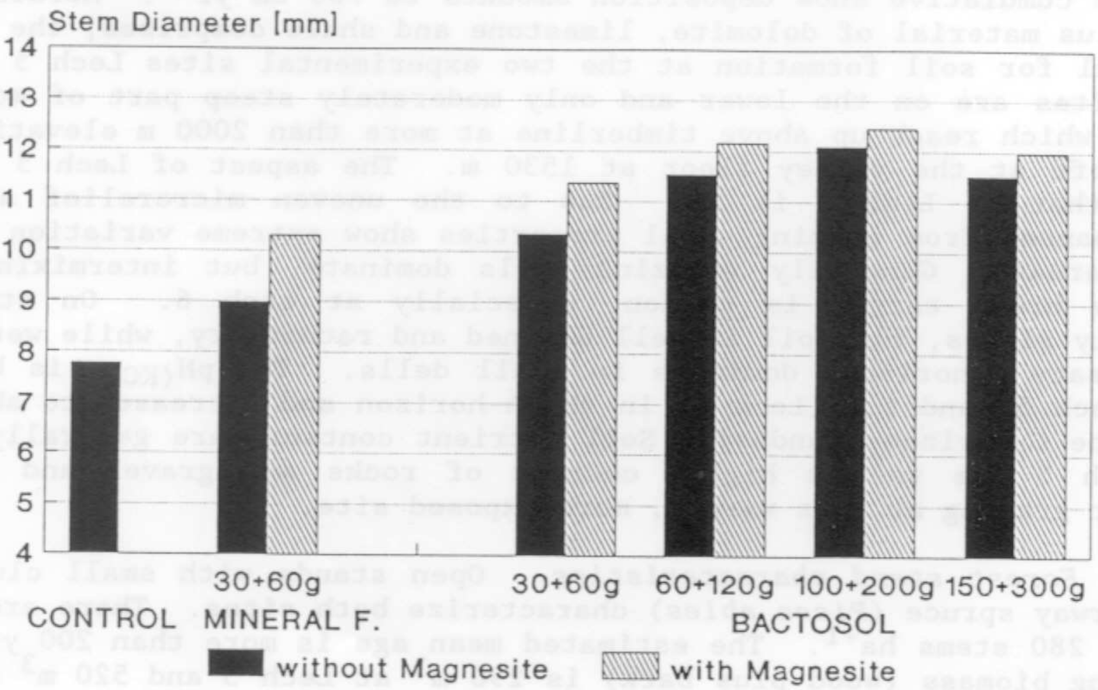

Figure 2. Mean stem diameter (MM) below first branches in 1989

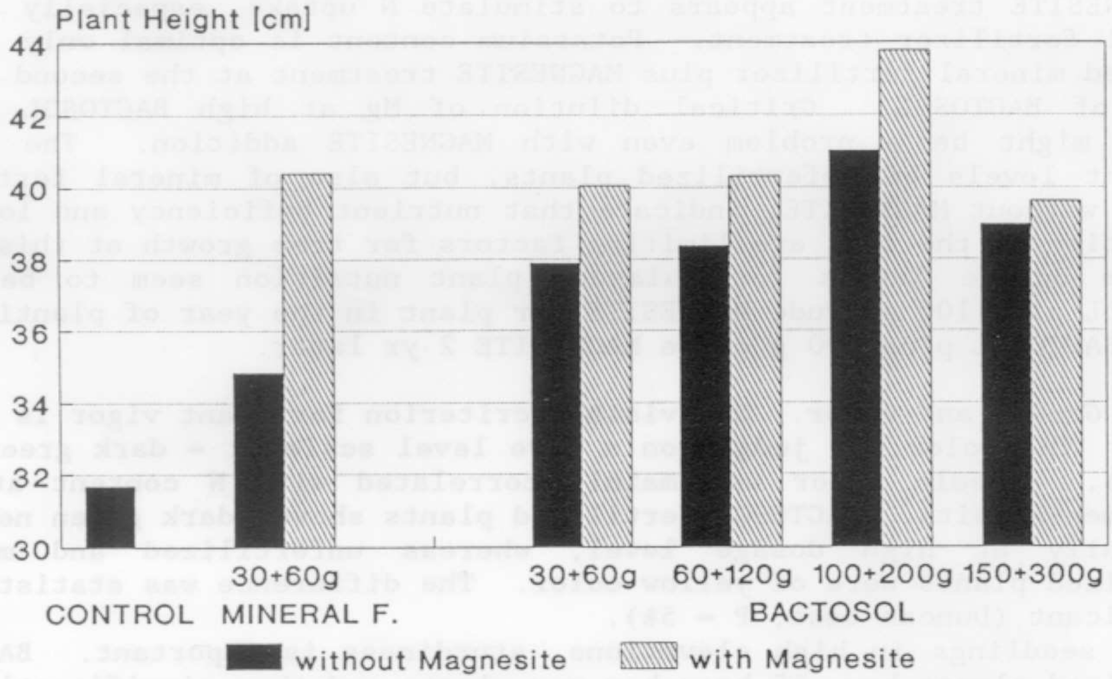

Figure 3. Mean plant height (cm) in the fall of 1989

3. Revitalization Experiments Lech

3.1 Methods and materials

3.1.1 *Experimental sites*. The elevation of the experimental area in Lech (Vorarlberg) is 1550 to 1600 m. The mean annual temperature is 3.8°C, the precipitation 1500 mm, the duration of snowcover is 193 days and the cumulative snow deposition amounts to 780 cm yr^{-1}. Moraine till and talus material of dolomite, limestone and shale comprises, the parent material for soil formation at the two experimental sites Lech 5 and 6. Both sites are on the lower and only moderately steep part of mountain slopes which reach up above timberline at more than 2000 m elevation and level off at the valley floor at 1530 m. The aspect of Lech 5 is SSE while that of Lech 6 is NE. Due to the uneven microrelief and the disturbances from grazing, soil properties show extreme variation within small areas. Generally rendzina soils dominate, but intermixing with shallow brown earths is common, especially at Lech 6. On stony or gravelly ridges, the soil is well drained and rather dry, while wet soils with peaty O-horizons dominate in small dells. The $pH_{(KCl)}$ is between 4.6 (Lech 5) and 5.4 (Lech 6) in the A-horizon and increases to about pH 7 at the C-horizon boundary. Soil nutrient contents are generally lower at Lech 5 due to its higher content of rocks and gravel and due to heavier grazing at this warmer, more exposed site.

3.1.2 *Forest stand characteristics*. Open stands with small clumps of old Norway spruce (*Picea abies*) characterize both sites. There are about 270 to 280 stems ha^{-1}. The estimated mean age is more than 200 yr. The standing biomass (wood plus bark) is 290 m^3 at Lech 5 and 520 m^3 at Lech 6. The visual assessment of tree vitality based on parameters such as needle loss and yellowing (Pollanschütz, 1985), gave a mean crown index of 1.6 which indicates above average needle loss.

Foliar analysis of needles harvested from the 7th whorl indicated N deficiency on both sites and, in addition, phosphorus deficiency at Lech 5 (Table III).

Table III

Mean nutrient content of current needles 1985 (before fertilization), 1987 and 1988 (mg g^{-1} DM) after fertilization (a, b, ab indicates grouping in Scheffe's multiple range test).

Site/ Element	Year	Control	BIOSOL	Mineral Fertilizer	Significance Level
LECH 6					
Nitrogen	85	12.16b	11.52ab	10.33b	*
	87	14.16	15.28	14.94	n.s.
	88	12.89	13.01	13.05	n.s.
Phosphorus	85	1.58ab	1.73b	1.35a	(*)
	87	1.47a	1.83b	1.67ab	(*)
	88	1.73	1.81	1.87	n.s.
Potassium	85	6.29a	7.78b	7.13ab	*
	87	7.58	7.87	7.42	n.s.
	88	7.21	7.41	7.12	n.s.
Calcium	85	3.36	3.45	3.39	n.s.
	87	3.18	3.08	3.23	n.s.
	88	4.67	4.05	4.40	n.s.
Magnesium	85	1.21	1.16	1.12	n.s.
	87	1.31	1.33	1.29	n.s.
	88	1.53	1.48	1.52	n.s.
LECH 5					
Nitrogen	85	10.35	9.90	11.32	n.s.
	87	12.55a	14.07ab	14.56b	(*)
	88	11.57	12.23	12.63	n.s.
Phosphorus	85	1.45	1.28	1.43	n.s.
	87	1.14	1.22	1.32	n.s.
	88	1.25	1.16	1.33	n.s.
Potassium	85	7.35	7.35	7.45	n.s.
	87	6.57	6.94	6.27	n.s.
	88	5.83	6.47	6.68	n.s.
Calcium	85	3.97	4.10	3.88	n.s.
	87	3.45	3.75	3.38	n.s.
	88	5.59	6.07	5.08	n.s.
Magnesium	85	1.53	1.28	1.33	n.s.
	87	1.48b	1.33ab	1.31b	(*)
	88	1.67b	1.60ab	1.43b	(*)

(*) Alpha = 0.1; * Alpha = 0.05

3.1.3 *Experimental design*. Because of the extreme heterogeneity of the soils and stands, conventional plot experiments were not possible. Therefore, tree clumps of similar density were singled out and used as experimental units. Fertilizer was applied in a circular area with a diameter of 30 m around the central tree. Measurements were taken from the central tree or from the next neighbors when the central tree was damaged by snow, storm or lightning during the experiment.

Table IV shows the treatments. The number of replications was 6 at Lech 5 and 9 at Lech 6.

Table IV

Fertilization design LECH (Doses of elements applied both 1985 and 1987 [kg ha^{-1}])

Nutrient	Treatment Control	BIOLSOL	Mineral Fertilizer
Total	--	400	1000
N	--	50-60	60
P (as P_2O_5)	--	10-20	20
K (as K_2O)	--	30-40	72
Ca (as CaO)	--	30-50	19
Mg (as MgO)	--	5-25	19

The composition of BIOSOL is given in Table I. Because part of the N is bound in chitin, it is only slowly released by microbial action in the soil. BIOSOL is also especially rich in siderophores ("iron carriers") and can therefore improve trace element nutrition (Haselwandter *et al*., 1988). The mineral fertilizer had the composition 15(N)-5(P_2O_5)-18(K_2O), chloride free with 3% MgO.

3.2 Results

3.2.1 *Tree growth*. Because the diameters of the study trees varied substantially and basal area increment is correlated with diameter, analysis of covariance was used to reduce the error due to variances in initial stem diameter. Table V shows the annual increments in basal area per tree. The increment was generally much smaller at Lech 5 due to its poorer soil. In 1987 an extremely cool summer led to a marked setback in growth. Both fertilizer treatments led to an increase in growth of 33% over a 3 yr period (statistically significant at the 1% level). The difference between the BIOSOL and the mineral fertilizer treatment was not significant at the 5%, but significant at the 10% level.

Table V

Mean annual increment (cm^2 basal area per tree)

Site/Year	Control	BIOSOL	Mineral Fertilizer
		Treatment	
LECH 5			
1986	17.4	19.7	19.8
1987	6.6	11.3	12.8
1988	16.9	24.5	22.0
1986 to 1988	13.6	18.5	18.2
LECH 6			
1986	27.8	35.1	29.9
1987	14.8	21.4	18.8
1988	19.9	32.5	27.1
1986 to 1988	20.8	29.7	25.3

3.2.2 *Foliar nutrient content.* Table V shows the mean values for the foliar nutrient levels in the current year's needles from the 7th whorl for the years 1986 and 1988. These values indicate that the fertilizer treatments did not induce pronounced changes in the foliar nutrient levels. As tree growth had significantly increased, it can be assumed that extra nutrients from the fertilizer enabled the trees to increase their canopy mass rather than their foliar nutrient content. It is extremely unlikely that the very small changes in the mineral content of the needles should affect hardiness of resistance against disease or insects.

3.2.3 *Soil biology and mycorrhiza.* Respiration of soil samples collected from the various treatments at Lech 6 in 1988 showed no significant differences under laboratory conditions. Microbial biomass as determined by the method of Anderson and Domsch (1978) in soil samples from Lech 6 collected in July and September 1988 was similar for all treatments in July, but showed a statistically significant decrease at the fertilized sites in September. Possibly the easily degradable material was utilized early in the vegetation period and microbial populations broke down later in the season.

The counts of mycorrhizal root tips of light color, which are usually considered to be a measure of functional mycorrhizae, for root samples taken from Lech 6 in 1987 and 1988 showed large variation. Statistically significant effects of the fertilizer treatments on mycorrhizal infections could not be detected.

3.2.4 *Seed production and viability.* During the first 3 yr of the experiment, less than half of the trees produced a moderate cone crop. There were no treatment effects. Table VI shows the percentage of viable seeds from X-ray analysis from the 1988 harvest. In Lech 6, BIOSOL treatment had a statistically significant effect on cone length. Cone diameter and cone mass were not significantly changed. The percentage of viable seeds was slightly higher in the BIOSOL treatment at both sites and lower in the mineral fertilizer treatments (at the 10% significance level).

Table VI

Mean percentage of viable seed (1988)

Site	Control	BIOSOL	Mineral Fertilizer
		Treatment	
LECH 5	67.6	71.3	55.3
LECH 6	64.3	67.7	52.7

4. Conclusions

From the experiments, the following conclusions on the use of the organic fertilizers BIOSOL and BACTOSOL can be drawn.

Due to its slow release characteristics, the tested organic fertilizer is far superior to mineral fertilizer, especially on soils with poor sorption capacity. The higher costs of the organic fertilizer are offset by the need for less frequent applications (every second or third year). Additions of MAGNESITE enhance the response to fertilization on highly acidic soils.

Growth and tree vigor can be significantly improved by both organic and mineral fertilization. So far only moderate effects were observed with regard to seed crop and seed viability. Organic fertilizers with a high percentage of organically bound N and thus slow N release are superior to soluble mineral fertilizers in situations where the possibility of groundwater contamination with N compounds is an issue.

References

Anderson, J.P.E. and Domsch, K.H.: 1978, *Soil Boil. Biochem* 10, 215.
Glatzel, G.: 1976, *Cbl. ges. Forstw* 93, 1.
Glatzel, G. and Fuchs, J.: 1986, *AFZ* 9/10, 201.
Haselwandter, K., Krismer, R., Holzmann, H.P. and Reid, C.P.: 1988, *J. Plant Nutr.* 11, 959.
Hüttl, R.F.: 1986, Forest Fertilization: Results from Germany, France and the Nordic Countries. The Fertilizer Society Proceedings 250.
Pollanschütz, J.: 1985, Instruktionen für die Feldarbeit der Waldzustands-inventur nach bundeseinheitlichen Richtlinien 1984-1988. Forstliche Bundesversuchsanstalt, Wien., 69 p.