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Field experiments on the effects of fertilizers and lime on the soil microfauna of an alpine pasture

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With 1 figure

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1. Introduction

In ski areas fertilizers and lime are applied to improve the soil fertility to enable a fast revegetation and a reduction of the erosion after the construction of ski runs. High amounts of fertilizers are also occasionally used to conserve the snow on the ski runs (Schönthaler 1983). Singh (1949), Chardez *et al.* (1972), and Kasi Viswanath & Pillai (1977) found in arable land and forest soils, that different fertilizers cause conspicuous qualitative and quantitative changes in the soil amoeba, testacea, and ciliate community, respectively. Foissner (1985) stated, that the biomass of protozoa amounts about one third of the whole zoomass of alpine soils. This indicates the importance of the protozoa in this terrestrial ecosystem.

Thus, we performed an experiment to investigate the effects of recommended maximum concentrations of compound fertilizer, thomasphosphate, and lime on the microfauna, especially on the protozoa of an alpine pseudogley. In a second experiment we assessed the influence of ammonium sulphate, which is often used for the chemical preparation of ski runs.

2. Material and methods

2.1. Site description and treatments

Both experiments were performed in the ski area of the Schloßalm, Bad Hofgastein, Salzburg, 1965 m above sea level. The study site is a grazed alpine pasture with dwarf shrubs, E, 10—15°, mica-slate, pseudogleyic brown earth. A detailed description including the soil profile is given by Berger *et al.* (1985).

Experiment 1: On June 17, 1984, 600 kg compound fertilizer ha^{-1} (NPK; 16 : 16 : 16; 96 kg N, 42 kg P, and 79 kg K ha^{-1}; containing chlorine), 600 kg thomasphosphate ha^{-1} (14.5 % P_2O_5, 38 kg P ha^{-1}; 45 % CaO), and 4,000 kg lime ha^{-1} (crushed limestone, $CaCO_3$) were applied in a randomized block design (3 blocks). The fertilizers were dissolved in spring water and applied with a watering can. The control plots received only water.

Experiment 2: Four plots, each 1 m × 2 m were treated on June 13, 1983 and June 17, 1984, with 0, 100, 400, and 1,200 kg ammonium sulphate ha^{-1} ($(NH_4)_2SO_2$; 21 % N, 0, 21.2, 84.8, and 254.5 kg N ha^{-1}). The application was done as described in experiment 1.

2.2. Sampling and counting procedures

Experiment 1: The 3 blocks were sampled on October 4, 7, and 15, 1984. Ten cubes (side = 5 cm) of the top soil were taken from each plot (0.5 m × 1.0 m) and pooled into 1 sample, from which a subsample (n = 10) of 0.4 g fresh soil was used to estimate the abundance of the active ciliates, nematodes, and rotatoria. The soil was suspended in 8 ml water and examined at a magnification of × 40 (objective 4 : 1, ocular 10 : 1). This method has been proven to yield reliable counts for relatively fast moving soil microorganisms, like ciliates and nematodes (Foissner 1983). The abundance

and species number of the testacea were determined from a subsample (n = 10) of 0.1 g fresh soil stained with aniline blue to descriminate between full and empty tests (SCHÖNBORN 1978). The examination of the suspension (3 ml) was performed at a magnification of ×100 (objective 10 : 1, ocular 10 : 1). The species number of the ciliates was determined using the technique described by FOISSNER (1985), however, 50 g instead of 30 g air dried soil were employed. This sample was also used to estimate the abundance of the ciliates (culture method!). Six replicates of each 10 µl were examined under ×40. For the estimation of the abundance of the fast moving and dominant species Lugol's solution was added. The determination of the biomass was done according to the method of FOISSNER (1985).

Experiment 2: Samples were collected on July 5, September 5, and October 18, 1983, and September 19, 1984. All other procedures were the same as described in experiment 1.

2.3. Chemical analysis

Soil water content: air-drying, 14 days at 20 °C.
*p*H-value: with a glass *p*H electrode in a 1 : 2.5 soil/water suspension.
Humus content: according to DE LEENHEER (ALVA 1972).
Total nitrogen: according to KJELDAHL (STEUBING 1965).
Ammonium- and nitrate-nitrogen: according to the method of ALVA (1972).
Calcium-carbonate: according to SCHEIBLER, gas-volumometric with HCl 1 : 1 (ALVA 1972).
Phosphoric-acid and potash: CAL-method according to SCHÜLLER (1969).
CO_2-release: according to ISERMEYER (1952).

2.4. Statistical analysis

Following indices were used to characterize the community structures: species identity (SØRENSEN 1948), dominance identity (RENKONEN 1938), the similarity index of BRAY & CURTIS (1957), and Shannon's diversity index and the evenness component (PIELOU 1966). The data in experiment 1 were analyzed with a two-way analysis of variance and the Dunnett-test was used for multiple comparison (DUNNETT 1955, 1964, SOKAL & ROHLF 1981). The diversity values were compared by using the method of HUTCHESON (1970). Since the 4 experimental units of each treatment of the experiment 2 are not independent, an analysis of variance cannot be performed (EISENHART 1947, HURLBERT 1984).

3. Results and discussion

3.1. Abiotical factors and CO_2-release

Experiment 1: The NPK treatment causes no conspicuous change of the *p*H value, whereas it is significantly increased by lime and the high Ca-content of thomasphosphate, which is recommended for the fertilization of acid soils (Table 1, Fig. 1a; SCHEFFER & SCHACHTSCHABEL 1979, RUCKENBAUER 1982). In spite of this increase the CO_2-release — which proves to be more an index of microbial activity than on the quantity of microbial cells (GOLEBIOWSKA & PEDZIWILK 1984) — is not altered significantly (Table 1, Fig. 1b). Likewise, BÅÅTH *et al.* (1980) find no changes in the microbial biomass after the application of lime. Contrary, MAI & FIEDLER (1969) report on a significant increase of soil respiration 6 years after a "moderate" liming. KASZUBIAK *et al.* (1983) ascertain a similar bacterial biomass in the control and the NPK treatment, whereas SCHINNER *et al.* (1980) show that compound fertilization reduces the CO_2-release conspicuously. A similar tendency is discernable from our experiment (Fig. 1b).

Experiment 2: One year after the first application of ammonium sulphate, the CO_2-release and the NH_4^+ — nitrogen are about 40 % and the total — nitrogen is about 50 % higher in the fertilized sites than in the control. The differences among the fertilized plots are insignificant (Table 2). Two months after the second fertilization the total — nitrogen is similar in all sites. Only the NH_4^+ — nitrogen concentration is about 40 % (100 kg ha^{-1}), 70 % (400 kg ha^{-1}), and 150 % (1,200 kg ha^{-1}) higher as compared to the control. On September 19, 1984, the fertilized sites have higher contents of approximately 50 % total — nitrogen and 210 % NH_4^+ — nitrogen than the control. The CO_2-release is 35 % higher in the plots 100 and 400 kg ha^{-1} compared to the unfertilized soil. In the sample 1,200 kg ha^{-1} the soil respiration is only 7 % higher than in the control.

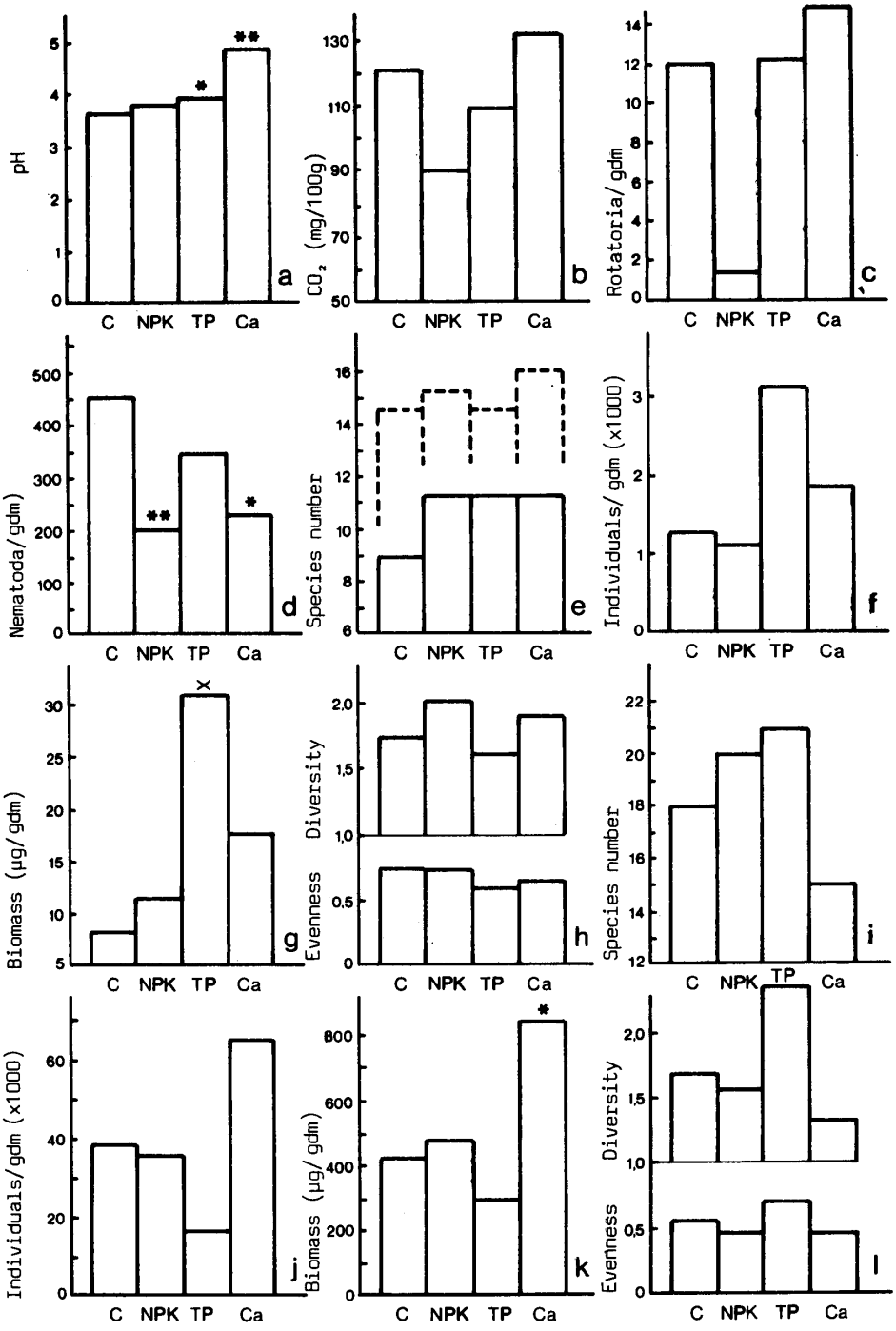

Fig. 1. Arithmetic mean (n = 3) of the soil *p*H, the CO_2-release, and some community parameters after compound fertilizer (NPK), thomasphosphate (TP), and lime (Ca) application. a: soil *p*H. b: CO_2-release. c, d: abundance of rotatoria and nematoda. e, f, g, h: species number (above, full and empty tests; below, full tests), abundance, biomass, and diversity and evenness of the testacean communities. i, j, k, l: species number, abundance, biomass, and diversity and evenness of the ciliate communities. ×, *, **, with $P \leqslant 0.10$, $P \leqslant 0.05$, or $P \leqslant 0.01$ different from the control (c). dm: dry mass.

Table 1. Effect of compound fertilizer (NPK), thomasphosphate (TP), and lime (Ca) on physical, chemical, and community parameters[1])

Parameter	Treatment ($\bar{x}$ (SD); n = 3)[2])				ANOVA	
	Control	NPK	TP	CA	F	P
Water content (% wet mass)	*43.3 (6.0)*	*41.0 (2.0)*	*45.3 (2.3)*	*45.0 (3.6)*	*0.82*	*<0.75*
*p*H (H_2O)	3.7 (0.2)	3.8 (0.3)	3.9 (0.2)	4.9 (0.1)	127.11	<0.001
Humus (%)	*8.0 (4.2)*	—	—	—		
Total-nitrogen (mg 100 g^{-1})	359 (125)	233 (97)	—	—		
NH_4^+-nitrogen (mg 100 g^{-1})	4.6 (0.2)	5.0 (2.0)	—	—		
NO_3^--nitrogen (mg 100 g^{-1})	3.2 (0.2)	6.5 (0.9)	—	—		
$CaCO_3$ (%)	0.0	—	0.0	0.1 (0.0)		
P_2O_5 (mg 100 g^{-1})	2.2 (1.0)	1.5 (0.9)	4.0 (1.3)	—		
K_2O (mg 100 g^{-1})	14.9 (4.3)	13.1 (3.2)	15.7 (1.4)	—		
CO_2-release (mg 100 g^{-1})	122 (51)	90 (54)	109 (8)	133 (55)	0.68	<0.75
TESTACEA						
Mean species number (f)[3])	9.0 (1)	11.3 (2.5)	11.3 (1.2)	11.3 (3.2)	1.00	<0.50
Total species number (f)[3,4])	10	16	15	19	X^2 = 2.80	<0.50
Total species number (f & e)[3,4])	20	22	19	23	X^2 = 0.48	<0.98
Individuals g^{-1} dm[5])	1,290 (500)	1,122 (365)	3,162 (2,592)	1,848 (1,365)	1.03	<0.50
Biomass in μg g^{-1} dm[5])	8.2 (3.8)	11.6 (5.8)	31.1 (11.2)	17.9 (15.8)	3.07	~0.10
full : empty tests	1 : 2.55	1 : 1.78	1 : 1.75	1 : 1.67	0.66	<0.75
Diversity[6])	1.74	2.07***	1.63**	1.91***		
Evenness[6])	0.75	0.74	0.60	0.65		
CILIATA						
Individuals g^{-1} dm (active)[5])	0	1.3 (2.3)	0	5.7 (6.6)	1.51	<0.50
Individuals g^{-1} dm (culture)[5])	38,956 (25,310)	36,569 (28,651)	16,672 (5,971)	66,611 (24.120)	2.82	<0.25
Biomass in μg g^{-1} dm[5]	430 (217)	480 (155)	296 (46)	847 (319)	5.97	<0.05
Mean species number	18.0 (5.2)	20.0 (2.6)	21.3 (4.6)	15.3 (4.0)	1.07	<0.50
Total species number[4])	27	32	32	22	X^2 = 2.43	<0.50
Diversity[6])	1.71	1.57***	2.37***	1.33***		
Evenness[6])	0.57	0.49	0.71	0.45		
NEMATODA g^{-1} dm[5])	452 (93)	199 (37)	347 (12)	233 (85)	8.58	<0.025
ROTATORIA g^{-1} dm[5])	12 (14)	1 (2)	12 (3)	15 (18)	1.07	<0.50

[1]) Treatment, June 17, 1984. Sampling, October 4 (block 1), October 7 (block 2), and October 17 (block 3), 1984.
[2]) $\bar{x}$, arithmetic mean; SD, standard deviation; n, sample size.
[3]) f, f & e, only full and full & empty tests considered, respectively.
[4]) Compared with the X^2-test.
[5]) dm, dry mass.
[6]) Shannon index and evenness component were calculated on means of 3 replicates per treatment. **, ***, highly ($P \leqslant 0.01$) or very highly ($P \leqslant 0.001$) significant different from the control.

Table 2. Effect of ammonium sulphate on selected chemical parameters 1 year after the first and 2 and 3 months after the second application[1])

Date	Treatment	Total-nitrogen	NH_4^+-nitrogen	CO_2-release
June 17, 1984[2])	Control	299	4.4	51.3
	100 kg ha^{-1}	420	5.7	74.8
	400 kg ha^{-1}	519	6.3	66.0
	1,200 kg ha^{-1}	482	6.4	71.9
August 15, 1984	Control	420	5.3	—
	100 kg ha^{-1}	449	7.5	—
	400 kg ha^{-1}	558	9.0	—
	1,200 kg ha^{-1}	471	13.5	—
September 19,	Control	358	2.2	95.7
1984	100 kg ha^{-1}	484	5.3	126.0
	400 kg ha^{-1}	601	8.4	130.9
	1,200 kg ha^{-1}	543	6.8	102.3

[1]) First treatment, June 13, 1983; second treatment, June 17, 1984. All data in mg 100 g^{-1} dry mass.

[2]) The samples were taken prior to the second treatment.

3.2. Testacea

Experiment 1: Both the mean and the total species number are not significantly different, however, both parameters (full tests) are increased in the fertilized samples (Table 1, Fig. 1e). So far, only CHARDEZ *et al.* (1972) investigated the effects of fertilizers on the testacean communities. Three years after the application of 325 kg urea ha^{-1} they find a statistically significant decrease in the species number, whereas PK and NPK cause no marked changes. Urea reacts alkaline, similar as thomasphosphate and lime. The last 2 induce greater modifications in the species composition than NPK (Table 4).

Only *Schoenbornia humicola* and *Trinema enchelys* show significant treatment effects ($F = 10.46$, $P < 0.01$ and $F = 6.33$, $P < 0.05$). They are more abundant in the thomasphosphate plots than in the control (Tables 1, 5). *Trinema lineare* is the most dominant species in all sites. It also causes the high mean abundance in the thomasphosphate treatment, where also *Centropyxis aerophila var. sphagnicola*, *Corythion pulchellum*, *Nebela parvula*, *Plagiopyxis declives*, and *T. complanatum* are more abundant compared to the other sites. Although the mean abundances and biomasses are rather different only thomasphosphate increases the biomass significantly ($P \sim 0.1$; Table 1, Figs. 1f, g). All treatments cause a significant alteration of the diversity index, however, qualitative and quantitative changes are conspicuous only after the thomasphosphate application (Tables 1, 4, Fig. 1h). CHARDEZ *et al.* (1972) observe a doubling of the abundance and biomass 3 years after the NPK treatment and a loss of two-thirds after the urea application.

Experiment 2: The differences in the species number, abundance, diversity, and evenness component are inconspicuous among the treatments and do not show a uniform trend (Table 3). Contrary, the mean biomass is about 30% higher in the site 1,200 kg ha^{-1} than in the other plots. This is mainly due to the increased dominance of *C. aerophila var. sphagnicola*, one of the largest species in this area. However, the abundances of other testacea are not markedly changed. SINGH (1949) finds that the abundances of the soil naked amoebae are much higher in the plots treated with complete minerals and ammonium sulphate than in the control sites.

The mean ratio of full to empty tests is distinctly higher in the site 1,200 kg ha^{-1} than in the other treatments (Table 3). Very probably this is also due to the raised dominance of *C. aerophila var. sphagnicola*, since according to LOUSIER & PARKINSON (1981) empty sediment particle tests disappear more slowly than those tests which are made of platelets.

Table 3. Dynamics of the water content, the soil *p*H, and some community parameters after the application of 100, 400, and 1,200 kg ammonium sulphate ha^{-1} [1])

Date[2])	Treatment	Water content (% wm)	*p*H (H_2O)	Testacea						Ciliata SN	Nematoda (I g^{-1} dm)	Rotatoria (I g^{-1} dm)
				SN[3])	I g^{-1} dm	BM ($\mu g\ g^{-1}$ dm)	f : e	H	E			
t1	Control	45.7	3.4	11	1,234	15.3	1 : 0.88	1.98	0.82	13	529	23
	100 kg ha^{-1}	55.2	3.3	9	2,796	29.4	1 : 1.03	1.88	0.86	8	290	17
	400 kg ha^{-1}	48.8	3.3	11	2,441	17.7	1 : 0.98	1.79	0.75	7	297	0
	1,200 kg ha^{-1}	55.2	3.5	11	3,326	41.1	1 : 1.32	1.88	0.78	11	196	0
t2	Control	55.2	3.4	9	4,531	34.8	1 : 0.84	1.57	0.71	13	345	11
	100 kg ha^{-1}	45.5	3.4	9	1,651	18.4	1 : 1.06	1.88	0.86	11	467	0
	400 kg ha^{-1}	53.4	3.3	8	2,108	17.9	1 : 0.92	1.61	0.77	13	473	11
	1,200 kg ha^{-1}	50.6	3.5	14	2,065	30.3	1 : 1.70	2.10	0.79	8	182	40
t3	Control	46.5	3.6	9	2,935	23.1	1 : 0.96	1.70	0.77	7	168	9
	100 kg ha^{-1}	49.1	3.4	10	2,692	16.9	1 : 0.93	1.64	0.71	8	412	15
	400 kg ha^{-1}	52.5	3.5	11	3,221	21.3	1 : 1.02	1.76	0.73	8	457	0
	1,200 kg ha^{-1}	52.8	3.4	11	3,051	36.3	1 : 1.17	1.82	0.76	12	487	16
t4	Control	49.3	3.3	14	2,939	32.4	1 : 0.65	2.02	0.76	17	227	5
	100 kg ha^{-1}	49.0	3.1	11	1,922	19.5	1 : 0.66	1.76	0.73	14	279	10
	400 kg ha^{-1}	50.7	3.0	13	3,773	28.0	1 : 1.02	1.98	0.77	16	294	46
	1,200 kg ha^{-1}	48.4	3.0	12	2,733	26.6	1 : 0.87	1.91	0.77	19	310	5
$\bar{x}$	Control	49.2	3.4	10.8	2,910	26.4	1 : 0.83	1.82	0.77	12.5	317	12
	100 kg ha^{-1}	49.7	3.3	9.8	2,265	21.1	1 : 0.93	1.79	0.79	10.3	362	10
	400 kg ha^{-1}	51.4	3.3	10.8	2,886	21.3	1 : 0.99	1.79	0.76	11.0	380	14
	1,200 kg ha^{-1}	51.8	3.4	12.0	2,794	33.6	1 : 1.23	1.93	0.78	12.5	294	15

[1]) First treatment, June 13, 1983; second treatment, June 17, 1984. Abbrevations: BM, biomass; dm, dry mass; E, evenness; e, f, empty and full tests, respectively; H, diversity; I, individuals; SN, species number; wm, wet mass.

[2]) t1, July 5, 1983; t2, September 5, 1983; t3, October 18, 1983; t4, September 19, 1984; $\bar{x}$, arithmetic mean (n = 4).

[3]) Only full tests are considered.

Table 4. SØRENSEN, RENKONEN, and BRAY & CURTIS index between the testacean and ciliate communities of the control and the fertilized sites[1,2])

Index	Testacea			Ciliata		
	NPK	TP	Ca	NPK	TP	Ca
SØRENSEN	77	72	69	77	81	69
RENKONEN; individuals	79	85	86	86	61	79
RENKONEN; biomass	61	61	75	78	68	78
BRAY & CURTIS	77	56	80	88	53	60

1) Data in %. All indices were calculated on means of 3 replicates per treatment.
2) NPK, compound fertilizer; TP, thomasphosphate; Ca, lime.

Table 5. Relative abundance of testacea in experiment 1[1])

Species	Relative abundance (%)			
	C	NPK	TP	Ca
Arcella arenaria var. compressa CHARDEZ	+ (1)	+ (1)	—	—
Assulina muscorum GREEFF	—	—	0.4 (1)	0.3 (1)
Centropyxis aerophila DEFLANDRE	—	+ (1)	+ (1)	0.4 (1)
Centropyxis aerophila var. sphagnicola DEFLANDRE	3.4 (3)	7.5 (3)	3.8 (3)	5.4 (3)
Centropyxis elongata (PENARD)	—	2.5 (3)	0.6 (2)	0.6 (2)
Centropyxis minuta DEFLANDRE	—	—	—	+ (1)
Centropyxis sylvatica DEFLANDRE	+ (1)	—	+ (1)	—
Corythion dubium TARANEK	+ (1)	0.5 (1)	+ (2)	+ (2)
Corythion pulchellum PENARD	6.7 (3)	7.6 (3)	4.3 (3)	5.4 (3)
Cyclopyxis eurystoma DEFLANDRE	+ (1)	+ (1)	0.2 (2)	0.4 (1)
Cyclopyxis kahli DEFLANDRE	+ (1)	1.0 (2)	—	0.7 (2)
Difflugia sp.	—	—	—	0.4 (1)
Edaphonobiotus campascoides SCHÖNBORN, FOISSNER & MEISTERFELD	—	0.5 (2)	—	—
Euglypha compressa CARTER	—	—	—	0.3 (1)
Euglypha cristata LEIDY	—	+ (1)	—	—
Euglypha laevis (EHRENBERG)	1.4 (3)	2.6 (2)	0.6 (3)	0.6 (3)
Euglypha rotunda WAILES & PENARD	14.6 (3)	15.7 (3)	10.4 (3)	19.4 (3)
Euglypha strigosa (EHRENBERG)	+ (1)	+ (1)	—	+ (2)
Euglypha sp.	+ (1)	1.0 (1)	—	—
Heleopera petricola LEIDY	—	+ (1)	+ (1)	—
Nebela parvula CASH	+ (2)	—	0.2 (1)	+ (1)
Phryganella acropodia (HERTWIG & LESSER)	4.4 (3)	3.1 (3)	1.5 (3)	7.6 (3)
Plagiopyxis declivis THOMAS	+ (3)	0.5 (3)	2.1 (3)	0.4 (3)
Schoenbornia humicola (SCHÖNBORN)	2.9 (3)	6.6 (3)	5.1 (3)	1.1 (3)
Schoenbornia viscicula SCHÖNBORN	3.7 (3)	7.2 (3)	0.6 (3)	2.0 (3)
Tracheleuglypha acolla BONNET & THOMAS	+ (1)	—	—	0.4 (1)
Trinema complanatum PENARD	15.1 (3)	6.1 (3)	13.9 (3)	12.8 (3)
Trinema enchelys (EHRENBERG)	3.0 (3)	0.5 (2)	2.9 (3)	2.7 (2)
Trinema lineare PENARD	44.8 (3)	37.1 (3)	53.4 (3)	39.1 (3)
Species number: full tests	10	16	15	19
full & empty tests	20	22	19	23

1) —, not present; +, only empty tests present; (1), (2), (3), in 1, 2, or 3 blocks present.

Table 6. Relative abundance of ciliates in experiment 1[1])

Species	Relative abundance (%)			
	C	NPK	TP	Ca
Blepharisma hyalinum PERTY	—	—	—	+ (1)
Bryometopus pseudochilodon KAHL	+ (2)	0.2 (3)	0.3 (2)	—
Chilophrya terricola FOISSNER	+ (1)	—	—	—
Cinetochilum margaritaceum PERTY	—	—	+ (1)	—
Colpoda henneguyi FABRE-DOMERGUE	0.9 (3)	2.5 (3)	3.3 (3)	2.7 (3)
Colpoda inflata (STOKES)	9.6 (3)	12.0 (3)	19.5 (3)	11.9 (3)
Cyclidium muscicola KAHL	6.6 (3)	6.6 (3)	13.6 (3)	7.8 (3)
Cyrtolophosis acuta KAHL	0.5 (2)	0.7 (3)	0.2 (2)	1.0 (3)
Dileptus anguillula KAHL	+ (1)	0.1 (1)	0.2 (2)	—
Dileptus terrenus FOISSNER	—	+ (1)	—	—
Drepanomonas revoluta PENARD	—	0.1 (1)	0.4 (1)	—
Enchelys multinucleata (DRAGESCO & DRAGESCO-KERNEIS)	—	0.1 (1)	—	—
Gonostomum affine (STEIN)	2.6 (3)	0.9 (3)	4.2 (3)	1.9 (3)
Gonostomum franzi FOISSNER	0.2 (1)	+ (1)	+ (1)	+ (2)
Grossglockneria acuta FOISSNER	1.9 (3)	1.0 (3)	0.6 (3)	0.7 (2)
Hemisincirra filiformis (FOISSNER)	0.1 (1)	—	—	—
Hemisincirra gellerti (FOISSNER)	0.4 (3)	0.7 (2)	2.4 (3)	1.5 (3)
Hemisincirra gracilis (FOISSNER)	—	—	0.1 (1)	—
Histriculus muscorum (KAHL)	+ (1)	0.1 (1)	0.2 (1)	—
Holosticha sigmoidea FOISSNER	0.2 (1)	—	1.6 (1)	—
Keronopsis muscicola (KAHL)	+ (1)	+ (1)	+ (1)	—
Lamtostyla perisincirra (HEMBERGER)	0.2 (1)	0.1 (1)	0.3 (2)	0.1 (3)
Leptopharynx costatus MERMOD	1.3 (3)	3.2 (3)	6.3 (3)	4.3 (3)
Microdiaphanosoma arcuata GRANDORI & GRANDORI	0.2 (2)	0.3 (2)	0.1 (1)	—
Nivaliella plana FOISSNER	6.3 (3)	1.6 (3)	8.7 (3)	0.6 (3)
Oxytricha setigera STOKES	0.1 (1)	0.2 (1)	1.1 (2)	—
Paracolpoda steinii (MAUPAS)	55.0 (3)	60.0 (3)	21.9 (3)	65.5 (3)
Plagiocampa rouxi KAHL	+ (1)	0.1 (1)	—	—
Platyophrya macrostoma FOISSNER	—	—	0.2 (1)	0.1 (1)
Platyophrya vorax KAHL	—	+ (1)	—	—
Protospathidium serpens (KAHL)	—	+ (1)	0.3 (2)	—
Pseudochilodonopsis mutabilis FOISSNER	—	0.2 (1)	0.3 (2)	0.1 (1)
Pseudocyrtolophosis alpestris FOISSNER	2.3 (2)	2.8 (3)	5.9 (3)	0.8 (3)
Pseudoplatyophrya nana (KAHL)	0.5 (2)	0.4 (2)	0.5 (2)	0.5 (1)
Pseudoplatyophrya terricola FOISSNER	—	+ (1)	—	0.1 (1)
Sathrophilus muscorum (KAHL)	8.3 (3)	5.7 (3)	7.1 (3)	0.1 (1)
Spathidium muscicola KAHL	—	0.1 (1)	0.2 (2)	+ (1)
Spathidium muscorum (DRAGESCO & DRAGESCO-KERNIS)	+ (1)	—	0.1 (2)	0.2 (1)
Spathidium spathula O. F. MÜLLER	—	0.4 (1)	—	—
Urosomoida agilis (ENGELMANN)	2.7 (3)	+ (1)	+ (1)	0.2 (1)
Vorticella astyliformis FOISSNER	—	—	0.1 (1)	—
Species number:	27	32	32	22

[1]) —, not present; +, only qualitative detectable; (1), (2), (3), in 1, 2, or 3 blocks present.

Moreover, it must be taken into account, that in communities which are dominated by small species as *T. linera*, *Euglypha rotunda*, and *Schoenbornia* spp. the abundances of the unstained empty tests are considerably underestimated by the direct counting procedure (FOISSNER 1983).

3.3. Ciliata

Experiment 1: The treatments cause no statistically significant changes in the number of active individuals and the species number. But it is evident from the mean and the total species number and the SØRENSEN index that liming slightly alters the species composition (Tables 1, 4, Fig. 1i). The mean abundances (cultivation method) are high after the lime treatment and low after the thomasphosphate application as compared to the control. However, the differences cannot be guaranteed at $\alpha = 0.05$ (Table 1, Fig. 1j). After liming *Colpoda henneguyi*, *C. inflata*, *Leptopharynx costata*, *Paracolpoda steinii* — the most dominant species in all treatments — and *Cyrtolophosis acutus* attain distinctly higher mean abundances than in the other treatments. But the two-way analysis of variance suggests that only the last species shows a significant treatment effect (Tables 1, 6; $F = 4.02$, $P < 0.1$). In all blocks the biomass is increased distinctly after lime application indicating a true treatment effect (Table 1, Fig. 1k). Thomasphosphate increases the diversity index by about 40 % compared to the control. This is mainly due to the increased species number and the reduced dominance of *P. steinii* (Fig. 1l).

A pronounced change of the coenosis, indicated by low values of the BRAY & CURTIS index, is only recognizable after phosphate and lime application (Table 4). However, the communities react very differently, because both qualitative and quantitative changes are contrary (Fig. 1i, j). The high abundance after liming is perhaps due to the considerably increased *p*H value and hence better soil conditions for bacteria on which many ciliates feed (FRANZ & LOUB 1959, MAI & FIEDLER 1979, FOISSNER *et al.* 1982). ROSA (1962) also finds that liming raises the abundance of the ciliates. But in contrast to our results, he states an increased species number as well. KASI VISWANATH & PILLAI (1977) report on a positive correlation between the concentration of superphosphate (which reacts acid; RUCKENBAUER 1982) and the abundance of the ciliates in an agricultural soil. Our results suggest, that about 4 months after the application the abundance is slightly reduced by heavy doses of the alkaline thomasphosphate (Fig. 1j).

Experiment 2: Active ciliates are only present in the control site on September 5, 1983 (6 individuals g^{-1} dry mass). The species numbers show considerable temporal variations but the differences among the treatments are not arranged uniformly. Moreover, they are independent from the concentration of ammonium sulphate (Table 3). On October 18, 1983 and September 19, 1984 quantitative investigations have been made. The data are rather similar indicating that the applied fertilizer does not conspicuously change the ciliate community.

3.4. Nematoda and Rotatoria

Experiment 1: The nematodes are significantly less abundant after the NPK fertilization and liming. A reducing effect of high concentrations of compound and nitrogenous fertilizers upon nematode communities is also reported by FRANZ (1975) and SALY & MATULIKOVA (1978). A few months after the application, a probable toxic effect of the compound fertilizer on lower metazoa is also suggested by the decreased mean abundance of the rotatoria (Table 1, Figs. 1c, d).

Experiment 2: About 3 weeks after the first application of ammonium sulphate the abundance of the nematodes is distinctly reduced. In the control site the abundance declines during the growing seasons, while the fertilized plots show an inverse dynamics. Three months after the second fertilization the amount of nematoda is about 30 % higher in the fertilized sites than in the control (Table 3).

4. Final remarks and practical relevance

The treatment of an acid alpine pasture with heavy doses of different fertilizers significantly influences some soil biological characteristics. The *p*H value is increased by the alkaline thomasphosphate and lime and slightly decreased by the acid ammonium sulphate. Perhaps, the changes in the H^+-concentrations are accountable for modifications in the reproduction success in several species. From our results it can not be concluded, whether the testacean and ciliate communities are altered by the *p*H value alone, or rather by other factors following the changes of the H^+-concentrations as alteration of the microbial and/or root biomass, since NPK treatment neither modified the *p*H value nor any parameter of the protozoan communities significantly.

The application of the long-lasting available thomasphosphate, which is also allowed in "organic farming systems", yields neither significantly qualitative nor quantitative decreases in the soil microfauna. This fertilizer even increases the biomass of the testacea, a very important group of soil protozoa, which provide one third of the zoomass in alpine soils (FOISSNER 1985). The NPK treatment has no influence on the protozoa a few months after the application. But the nematode community is significantly affected by the easily soluble compound fertilizer. Most likely, excessive liming also reduces the abundance of these soil organisms at least a few months after the application.

With regard to ammonium sulphate, which is most widely employed to harden the snow on the ski runs, the effects do not seem to be very serious on the protozoa. However, the lower metazoa need a few weeks to overcome the depression which is caused immediately after the fertilization.

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6. Zusammenfassung

Experimentelle Freilanduntersuchungen zur Wirkung von Mineraldüngern und Kalk auf die Mikrofauna eines Almweidebodens

Im ersten Experiment wurde 4 Monate nach der Anwendung der empfohlenen Maximalkonzentrationen von NPK (600 kg ha^{-1}), Thomasphosphat (600 kg ha^{-1}) und Kalk (4000 kg ha^{-1}) mittels randomisierter Blockanlage die Struktur der terrestrischen Testaceen-, Ciliaten- und Nematodenzönose einer Almweide untersucht. Der *p*H-Wert des Bodens nach Thomasphosphat- ($\bar{x} = 3{,}9$) und Kalkbehandlung ($\bar{x} = 4{,}9$) ist signifikant höher ($P < 0{,}05$) als in der Kontrolle ($\bar{x} = 3{,}7$). Testaceen: Die Unterschiede in der Artenzahl sind nicht signifikant. Nur *Schoenbornia humicola* und *Trinema enchelys* zeigen Behandlungseffekte ($P < 0{,}05$). Sie sind in den Thomasphosphatflächen häufiger als in der Kontrolle. Die mittleren Abundanzen und Biomassen sind ziemlich verschieden, aber nur Thomasphosphat erhöht die Biomasse signifikant ($P \sim 0{,}1$). Ciliaten: Die Dünger verursachen keine signifikanten Veränderungen in der Anzahl der aktiven Individuen (direkte Methode) und der Artenzahl (Kulturmethode). *Cyrtolophosis acuta* tritt nach der Kalkbehandlung häufiger auf als in der Kontrolle ($P < 0{,}1$). Durch Kalkung wird auch die Biomasse signifikant erhöht ($P < 0{,}05$). Nematoda: Die Abundanz wird durch Kalk ($P < 0{,}05$) und NPK ($P < 0{,}01$) signifikant verringert. Eine wahrscheinlich toxische Wirkung von NPK auf niedere Metazoen wird auch durch die niedrige mittlere Abundanz der Rotatorien indiziert.

In einem zweiten Experiment wurden 4 Flächen einer Almweide mit 0, 100, 400 und 1200 kg Ammoniumsulfat ha^{-1} behandelt. Dieser Dünger wird häufig zur chemischen Präparation von Ski-Pisten verwendet. Es treten keine bemerkenswerten Unterschiede in der Artenzahl und Abundanz der Testaceen auf. Durch eine erhöhte Dominanz von *Centropyxis aerophila var. sphagnicola* ist in der Fläche 1200 kg ha^{-1} die Biomasse um ca. 30% höher als in den anderen Flächen. Die qualitativen Veränderungen in der Ciliatenzönose sind gering und unabhängig von der Konzentration des Düngers. Die Abundanz der Nematoden ist einige Wochen nach der ersten Behandlung beträchtlich vermindert.

Die Untersuchungen zeigen, daß die Testaceen- und Ciliatenzönosen durch hohe Dünger- und Kalkkonzentrationen nicht ernstlich beeinträchtigt werden. Thomasphosphat, das auch im „biologischen Landbau" verwendet wird, erhöht die Biomasse der Testaceen signifikant, wogegen das

schnell verfügbare NPK, das saure Ammoniumsulfat und hohe Mengen von Kalk zumindest wenige Wochen nach der Anwendung die Abundanz der Nematoden reduzieren.

Schlüsselwörter: Protozoa, Testacea, Ciliata, Nematoda, Rotatoria, Kalk, Mineraldünger, Almweide, Ski-Piste.

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Berger, H., W. Foissner & H. Adam, 1986. Field experiments on the effects of fertilizers and lime on the soil microfauna of an alpine pasture. Pedobiologia **29**, 261—272.

In the first experiment the structure of the terrestrial testacean, ciliate, and nematode communities of an alpine pasture was studied by means of a randomized block design 4 months after the application of the recommended maximum concentrations of NPK (600 kg ha^{-1}), thomasphosphate (600 kg ha^{-1}), and lime (4,000 kg ha^{-1}). The *p*H value of the thomasphosphate ($\bar{x} = 3.9$) and lime treatment ($\bar{x} = 4.9$) is significantly higher ($P < 0.05$) than in the control ($\bar{x} = 3.7$). Testacea: The differences in the species number are insignificant. Only *Schoenbornia humicola* and *Trinema enchelys* show treatment effects ($P < 0.05$). They are more abundant in the thomasphosphate plots than in the control. The mean abundances and biomasses are rather different, but only thomasphosphate increases the biomass significantly ($P \sim 0.1$). Ciliates: The fertilizers cause no significant changes in the number of active individuals (direct method) and species number (culture method). *Cyrtolophosis acuta* is more abundant in the lime treatment than in the control ($P < 0.1$). Liming also increases the biomass significantly ($P < 0.05$). Nematoda: Their abundance is reduced significantly by lime ($P < 0.05$) and NPK ($P < 0.01$). A probably toxic effect of NPK to lower metazoa is also indicated by a low mean abundance of the rotatoria.

In a second experiment we treated 4 sites of an alpine pasture with 0, 100, 400, and 1,200 kg ammonium sulphate ha^{-1}, a fertilizer often used to conserve the snow on the ski runs. There are no conspicuous differences in the species number and abundance of the testacea. Due to an increased dominance of *Centropyxis aerophila var. sphagnicola*, the biomass is about 30% higher in the site 1,200 kg ha^{-1} than in the other plots. The qualitative changes in the ciliate community are inconspicuous and independent from the concentration of the fertilizer. The Nematoda show a considerable decrease a few weeks after the first application.

The results obtained indicate that the testacean and ciliate communities are not seriously affected by heavy doses of fertilizers and lime. Thomasphosphate, also allowed in "organic farming systems", increases the biomass of the testacea significantly, whereas the easily soluble NPK, the acid ammonium sulphate, and high amounts of lime reduce the number of the nematodes, at least a few weeks after the application.

Key words: Protozoa, Testacea, Ciliata, Nematoda, Rotatoria, lime, fertilizer, alpine pasture, ski run.