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Effects of nitrogen, phosphorus, and potassium to Surtsey lava soils on the growth of a test plant (*Avena sativa* L.)

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ABSTRACT: The nitrogen deficiency in Surtsey soils for the development of higher plants was demonstrated employing a semisized culture method under laboratory controlled conditions using *Avena sativa* L. as the test organism. Addition of nitrogen as nitrate stimulated growth but higher stimulation resulted from addition of nitrate and potassium together. The results suggest that the nitrogen deficiency is made more pronounced by a simultaneous deficiency of K^+ together with an unfavourable Na^+: K^+ ratio.

In soil analyses made from Surtsey 1965, PONNAMANPERUNA *et al.* (1967) reported no or very low contents of NH_4^+-nitrogen, NO_3^--nitrogen, and Kjeldahl-nitrogen in the virgin soil of the island. In 1972 slightly higher values were recorded and it was suggested that the deficiency of available nitrogen for the growth of vascular plants might be the major limiting factor in the actual ecosystems on the island (HENRIKSSON and HENRIKSSON, 1974). Photoautotrophic nitrogen fixing blue-green algae are generally present on Surtsey (SCHWABE, 1971, SCHWABE and BEHRE, 1972) and their nitrogen fixation in the Surtsey soil has been verified by *in situ* experiments (HENRIKSSON and HENRIKSSON, 1974). This algal activity undoubtedly favours the immigration and development of mosses and lichens found on the island. The mosses colonizing Surtsey are very closely associated to blue-green algae (SCHWABE, 1974) and it has been shown by culture experiments that nitrogen fixing blue-green algae stimulate the growth of the moss *Funaria hygrometrica* Hedw. in Surtsey soil (RODGERS and HENRIKSSON, 1976).

FRIÐRIKSSON (1975) studied different types of soils in respect to the colonization of higher plants on the island. He placed containers of Surtsey soil outside Reykjavík for a three years period. When the experiments were finished, however none of the ten different species of vascular plants found in the containers had yet been registered on Surtsey.

The present study is an introductory investigation of how phanerogams react to the deficiency of available nitrogen in the Surtsey soil under controlled laboratory conditions, and how the plants react to additions to the soil of nitrate, potassium, and phosphate, alone and in combinations.

MATERIAL AND METHODS

The soils tested were collected on Surtsey on July 9, 1972. Two types of soil were chosen, lava sand (No. 14/1972) and tephra (No. 18A/1972). The collection localities are plotted on the map in HENRIKSSON and HENRIKSSON (1974), and the chemical soil analyses are recorded in the same paper. Some of them are quoted in table 1. At site No. 18A/1972, nitrogen fixation *in situ* was recorded ($0.4 \pm 0.2\ \mu g$ N fixed $cm^{-2}h^{-1}$). In order to eliminate unwanted effects of microorganisms in the experiments, especially those by nitrogen fixers, the soil samples were heated at 110°C for two hours.

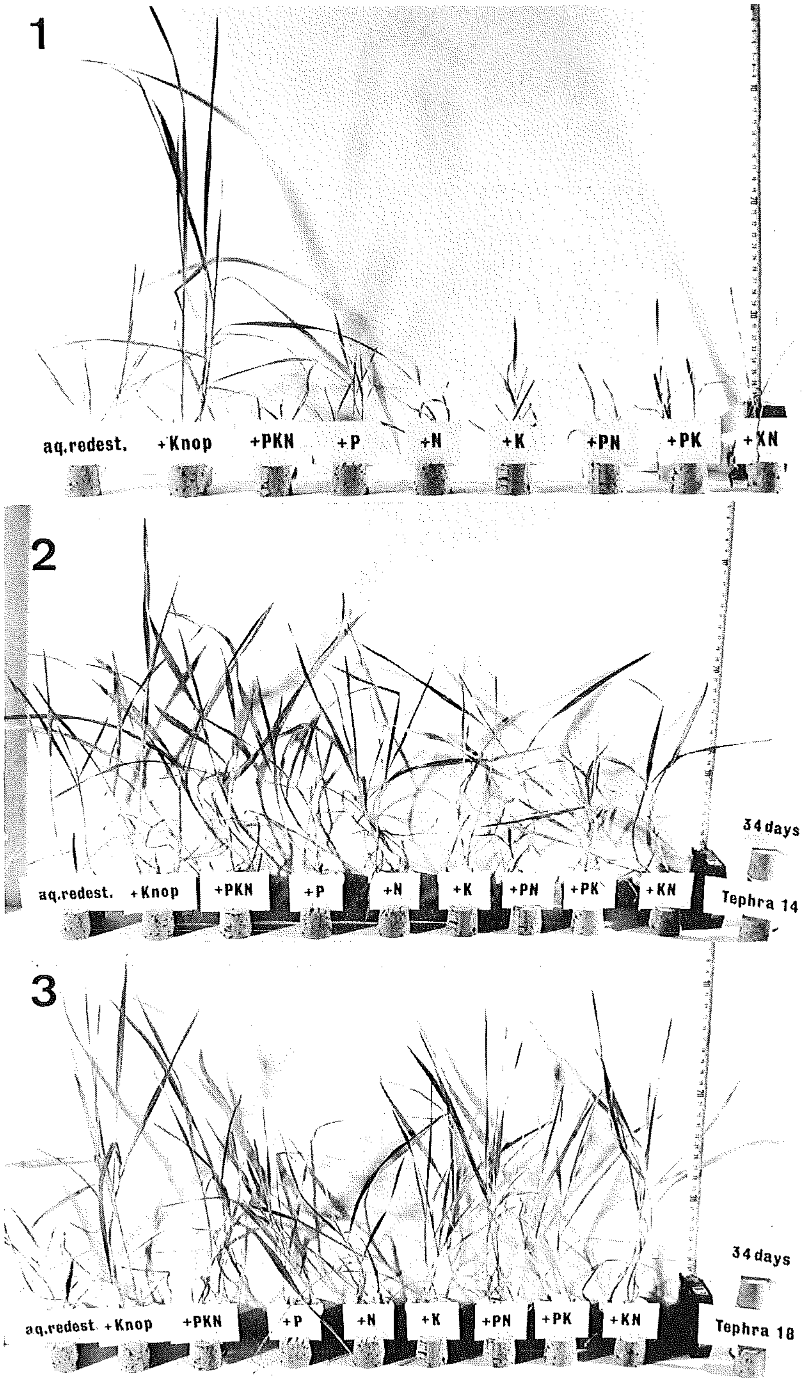
In 1972 it was not possible to collect on Surtsey enough seeds for experimental work. Consequently, *Avena sativa* L. cultivar Sun II (The General Swedish Seed Company Ltd., Svalöf, Sweden) was choosen as the test material for this investigation. This well known oat variety is famous for its clear out reaction to a variety of mineral deficiencies and has therefore been recommended for experimental work where mineral deficiencies are involved.

The *Avena* seeds were immersed in 70% ethyl alcohol for 10 min. followed by immersion in sterile water for four hours at room temperature. They were then placed under sterile conditions on wet filterpaper in petridishes for 48 hours at 25°C in the dark to germinate before planting in the experimental boxes. In the actual growth experiments, however, it was not possible to maintain totally aseptical conditions.

A small amount of soil (25 g) or distilled water (10 ml), in addition to 30 ml of either modified Knop's solution or a partial nutrient solution was placed in each of 81 plastic containers (40 ml total volume, Cerbo, Sweden) fitted with snap on covers. Four holes were cut in each cover, a center hole 10 mm in diameter for aeration and the replacement of water by evaporation and transpiration of plants, and three holes 4 mm in diameter in which the seedlings were placed.

Knop's nutrient solution (FREY-WYSSLING, 1949) was used as the standard reference medium. It was slightly modified by replacing ferric chloride with ferric citrate. The mineral composition per liter of medium was: $Ca(NO_3)_2 \cdot 4H_2O$ 1.0 g, $MgSO_4 \cdot 7H_2O$ 0.25 g, KH_2PO_4 0.25 g, KCl 0.125 g, and ferric citrate 0.01 g. Partial nutrient solutions were prepared by adding equivalent amounts of $NaH_2PO_4 \cdot H_2O$, $NaNO_3$, and/or KCl to redistilled water in order to test the effects of nitrogen, phosphorus, and potassium fertilization of the Surtsey soil (see table 2). All chemicals were pro analysii, and only redistilled water was used in the experiments.

The experiment was set up in three series with 27 boxes in each


1
aq.redest.
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series and with three oat seedlings in each box.

I. Reference serie. 30 ml nutrient solution + 10 ml redist. water.
II. 25 g lava sand (14/1972) + 30 ml nutrient solution. Total 40 ml.
III. 25 g tephra (18A/1972) + 30 ml nutrient solution. Total 40 ml.

All 81 boxes were placed in a control chamber at 20°C and 3000 lux (Philips TL/33) with a photoperiod of 16 hours light and 8 hours darkness. Water lost by transpiration and evaporation was daily replaced by adding redistilled water to each culture.

At the end of the experiment the fresh weight was obtained of each plant and it was then dried at 104°C for 24 hours in order to obtain its dry weight.

RESULTS AND DISCUSSION

The experiment lasted 34 days, at which time the very first symptoms of potassium deficiency could be observed on the plants in the total Knop´s solution, where the healthiest development, of course, took place. Data and observations are presented in table 2 and fig. 1-4. There was no evidence of blue-green algae or other microorganisms in any of the cultures.

Except as noted in col. 10 and 11 of table 2, the plants in the Surtsey soils series (ser. II and III) were healthy appearing. The appearance of the roots (fig. 4) indicates that the magnitude of available phosphorus was quite sufficient for normal plant development (PEARSON, 1967). This is in agree with the chemical analyses (HENRIKSSON and HENRIKSSON, 1974).

Decidedly dwarfed plants were observed only in the cultures without Surtsey soil (ser. I) and could be regarded as due to phosphorus deficiency. In ser. II and III, the addition of phosphorus in combination with nitrogen and/or potassium seemed to stimulate growth (dry weight increase), as is often the case in agricultural experiments; however, the deficiencies are not statistically significant.

Growth was much more better in the distilled water to which Surtsey soil had been added than in distilled water alone (compare first plants on the left in fig. 1-3). Knop´s medium was a very effective fertilizer and resulted in still greater growth. Likewise the addition of soil to the media improved their buffer capacity (table 2, last column).

Addition of nitrogen alone stimulated the growth in both the series with Surtsey soils, and the plants were in good condition (fig. 2 and 3). Nevertheless, both fresh weight and dry weight were lower than those in total Knop´s solution. The addition of nitrogen together with either potassium or phosphorus stimulated growth much more than the additions of the individual minerals, especially in series III. These results are in harmony with the

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Fig. 1-3. Oat plants after 34 days in redistilled water with or without addition of nitrogen, phosphorus, and/or potassium. Fig. 1 without the addition of Surtsey soil. Fig. 2 lava sand added. Fig. 3 tephra added. The control is a complete nutrient medium, modified Knop´s solution.

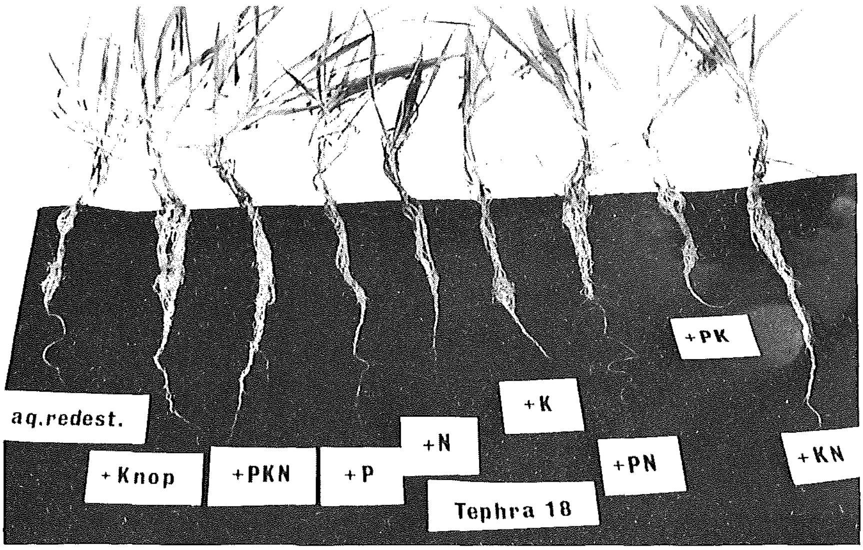

Fig. 4. Root systems of the plants shown in Fig. 3. 34 days old oat plants grown hydroponically in 30 ml of redistilled water to which nitrogen, phosphorus and/or potassium plus 25 g tephra soil from Surtsey had been added. The best root development occurred when nitrogen plus either potassium or phosphorus or both had been added.

The uptake of inorganic nitrogen by higher plants is dependent on the supply of K^+ in the substratum. Therefore the present limiting nitrogen content in the Surtsey soil is accentuated by the deficit of available K^+. In addition available analyses imply an unfavourable $Na^+:K^+$ ratio in Surtsey soils at the present time further complicating the already complicated picture.

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