SOME SEASONAL TRENDS IN NUTRIENT CONTENT OF THE SOILS OF SIGNY ISLAND, SOUTH ORKNEY ISLANDS

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ABSTRACT. An investigation of the nutrient content of two soil types at Signy Island, South Orkney Islands, revealed a winter peak in the levels of certain nutrients, particularly nitrogen and phosphorus. Laboratory experiments suggest this is not a direct effect of freezing on the soil. The significance of the fauna of the island in relation to the seasonal pattern of nutrients is discussed.

PHYSICAL disintegration as a result of freezing is a dominant feature of soil formation in tundra and high mountain regions, and it has frequently been investigated. However, much less has been reported about chemical changes which may also occur during a freeze-thaw cycle. Signy Island in the South Orkney Islands was considered very suitable for investigations of this nature because of the frequency of freeze-thaw cycles during the course of the year. This paper records seasonal variations in the levels of some extractable plant nutrients in two Signy Island soils, and it describes experiments carried out to assess the possible significance of freezing on the levels of these nutrients.

MATERIALS AND METHODS

Field study (*Signy Island*)

Two soil types were chosen, a semi-ombrogenous peat occurring under a moss community composed of *Polytrichum strictum* and *Dicranum aciphyllum*, and a brown loam-like mineral soil from under the only grass, *Deschampsia antarctica*. Both sites were within 100 m. of the sea and were sampled throughout the year 1965–66. The peat was sampled at approximately monthly intervals but the brown mineral soil less frequently due to site and climatic difficulties. Ten 3 cm. diameter cores were taken from the top 4 cm. of peat or soil below the living vegetation. These were mixed and divided to give two samples for analysis. All the samples were freshly extracted on the day they were collected and the extracts were either analysed the following day or stored in sealed containers. As an additional precaution, the polythene bottles used for phosphorus extraction and storage were treated with iodine (Heron, 1962) to eliminate potential losses due to microbial activity. The extractants used were:

i. N ammonium acetate at pH 7·0 (for Na^+, K^+, Ca^{++} and Mg^{++}).
ii. 0·002N sulphuric acid buffered at pH 3·0 (Truogs reagent for PO_4'''—P).
iii. 6 per cent w/v sodium chloride (for NH_4^+—N).

The moisture contents of the fresh samples were also determined. All these data are presented in Figs. 1 and 2.

Laboratory experiments (*Merlewood Research Station*)

The soils of Signy Island have been described by Holdgate, Allen and Chambers (1967). Those used in this investigation were taken from a series collected by M. W. Holdgate in February 1962, transported in cold storage to Merlewood Research Station and later analysed (Allen, Grimshaw and Holdgate, 1967). Six types were chosen covering the range of soils found on the island (Table I). The "loam" and "ombrogenous peat" were equivalent to those used in the field study. The peat, described as "soligenous", was flushed by mineral drainage water. The "mineral" sample was largely skeletal schistose material whilst the "clay" had a much higher content of colloidal particles. The contaminated material came from the immediate vicinity of the bird and elephant seal colonies.

Three British soils were included for comparison. The peat was sampled from Pennine blanket bog in the Moor House National Nature Reserve, the clay from under heather on Kirkby Moor in the Furness district of Lancashire and the loam (containing a proportion of drift) from over limestone near Grange-over-Sands.

To simulate a long-term freeze, some of each Signy Island soil was stored for 8 weeks in polythene bags at −10° C. Some British material was similarly left for 5 weeks. Other material

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was alternately frozen at −10° C for 24 hr. and left at room temperature for a further 24 hr. This was repeated twelve times to simulate repeated freeze-thaw cycles. All samples and the reference material were extracted fresh and in triplicate for phosphorus and ammonia–nitrogen as before. The latter extraction was also used for nitrate–nitrogen. The ammonium acetate extraction and the iodinated bottles were both omitted. These data are given in Table I.

Analytical methods

Phosphorus was determined by the molybdenum-blue procedure using stannous chloride as the reductant. Ammonia–nitrogen was determined by steam distillation and titration with standard hydrochloric acid. Magnesium oxide was used to release the ammonia. This distillation was followed by the addition of Devarda's alloy to reduce nitrate to ammonia which was then distilled with magnesium oxide as before. Sodium and potassium were determined using an EEL flame photometer, and calcium and magnesium by EDTA titration. Moistures were determined by drying a sub-sample of the fresh material to constant weight at 105° C. Loss on ignition was carried out by igniting at 550° C for 2 hr. All results including moistures are expressed on a dry (105° C) basis.

Temperature measurements

The air temperatures were recorded in a Stevenson screen. Soil temperatures were measured with resistance thermometers as described by Chambers (1966).

Results and Discussion

The results given in Fig. 1 show a winter peak in the levels of extractable ammonia–nitrogen and phosphorus, and to a lesser extent for sodium and potassium. Calcium and magnesium showed very little seasonal change. These trends were more pronounced in the "loam". However, the water content of both soils considerably increased during winter (Fig. 2).

The mean monthly air temperatures for 1965 demonstrate the prolonged nature of the winter freeze (Fig. 3). Comparable results for 1963 are included together with the mean monthly temperatures at 2·5 cm. depth in a *Polytrichum dicranum* bank (Chambers, 1966), indicating that air temperatures are not a reliable guide to the temperature regime in the ground. Chambers has shown that there are numerous freeze-thaw cycles at 2·5 cm. during spring and autumn when the mean is close to 0° C.

It was initially thought that the winter and early spring increase might be due mainly to the action of freezing, whilst the fall in late spring would result from dilution and washing away by melt water. Laboratory experiments were carried out to investigate the effect of freezing (Table I). With one or two exceptions, there were only marginal increases in the contents of extractable nitrogen and phosphorus after freezing the Signy Island soils, the influence of repeated freeze-thaw cycles being slightly greater than prolonged freezing. The British material, however, showed significant changes in ammonia–nitrogen and phosphorus after freezing and confirmed the findings of Allen and Grimshaw (1962), who found similar effects in Lake District soils. The difference between the British and Signy Island material is not yet explained though it is known that the Signy Island soils are more primitive and skeletal, and they probably have fewer exchange sites for nutrient ions (Holdgate, Allen and Chambers, 1967).

The evidence from Table I suggests that freezing is not the main cause of the winter increases obtained in the field and that other factors must be operating. For instance, Allen, Grimshaw and Holdgate (1967) concluded that the nutrient regime on Signy Island is considerably influenced by the fauna, and in particular the droppings from the large population of birds which begins to build up before the spring melt season. Some birds remain until the freeze-up is re-established in autumn.

The increasing water content in late winter (Fig. 2) also seems to be important since the additional water must be derived from the overlying snow and ice. Areas of contamination may tend to become locally melted, perhaps due to their somewhat better absorptive surface and slightly lower melting point than pure snow. Consequently, as winter progresses, the ground will contain increasing amounts of ions derived from the droppings.

TABLE I. EXTRACTABLE NITROGEN AND PHOSPHORUS BEFORE AND AFTER FREEZING (mg./100 g. DRY SOIL)

		Ammonia—nitrogen			*Nitrate—nitrogen*			*Phosphorus*		
	Loss on ignition (per cent dry weight)	*Unfrozen*	*Repeated freeze-thaw*	*Prolonged freeze*	*Unfrozen*	*Repeated freeze-thaw*	*Prolonged freeze*	*Unfrozen*	*Repeated freeze-thaw*	*Prolonged freeze*
Signy Island material										
Clay	5·0	0·22	1·9	0·48	*	*	*	3·2	4·0	2·6
Mineral	1·2	0·54	0·60	0·67	*	*	*	5·9	7·1	6·0
Loam	24	10·7	10·4	9·6	11·2	13·2	10·4	10·3	13·0	8·9
Ombrogenous peat	84	3·1	—	7·6	*	*	*	9·3	9·8	6·5
Soligenous peat	51	28	30	29	5·5	5·8	4·7	16·8	16·8	14·0
Contaminated soil	7·5	75	85	83	1·8	2·0	3·8	—	—	—
British material										
Clay	8·9	0·75	2·4	1·2	<0·07	0·07	<0·07	*	*	*
Loam	15	0·31	3·3	2·5	0·10	0·35	<0·09	*	*	*
Acid peat	96	1·8	28	3·9	<0·50	0·75	<0·46	*	4·3	2·8

* Levels too low for accurate determination.

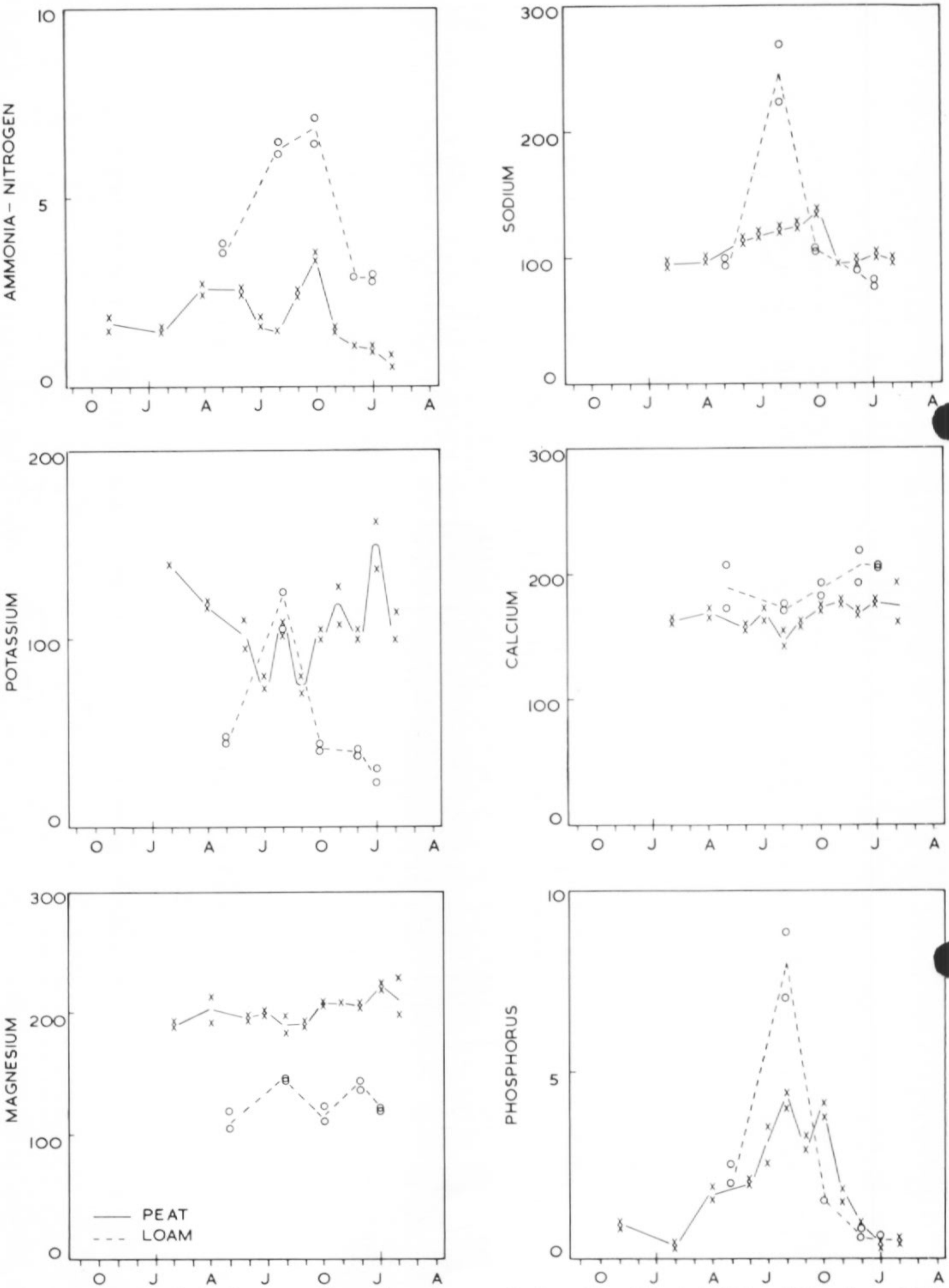

Fig. 1. Seasonal variation in extractable nutrients in two soils from Signy Island, 1965 (mg./100 g. dry weight).

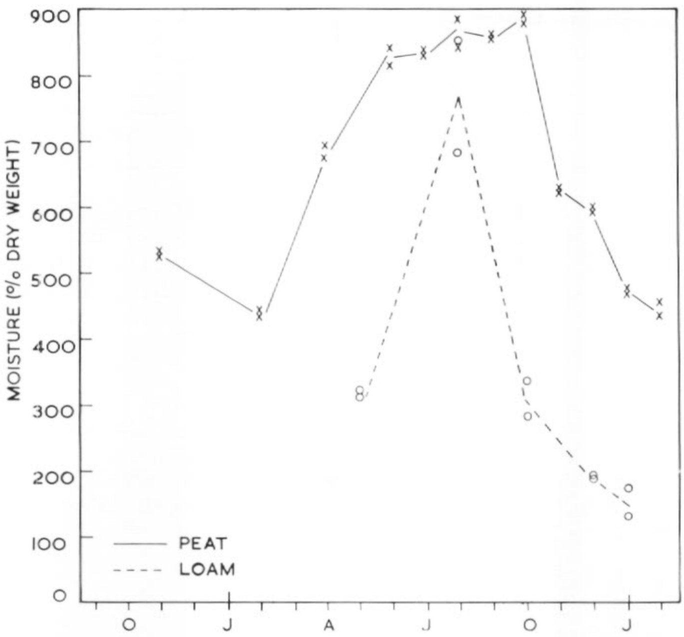

Fig. 2. Seasonal variation in moisture content of two soils from Signy Island, 1965.

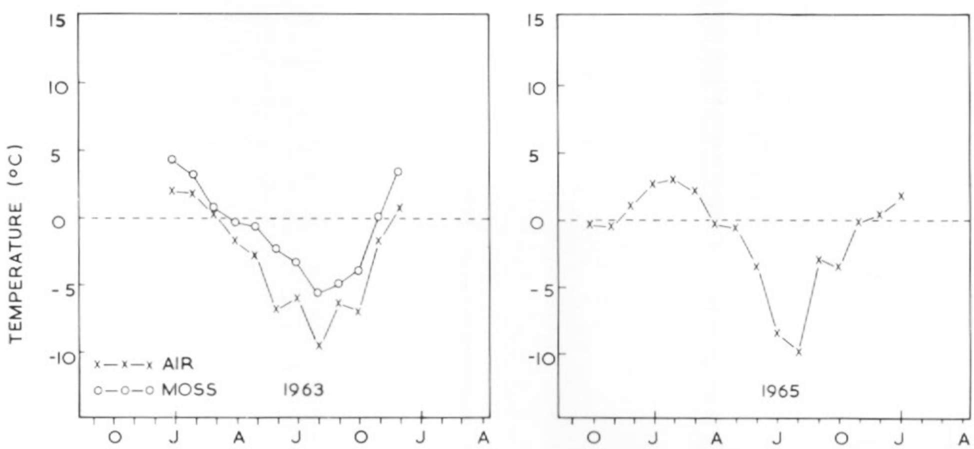

Fig. 3. Comparison of air and moss (2·5 cm. depth) temperatures at Signy Island in 1963 and air temperatures in 1965.

Additional evidence was obtained from a water extract of droppings from the cape pigeon (*Daption capensis*) (Table II). Both nitrogen and phosphorus were major constituents of the extract, and they contrast markedly with the low extractable levels in both peat and "loam". Addition of contaminated material would therefore give a relatively large percentage increase. The lack of any trend in the calcium levels may reflect the relatively small contributions made by the droppings.

Apart from calcium and magnesium, all the ions examined were eluted by the somewhat purer melt water during the spring. This would appear to confirm that in general the soils were lacking in available sites to hold these ions.

TABLE II. WATER-EXTRACTABLE NUTRIENTS IN DRIED CAPE PIGEON DROPPINGS (mg./100 g. DRY WEIGHT)

Na^+	K^+	Ca^{++}	PO_4'''—P	NH_4^+—N
1,210	612	82	690	1,790

There is little evidence for any deficiency of major nutrients on Signy Island, so any removal by melt water in spring is unlikely to retard plant growth. Nevertheless, the results support the theory of Siple (1938), whose survey of moss and lichen distribution in Marie Byrd Land led him to conclude that "the most important part played by birds is enrichment of rock exposures by guano".

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TABLE I. EARTH TEMPERATURES (°C) AT BIRD ISLAND, SOUTH GEORGIA, MARCH 1963–FEBRUARY 1964

Depth	4 in. (0·10 m.)					1 ft. (0·30 m.)					2 ft. (0·61 m.)					4 ft. (1·22 m.)				
	Mean	*Maximum*	*Date*	*Minimum*	*Date*	*Mean*	*Maximum*	*Date*	*Minimum*	*Date*	*Mean*	*Maximum*	*Date*	*Minimum*	*Date*	*Mean*	*Maximum*	*Date*	*Minimum*	*Date*
1963																				
January	6·3	9·1	7	3·9	1															
February	6·1	7·8	3	4·3	23															
March	4·4	5·8	4	2·3	29	4·5	5·2	1	3·5	30	4·5	5·1	1	3·8	31	4·4	4·9	4	3·9	31
April	2·7	5·1	3	1·0	30	3·2	4·4	7, 8	1·9	30	3·4	4·1	7–11	2·4	30	3·5	4·1	3	2·8	30
May	0·6	1·1	14	0·3	24, 25, 27–30	1·2	1·9	1	0·8	31	1·6	2·6	1	1·2	29–31	2·1	2·8	1, 2	1·6	29, 30
June	0·1	0·4	8	0·0	26–28, 30	0·6	0·9	1	0·4	29	0·9	1·2	1–6	0·7	28	1·3	1·6	1	1·0	28
July	−0·1	0·1	1, 4–8	−0·3	31	0·4	0·6	—	0·3	29, 30	0·7	0·8	1–4	0·6	30	1·0	1·2	3	0·8	30
August	−0·3	0·0	8	−0·8	26, 27	0·3	0·4	1	0·1	27	0·6	0·6	—	0·5	23, 24, 28–31	0·8	0·9	—	0·7	23, 28, 29
September	−0·2	−0·1	14, 19, 20	−0·4	6, 7	0·1	0·2	—	0·1	11, 13, 22	0·4	0·6	1	0·4	—	0·7	0·8	1, 2, 17, 18, 20	0·7	—
October	−0·3	−0·1	21, 22	−0·4	11–13	0·1	0·2	2, 11, 19, 28	0·0	24–30	0·4	0·5	—	0·3	—	0·7	0·9	7	0·6	—
November	0·4	4·5	29	−0·3	2, 3	0·2	0·6	29	−0·1	1	0·4	0·6	30	0·2	20	0·6	0·7	29, 30	0·6	—
December	3·0	6·4	17	−0·1	2, 3	2·4	4·4	25	0·6	1–3	2·1	3·6	30, 31	0·6	1	1·8	2·8	31	0·8	1, 2
1964																				
January	4·8	6·9	5	3·4	15	4·3	5·1	7	3·7	1	4·0	4·5	25	3·5	1, 2	3·4	3·8	27, 28	2·8	1
February	5·1	6·7	9	3·6	23	4·6	5·1	14, 15	4·1	23, 24	4·4	4·7	15, 16	4·1	23–25	3·9	4·1	16–19, 21	3·7	1
MEAN	1·7	3·1		0·7		1·8	2·4		1·3		1·9	2·4		1·5		2·0	2·4		1·7	

When no date is given for extremes, the temperature occurred many times during the month.