Nitrogen fixation by blue-green algae on the Island of Surtsey, Iceland

By
ELISABET HENRIKSSON, LARS ERIC HENRIKSSON, and BIRGER PEJLER
Institute of Physiological Botany and Zoological Institute, Uppsala University, Sweden

The colonization of blue-green algae on the new volcanic island Surtsey/Iceland has been studied by Schwabe (1970 a, 1971, Behre & Schwabe 1970). He started his investigation in July 1968, only one year after the violent eruptions which formed the island, had ceased. Already at that time different types of algae were detected, growing in association with each other and with a moss, *Funaria hygrometrica* Hedw.

Among the algae recorded the first summer (1968) only one, *Anabaena variabilis* Kütz., had the potential ability of fixing molecular nitrogen. Next summer (1969), at least three *Nostoc* species with the same ability were detected as well. In these algae the vegetative cells very easily are converted to spores (akinetes). Thus, when conditions are unfavourable for growth, the algae are able to survive for long periods as spores. On Surtsey the spores are very easily transported by wind together with dry ash over wide areas. The original volcanic ash and lava are very unfavourable for growth and nitrogen fixation by blue-green algae on account of the incapability of these substrates to hold water and their high concentration of heavy metals and salt (Schwabe 1970 a, 1970 b, 1971). For that reason experiments have been carried out in order to measure the capacity of the nitrogen fixation in samples collected at different localities on Surtsey, and to find out to which extent nitrogen fixation by blue-green algae occurs in the early phase of the colonization of this island.

The samples studied in this investigation were collected on August 5–9, 1970, at localities where mosses and other lower plants already had developed to a visible layer on the surface of the juvenile soil. For the sake of comparison a few samples from Geysir, in the south-west part of Iceland, have been studied as well.

METHODS AND CULTURAL CONDITIONS

About 1 gram of each sample was put in a small bottle (7 ml volume and 1.4 cm^2 bottom area). 1 ml redistilled water was added to each bottle, and the bottles were fitted with rubber stoppers and kept in a chamber with controlled conditions, 20°C and about 3.000 Lux, during a period of 66 days (Aug. 17 – Oct. 23, 1970). At different times of the period (Aug. 21, Aug. 26, Sept. 16, Oct. 14, Oct. 16 and Oct. 23) the capacity of the nitrogen fixation was measured by using the acetylene-reduction technique (Stewart *et al.* 1967, 1968). Contrary to the original method, the samples in this study were not preserved after the experimental periods. Therefore, the same sample could be used several times. After the analyses had been performed the bottles were aired in 20 minutes to be rid of the unnatural gases, before the incubation continued (Henriksson *et al.* 1972). For practical reasons the period of treatment with acetylene usually exceeded one hour, which may have resulted in the occurrence of unhealthy algal cells, deficient in nitrogen, in our experiments (cf. Stewart 1968).

In order to determine the extent of the heterotrophic nitrogen fixation the reduction of acetylene on Oct. 16 was made in dark and on this occasion the samples had been adapted to dark conditions since the preceding analyses, on Oct. 14.

The determination of the algae involved was made by cultivating small parts of the samples in the following medium, recommended by the IBP project coordinate: A. S. M. Medium (after Gorham *et al.* 1964, modified) K_2HPO_4 17.4 mg, $FeCl_3$ 0.3 mg, E.D.T.A. 7.4 mg, $MgCl_2.6H_2O$ 19.0 mg, $MgSO_4.7H_2O$ 49.0 mg, $CaCl_2.2H_2O$ 14.7 mg, NaCl 58.5 mg, and redistilled water 1.000 ml. Trace elements (after Clendenning *et al.* 1956) $Na_2MoO_4.2H_2O$ 5.0 mg, $CoCl_2.6H_2O$ 0.8 mg, $ZnSO_4.10H_2O$ 0.9 mg, $MnCl_2.4\ H_2O$ 7.2 mg per litre medium.

The identification of the nitrogen fixing algae was made according to Geitler (1932).

RESULTS AND DISCUSSION

The results concerning nitrogen fixation in juvenile soils of Surtsey are shown in Table 1. According to the results received, algae are in fact fixing molecular nitrogen at this early phase of colonization. However, in five of the localities studied (S 21, 22, 23, 24, 20) the capacity of the nitrogen fixation seems to be very low, and in the other localities (S 7, 27, 18, 8, 14) the nitrogen fixation is rather low compared to that occurring at Geysir. If the eventual enfeeblement of the algal cells which may be caused by the long treatment with acetylene, is left out of account (see Methods and Cultural Conditions), the conditions involved in our experiments may on the whole be better than those usually occurring on Surtsey. Therefore, it may be concluded that the nitrogen fixation of the algal pioneers probably occurs at a rather low level. In spite of this, the nitrogen fixed may be of great importance for the following immigration of plants and animals.

The table also shows that nitrogen fixation occurs in dark, possibly caused by bacteria. However, there are also possibilities that the algae, in spite of being kept in dark during such a long time as two days before the acetylene treatment was made (see Methods and Cultural Conditions), still had the ability of fixing nitrogen in dark on account of their utilization of stored photosynthetic products.

The extent of the algal nitrogen fixation occurring in soils in other parts of the northern temperate zone is surveyed and discussed by Henriksson (1971).

Table 2 shows the algae involved in the analyses and a short description of the localities studied. It is evident that only the presence of potential nitrogen fixing algae in a sample cannot give the whole picture concerning the extent of nitrogen fixation, since the qualifications of the substrate is of decisive importance.

ABSTRACT

Blue-green algae occurring as pioneers on Surtsey/Iceland, are shown to fix nitrogen in the juvenile soil of volcanic origin of this island.

ACKNOWLEDGEMENT

This work is part of an IBP-project on the distribution and ecological importance of nitrogen-fixing blue-green algae and was supported by the Swedish Natural Research Council.

Table 1.

Values of the analyses on the capacity of the acetylene-reduction in different soil samples, collected on Surtsey (S) and at Geysir (G). The extent of the nitrogen fixation is calculated by using the theoretical 3:1 ratio for C_2H_2 reduced: N_2 fixed.

Only the highest value received during the incubation time in light is here presented (see Methods and Cultural Conditions). The figures in parenthesis mean the number of parallels. Each sample weighed about 1 gram and had an area of about 1.4 cm^2.

Table 1.

Sample	nmoles C_2H_4/sample/hr		ng N_2 fixed/sample/hr	
	In light	In dark	In light	In dark
S 21	0.2 (1)	0 (1)	2	0
S 22	0.2 (1)	0 (1)	2	0
S 24	0.2 (1)	0 (1)	2	0
S 20	0.4 ± 0.0 (4)	0 (4)	4	0
S 7	0.9 ± 0.6 (2)	0.4 ± 0.2 (2)	8	4
S 27	1.0 ± 0.0 (4)	0.4 ± 0.0 (4)	9	4
S 18	3.2 ± 0.9 (2)	0.4 ± 0.1 (2)	30	4
S 8	3.5 ± 0.4 (2)	0.3 ± 0.1 (2)	33	3
S 14	5.8 ± 1.0 (5)	1.0 ± 0.6 (4)	54	9
G 2	14.3 ± 9.0 (3)	0.5 ± 0.2 (2)	133	4
G 1	16.3 ± 5.7 (2)	3.2 (1)	152	30
G 3	57.9 ± 7.0 (4)	6.0 ± 2.2 (4)	540	56

Table 2.

Short description of the localities studied on Surtsey (S) and at Geysir (G). The localities S 14 and S 18 on Surtsey are situated in the lava fields, all other Surtsey localities in the ashy areas in connection with steam vents where condensation of water occurs (cf. Schwabe 1970 b). The potential nitrogen fixing algae (cf. Stewart 1966) cultivated from each sample are also recorded. They were identified according to Geitler (1932).

Table 2.

Sample	Description of the locations	Occurrence of potential nitrogen fixing algae
S 21	Sparsely moss-covered, rather moist, solid substrate.	—
S 22	Visible blue-green algae. Moist, solid substrate.	*Nostoc muscorum* Ag.
S 24	Densely moss-covered, moist, solid substrate.	*N. muscorum*
S 20	Densely moss-covered, very moist, solid substrate.	—
S 7	Densely moss-covered, moist, solid substrate.	*N. muscorum*
S 27	Densely moss-covered, moist, solid substrate.	*Anabaena variabilis* Kütz., *N. muscorum*
S 18	Densely moss-covered substrate. Shadowy.	*A. variabilis*
S 8	Dried puddle. Superficial soil layer down to a depth of about 2 mm.	*A. variabilis*
S 14	Densely moss-covered substrate. Near the shore. Birds were common.	*Nodularia Harveyana* Thur., *N. muscorum*, *Tolypothrix* sp.
G 2	Visible blue-green algae. Moist soil.	*A. variabilis*
G 1	Visible blue-green algae. Moist soil.	*A. variabilis*
G 3	Visible blue-green algae. Moist soil.	*A. variabilis*

References:

Behre, K. & Schwabe, G. H., 1970: Auf Surtsey/Island im Sommer 1968 nachgewiesene nicht marine Algen. — Schr. Naturw. Ver. Schlesw-Holst. Sonderband: 31—100.

Clendenning, K. A., Brown, T. E. & Eyster, H. C., 1956: Comparative studies of photosynthesis in *Nostoc muscorum* and *Chlorella pyrenoidosa*. — Canad. J. Bot. 34:943-966.

Geitler, L., 1932: Cyanophyceae von Europa unter Berücksichtigung der anderen Kontinente. — Rabenhorsts Kryptogamenflora 14.

Gorham, P. R., MacLachlan, R., Hammer, U., & Kim, W. D., 1964: Isolation and culture of toxic strains of *Anabaena flos-aquae* (Lyngb.) de Bréb. — Verh. int. Ver. Limnol. 15:796—803.

Henriksson, E., 1971: Algal nitrogen fixation in temperate regions. — Plant and Soil, Special Volume. In press.

Henriksson, L. E., Enckell, P. H., & Henriksson, E., 1972: Determinations of nitrogen fixing capacity of algae in different soils. — Oikos 23.

Schwabe, G. H., 1970 a: Blaualgen und Vorstufen der Bodenbildung auf vulkanischem Substrat (bisherige Befunde auf Surtsey/Island). — Mitt. Dtsch. Bodenkundl. Ges. 10:198-199.

— 1970 b: Zur Ökogenese auf Surtsey. — Schr. Naturw. Ver. Schlesw.-Holst. Sonderband: 101—120.

— 1971: Blue-green algae as pioneers on postvolcanic substrate (Surtsey/Iceland). — Proc. 1st Int. Symp. Taxonomy and Biology of blue-green algae. Madras 1970. In press.

Stewart, W. D. P., 1966: Nitrogen fixation in Plants. — The Athlone Press, London.

— 1968: Nitrogen input into aquatic ecosystems. — In: Algae; Man, and the Environment. Ed. D. F. Jackson. Syracuse, New York.

Stewart, W. D. P., Fitzgerald, G. P., & Burris, R. H., 1967: *In situ* studies on N_2 fixation using the acetylene reduction technique. — Proc. nat. Acad. Sci. Wash. 58:2071—2078.

— 1968: Acetylene-reduction by nitrogen-fixing blue-green algae. — Arch. Microbiol. 62:336—348.