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HOW AGRICULTURE AFFECTS LICHEN VEGETATION IN CENTRAL SWITZERLAND

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Abstract: The results from several floristic and bioindication projects in Central Switzerland (1986–1998), focusing on the effects of agriculture, particularly from nitrogen and agrochemical emissions, are summarized. The abundance of nutrient-tolerant lichen species and the decreased occurrence of nitrophytic lichens are both correlated with agricultural land use and high atmospheric deposition. The impact could be demonstrated not only by the distribution patterns of nutrient-tolerant species, but also by the high N content of lichens such as *Physcia caesia*. Positive growth response of *Cetraria islandica* to application of mineral nutrients and increased CO_2 in open-top chambers at high altitudes was also observed. The methods and a survey of the results from studies conducted within the framework of the lichen research programme of the Natural History Museum of Lucerne are presented here. A discussion of the issues shows the need for further studies concerning the influence of introduced nutrients on the biodiversity of lichens.

Introduction

Studies conducted in Central Switzerland from 1986 to 1991 in agricultural and remote prealpine areas showed lichen distribution to be closely correlated with high nutrient emissions and with atmospheric deposition (Ruoss & Clerc 1987; Ruoss 1992; Ruoss *et al.* 1992). The question arose as to what extent agriculture affected lichen vegetation. Therefore additional projects by the Natural History Museum of Lucerne (NML) lichen research programme dealing with the impact of agriculture were carried out. The lichen mapping project in the canton of Lucerne included the characterization of landscapes in Central Switzerland and the monitoring of nitrogen emissions using lichens as indicators (Ruoss 1991, 1992; Müller *et al.* 1993). The nitrophytic lichen vegetation in rural areas is not only a result of high input of nutrients through farming, but also of considerable atmospheric nitrogen (N) deposition. In an additional study, the effects of atmospheric deposition upon bog vegetation including lichens and bryophytes were studied in the prealpine area (Dussex & Held 1990).

Comparative lichen mapping studies showed similar effects in other parts of Switzerland such as the Lake Zürich region (Vonarburg *et al.* 1990), the agglomeration of St. Gallen (Meile 1993) and the southern prealpine area in Tessin of southern Switzerland (Walter 1997). Microclimatic studies connected with the water balance of lichens showed that lichen colonization depends strongly on the interaction between microclimatic factors and

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immission (Vonarburg 1993). In alpine grasslands, the factors limiting growth are mainly nutrients, which play an important role in promoting or inhibiting growth (Ineichen 1994).

The air pollution programmes conducted by the Department of Environment of Lucerne (Amt für Umweltschutz 1993) and the Federal Office of Environment, Forests and Landscape (FOEFL 1996) show considerable N deposition in the study area. The aim of this paper is to summarize the different ways agriculture affects lichens, based on results and observations obtained from the various studies of the NML lichen research programme. Possible issues for follow-up studies and for using lichens in large-scale biomonitoring experiments are also discussed.

Survey of methods

The study area is situated in the northern and southern prealpine area, which includes the cantons Lucerne, Zug, Schwyz, Obwalden, Zürich, St. Gallen and Tessin. Below is a summary of the principal methods used. More specific methods are outlined in appropriate references.

Mapping studies

For the studies within the NML lichen research programme, comparable mapping methods were used. The epiphytic lichen flora on the following isolated deciduous trees were studied: *Quercus robur*, *Fraxinus excelsior*, *Juglans regia*, *Tilia cordata*, *T. platyphyllos*, *Aesculus hippocastanum*, and *Acer pseudoplatanus*. Plots ranging from one to two metres in height were registered in the following locations: canton Lucerne 368 plots (Ruoss 1992) and 323 plots (Graf 1998), Lake Zürich 131 plots (Vonarburg *et al.* 1990), canton Tessin 211 plots (Walter 1997), canton St. Gallen 160 plots (Meile 1993). Frequency of individual lichen species, total cover and species number were calculated. The phytosociological methods of Braun-Blanquet (1928) and Wirth (1972) were used, with indication values (especially N-values) being interpreted according to Wirth (1991). The influence of nutrients is defined by the N-value, which is taken to represent different amounts of mineral supply, using the presence or absence of appropriate lichen species on a scale of 1–9. Nomenclature follows Wirth (1995).

A lichen diversity index ($LI=c \times \frac{s}{100}$; c=total cover, 0–100%; s=species number, range 1–34) was calculated to describe quantitatively the diversity and abundance of lichens and the natural potential of habitats. In order to observe changes in lichen diversity, the optimum and the range of LI for lichen colonization from different regional types had to be defined (Fig. 1). Actual colonization of lichens on trees in an area could then be compared to this ' hypothetical ' optimum of region types.

Measurements of atmospheric deposition

In the study from 1988–1989 the atmospheric N deposition in the prealpine area was measured in four bogs and correlated with studies of vegetation in 13 bogs (Dussex & Held 1990). Ninety permanent plots (1 m^2) were established in bogs for the purpose of follow-up studies. Field methods included measurements with passive NO_2 collectors and precipitation collection with bulk samplers. Laboratory analyses included: acidity by pH electrode, ammonium by flow injection analysis, cations by atomic absorption spectrophotometry, and anions by ion chromatography.

Nitrogen content of lichens

The lichens on a barn roof were studied in 1988 near Lucerne in an area subject to intensive agriculture. Unwashed samples of *Physcia caesia* from the barn roof and from control sites were analysed for their nitrogen content by the method of Kjeldahl (Ugrinosits 1980) and the nitrate content with high pressure liquid chromatography (HPLC).

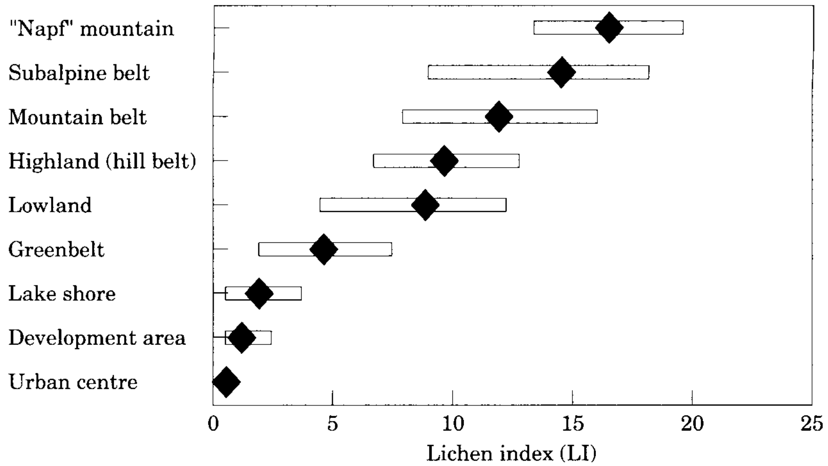

FIG. 1. Lichen index (average and standard deviation) of different landscapes in the canton of Lucerne. Intensive agriculture is located in lowland/greenbelt regions. ◆ = Average LI; $n = 368$.

Growth response of alpine lichens

The growth response of *Cetraria islandica* and *Stereocaulon alpinum* exposed to controlled concentrations of carbon dioxide ([CO_2]) in open-top chambers (OTCs) was studied between July 1992 and September 1994. Located in alpine grasslands dominated by *Carex curvula*, the field station with a total of 48 plots in the Swiss Central Alps at Bidmeren at an altitude of 2470 m was part of a larger ecosystem study (Körner *et al.* 1997). The plots were assigned to three treatments (16 plots per treatment): OTCs with doubled [CO_2] ($\pm$ 680 ppm), OTCs with ambient [CO_2] and an unenclosed control group. To simulate the effect of lowland nitrogen deposition rate, 12 plots were treated with mineral nutrients. Growth measurements included four lichen samples per plot weighed before and after exposure during the study period.

Synopsis of Results

Mapping as a tool to study the effects of agriculture upon lichens

The average lichen index (LI, Fig. 1) on the Swiss Plateau (altitude 450–900 m) clearly decreased from regions with less disturbed landscapes (LI: 8·4–12·4) to regions with intensive agriculture (LI: 4·3–8·6) and to urban areas (LI: 0·4–4·8). In mountain and subalpine areas in the Prealps (900–1600 m), the average LI decreased from less intensively cultivated regions (LI: 13·9–20·5) to regions with year-round stock farming (LI: 9·3–11·0). The number of lichen species increased from agricultural areas (total 84 epiphytic species) to mountain areas (140 species): from 15–19 species to 20–27 species per tree, respectively. On the Swiss Plateau, 70% of the lichens common to this area (minimum 10% of trees) were nitrophytic species (*Xanthoria*, *Physcia*, *Phaeophyscia*), whereas the remaining 30% were anitrophytic. ‘ Sensitive ’ lichens were absent (e.g. *Usnea*, *Bryoria*, *Anaptychia*, *Parmelia*). In the prealpine area both anitrophytic and nitrophytic lichens were equally prevalent (50% each). The gradient also correlated with climatic changes and increasing altitude.

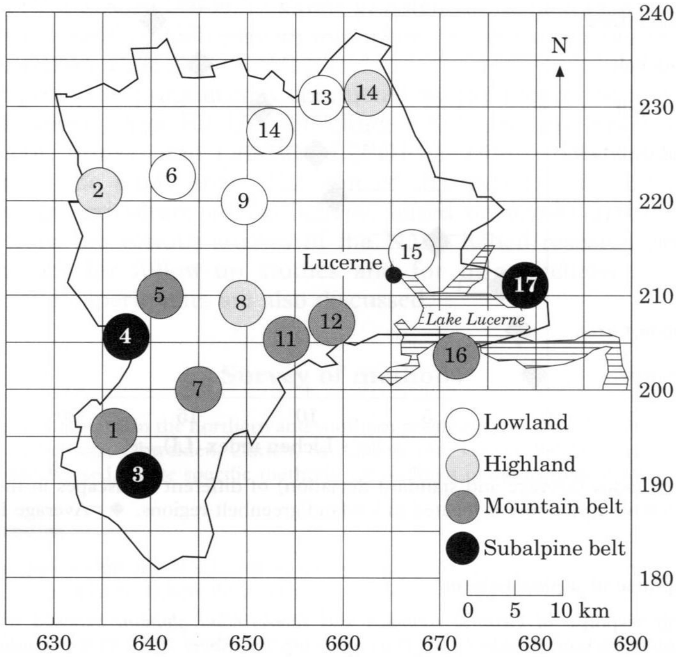

FIG. 2. Mean N-values of lichens from different regions with changing intensity of agriculture in the canton of Lucerne (see Table 1).

A high occurrence of nitrophytic lichens corresponded with the intensity of farming. In the city of Lucerne the lichen diversity in greenbelt areas with intensive agriculture (average: LI=4·3) was higher than in residential areas (LI=0·4). Eutrophication, connected with ecological factors, was conducive to lichen colonization. The rich lichen flora of mountain areas contrasted considerably with the flora of agricultural areas, where few species with abundant cover (*Physcia adscendens*, *Xanthoria candelaria*, *X. fallax* group) exist and are thought to be influenced by eutrophication.

Based on the N-values, a gradient from nitrophytes in regions with different intensity of land usage could be shown (Fig. 2, Table 1). High mean N-values (>4·0) could be observed in both lowland and highland areas. Scattered high mean N-values existed in mountain belt areas where intensive summer pasturing occurred. Low values were well correlated with the presence of anitrophytic lichens in the subalpine belt and the remaining mountain belt (Fig. 3).

Lichen data involving the tree species *Juglans regia* had to be excluded from the studies in Central Switzerland. The results from *Juglans* did not correlate with those from other tree species considered (Ruoss & Keller 1988). This tree was planted mainly near farms and had lichen cover that was relatively homogeneous and consisted of nitrophytic species. *Candelariella xanthostigma*, *Parmelia tiliacea*, *Physcia adscendens*, *Phaeophyscia orbicularis* and *Xanthoria parietina* dominated with frequencies >80% (n=16).

TABLE 1. *Mean N-value and altitude of different regions in the canton of Lucerne*

Region		n*	Mean N-value	Altitude
1	Escholzmatt	13	4·50	1066
2	Zell	19	4·18	669
3	Hilferen	8	3·94	1246
4	Napf	5	4·02	1349
5	Menzberg	8	4·04	1056
6	Schötz	9	4·21	557
7	Schüpfheim	8	4·11	1056
8	Werthenstein	8	4·27	908
9	Nottwil	9	4·43	636
10	Sursee	22	4·42	596
11	Schwarzenberg	15	4·32	1016
12	Eigental	8	3·96	1004
13	Menziken	7	4·17	545
14	Müswangen	7	4·40	771
15	Rotsee	5	4·78	446
16	Bürgenstock	15	4·07	987
17	Rigi	33	3·80	1330

*n=number of plots per region.

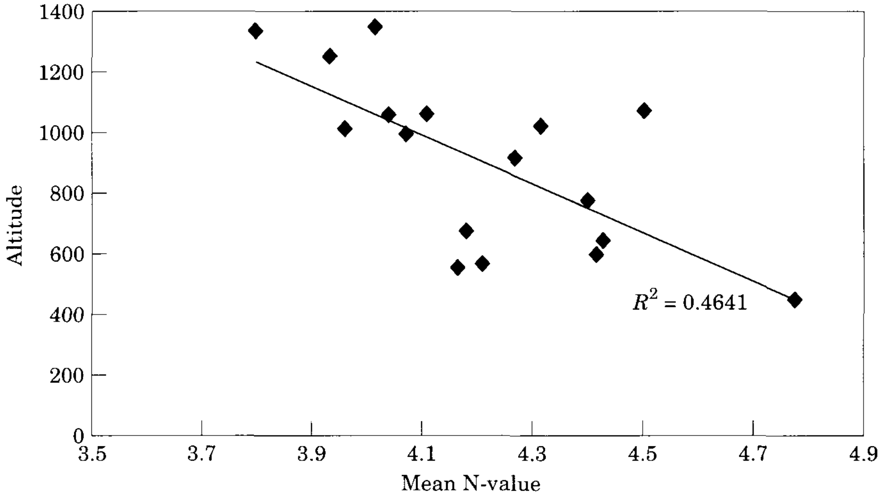

FIG. 3. Mean N-values of the different regions correlated with altitude.

In canton Tessin in southern Switzerland, *Juglans* was widespread in the investigation area and showed a marked difference in lichen colonization to the northern prealpine *Juglans*. Here it was covered with a more heterogeneous lichen flora indicating a mineral-rich substratum (Walter 1997). In addition to species prevalent in the northern prealpine region, species likewise dominating were *Candelaria concolor*, *Lecanora allophana*, *L. chlarotera*, *X. fallax* group,

TABLE 2. *Mean N-values and lichen indices of different species*

Tree species	n*	Lichen index	Mean N-value
Populus italica & *P. tremula*	9	5·63	4·95
Juglans regia	18	8·34	4·70
Fraxinus excelsior	52	9·70	4·38
Aesculus hippocastanum	114	1·50	4·34
Quercus robur	29	9·10	4·17
Acer pseudoplatanus	93	12·77	4·03
Tilia cordata & *T. platyphyllos*	55	7·20	3·86
Betula pendula	7	7·56	3·67
Fagus sylvatica	7	5·74	3·44
Picea abies	7	5·43	2·38
Abies alba	7	7·76	2·29

*n=number of plots.

Physconia distorta, *Parmelia exasperatula*, *P. subrudecta* and *Physcia aipolia*. The results were comparable to those of other tree species considered, with the LI ranging from 0·02 (town centre of Chiasso, 230 m a.s.l.) to 20·7 (Monte San Giorgio, 1110 m a.s.l.). The LI values on *Juglans* in rural areas in southern Switzerland (LI: 4·5–7) corresponded to those in rural areas of the northern Prealps. *Juglans regia* was therefore regarded as a suitable tree for lichen bioindication in southern Switzerland.

With regard to the mean N-values of the lichens from each tree species, a clear difference between trees with anitrophytic species (i.e. *Picea abies* or *Abies alba*) and those with lichens showing a high mean N-value (i.e. *Populus* species and *J. regia*) could be seen (Table 2).

Locally, the effects of eutrophication and pH changes could be observed along the city of Lucerne's narrow roads, railways and trails (dog walks). There, *Xanthoria parietina* and even *Parmelia acetabulum* grew well (Fig. 4—bottom; tree nos 180–210), whereas other common lichen species were absent. Similar observations were made in other regions (Vonarburg *et al.* 1990). Well-developed *X. parietina* could also be found near Allmend (Fig. 4—top; tree nos 80–100), an area known for its sportsfields, where intense fertilization occurs.

Effects of nitrogen deposition upon bog vegetation

Measurements in the Mt. Rigi area showed a high deposition rate of ammonium with rain following periods of dry weather (Ruoss *et al.* 1992). Instead of acidification, neutralization of precipitation on Mt. Rigi was observed (pH of rain>5). Annual averages of pH in the prealpine area were 4·8–5·0. The ' high ' pH was interpreted as neutralization by high ammonium concentration derived from NH_3 emitted by the intensive agriculture in this region, an area of 5000 km^2 with 440 000 pigs (22·7% Swiss stock) and 170 000 cattle (9·2% Swiss stock) in 1993.

Wet N depositions of 11·6 kg ha^{-1} $year^{-1}$ in remote prealpine areas and 17·8 kg ha^{-1} $year^{-1}$ in lowland areas were regarded as only a fraction of the total N input of 30 to 60 kg ha^{-1} $year^{-1}$. Between 65% and 83% of the total

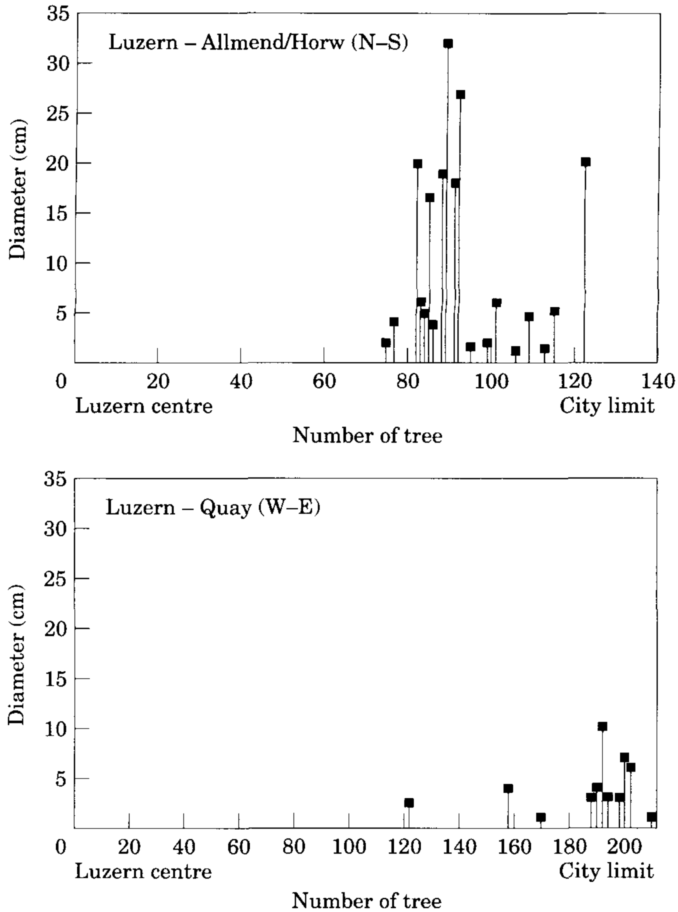

FIG. 4. Diameter of *Xanthoria parietina* colonies on *Aesculus hippocastanum* along two gradients from the centre of Lucerne to the city limit. The occurrence of well-developed *Xanthoria* is connected with high nutrient input. Each tree was assigned an identification number.

annual N deposition occurred during the growing season (Table 3). Other ions such as chloride, calcium, magnesium, sodium, potassium and phosphate occurred in trace amounts. The ratio of ammonium to nitrate (2:1) was considered important for bog vegetation, especially for *Sphagnum*. Between 1974 and 1989 the vegetation cover within a permanent plot in a bog changed considerably: *Sphagnum* species decreased from 70 to 10%, bryophytes increased from 10 to 75%, shrubs increased from 15 to 45%. Lichens were not competitive in the prealpine bogs, and therefore they became rare in the study area.

A 1994 follow-up study verified the impact of cultivation upon bogs (Bründler Rodriguez 1997). Left alone, primary bogs showed stability in plant cover. Major changes were observable only in the cultivated secondary areas.

TABLE 3. *Nitrogen wet deposition (kg ha^{-1} year^{-1}) during growing season, NO_2 calculated from average NO_2 concentration and average deposition velocity for grassland (0·5 cm s^{-1}), according to Dussex & Held (1990)*

Locality*	Altitude	NO_3-N	NH_4-N	NO_2-N	Total N	Total N per growing season	
Salwideli	1370 m	4·2	7·4	0·2	11·8	9·8	83%
Tällenmoos	850 m	4·7	7·7	0·4	12·8	8·3	65%
Lucerne town	435 m	6·5	10·0	3·2	19·7	14·6	69%
Eigenried	990 m	6·8	11·0	–	17·8	12·2	74%
Breitried	890 m	6·5	10·9	0·4	17·8	13·1	74%

*Salwideli and Tällenmoos: moorlands *c.* 40 km west of Lucerne; Eigenried and Breitried: moorlands *c.* 50 km south-east of Lucerne.

Lichen monitoring of nitrogen emissions

On a barn roof, near intensive emission of ammonia, a dense vegetation with the following nutrient-tolerant lichen species could be observed: *Candelaria concolor*, *Lecanora muralis*, *Physcia caesia*, *Phaeophyscia sciastra*, *P. orbicularis*, *X. parietina*. Samples of *Physcia caesia* contained 89–119 mg kg^{-1} nitrate and 4·2–4·4% total N; control samples 41–48 mg kg^{-1} nitrate and 1·7–1·8% total N (Ruoss *et al.* 1992). Lichens near emission sources seemed to have a higher nitrogen and nitrate uptake. *Physcia caesia* was considered a widespread and N-tolerant monitor in the study area.

Effects of agrochemicals on lichens

The effects of agrochemicals upon lichens on fruit trees was the subject of two studies. The mapping study in St. Gallen showed no influence of agrochemicals on the lichen flora on pear (n=120) and apple trees (n=40). Apparently less chemical was used in this region. Differences between apple and pear trees (higher species number and more nitrophytic species on pear trees) seem to correlate with the surface texture of the substratum, since the bark pH of both trees do not differ (Meile 1993). Äberhardt (1985) compared the lichen cover and frequency of apple trees treated regularly with Oleo-Diazinon insecticide with trees untreated for 40 years (Fig. 5). Observations showed better vitality of lichens and higher species number on untreated trees. From a total of 12 species, *Parmelia flaventior* and *Pseudevernia furfuracea* were not found on treated trees. However these are preliminary observations and further detailed studies are required.

Growth response of lichens in alpine grasslands to treatment with mineral nutrients

The growth response of *Cetraria islandica* and *Stereocaulon alpinum* exposed in 32 OTCs in the Swiss Central Alps was independent of CO_2 treatment. *Cetraria islandica* showed almost no growth and *S. alpinum* even regressed during a single vegetation period in the OTC. In freeland control plots, on the other hand, both species showed considerable growth within the same period. With regard to the poikilohydric structure of lichens, the responses observed

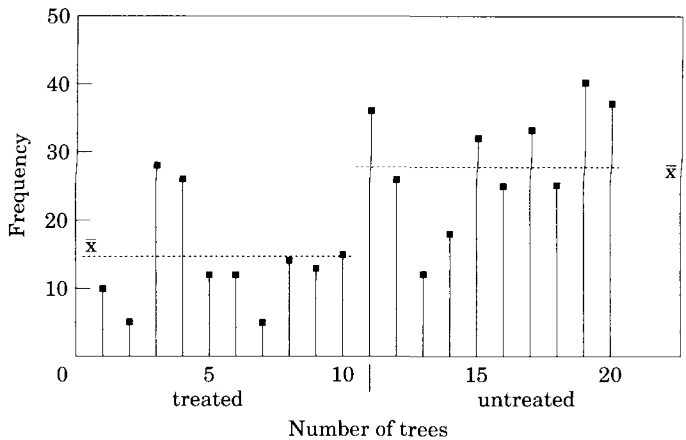

FIG. 5. Summation of frequency of lichens occurring on apple trees with and without insecticide treatment (according to Äberhardt 1985).

might be more closely tied to microclimatic factors (i.e. air flow, humidity) rather than to elevated [CO_2] (Ineichen 1994). In OTCs treated with mineral nutrients, the samples of *C. islandica* in plots with double [CO_2] increased in weight (+0·75% p.a.) whereas *S. alpinum* showed a decrease (− 0·72% p.a.). In control OTCs *C. islandica* was nearly stable (+0·3% p.a.) and *S. alpinum* decreased (− 0·88% p.a.). *Cetraria islandica*, with the green alga *Trebouxia* as its photobiont, is more dependent on mineral nutrients than *S. alpinum*, which contains the cyanobacterium *Nostoc* along with *Trebouxia* (Ruoss & Ineichen, unpublished data). The presence of cyanobacteria seems to reduce the impact of fertilizers and increased CO_2.

Discussion

The results from the projects conducted within the NML lichen research programme show the need for further study on the effects of agriculture on lichens. Results and further observations showed the considerable influence of nutrients upon the lichen vegetation in lowland and mountain regions. The effects can occur by direct application of nutrients, as with farming, or indirectly through atmospheric depositions, especially near emission sources. They result in the following effects on lichens: changes in composition of lichen cover, species distribution patterns and pattern of colonization, damage, and increased uptake of nitrogen. Very little is known about the influence of such agrochemicals as herbicides and insecticides upon lichens.

Terricolous lichens are very sensitive to agricultural impacts such as grazing, trampling, traffic, and fertilization. They have therefore become rare in the rural areas of Central Switzerland (Ruoss & Clerc 1987; Dussex & Held 1990). The idea of using terricolous lichens (e.g. species of *Cladonia*, *Cetraria islandica*) in prealpine bogs as biomonitors could not be realized, although this seems to be possible in boreal areas such as Scotland, Scandinavia and the high Alps. The effects of nitrogen immissions on bog vegetation seem to be considerable. Studies in the prealpine areas of Bavaria showed comparable results (Melzer *et al.* 1992; Pohl 1991). Connected with the restoration of bogs and the extension of grazing and farming in prealpine and mountain areas, the re-establishment of former lichen-rich stands could be of general interest in monitoring studies. Mineral nutrients seem to be the limiting factor in alpine ecosystems. Additional field studies in undisturbed alpine ecosystems could give more information on the response of lichens to nutrients under natural conditions. This would become important information for studies on the effects of agriculture on terricolous lichens.

A correlation between N deposition and the total N content of lichens near emission sources was shown by analyses of *Physcia caesia*. Significant correlations between wet deposition of ammonia and the total N content of exposed *Hypogymnia physodes* were demonstrated in studies conducted by Metzger (1993).

In the area of Canton Lucerne, the N deposition showed a significant correlation with the intensity of agriculture (Amt für Umweltschutz 1993). Both N deposition rates and the N load in Switzerland were calculated by the Federal Office of Environment, Forests and Landscape (FOEFL). The N loads calculated from 1993–1995 were: for deciduous forest 43·3 kg ha^{-1} $year^{-1}$, species-rich grassland 29·3 kg ha^{-1} $year^{-1}$, alpine grassland 18 kg ha^{-1} $year^{-1}$. The exceedance of critical load of N was 26 kg ha^{-1} $year^{-1}$ in deciduous forests, 4·3 kg ha^{-1} $year^{-1}$ for species-rich grassland and 8·0 kg ha^{-1} $year^{-1}$ for alpine grasslands. Nitrogen deposition was considered to be homogeneous over a large area of the Swiss Plateau, especially in the study area of the Canton Lucerne. Large-scale lichen monitoring studies with regard to agricultural effects would show the feasibility of using nitrophytic lichens as bioindicators of atmospheric nitrogen deposition. So far, preliminary results have shown how difficult it is to interpret the indication values of lichens and to correlate them with emission calculations, immission measurements and ecological factors. The interactive balance between decreasing acid pollutants and increasing N deposition along with ecological factors is very sensitive. Thus the re-establishment of lichens and the direction of such is unpredictable and difficult to explain.

The projects were conducted in association with the Department of Environment of Lucerne, the Botanical Institutes of the University of Bern, the Geographical Institute of the University of Zürich and the canton laboratory. The following collaborators contributed results to this paper: Andreas Burri, Andreas Graf, Nicola Dussex, Thomas Held, Ruth Ineichen, Christine Keller, Patrick Meile, Evelin Pfeifer, Corinna Walter. I am very grateful to Elizabeth Gosselin who patiently corrected the English.

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