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Uptake of Water from the Atmosphere by Lichens in Continental Antarctica

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Abstract

Microclimate relative humidity and temperature and lichen thallus temperature were measured from August 1992 to January 1993 at the crest of a hill on Clark Peninsula in the Windmill Islands, continental Antarctica. The water potential of the air in the lichen microhabitat was modelled and compared with the water potential assumed to be necessary for lichen photosynthesis due to water vapour uptake. It was found that for most of the spring the atmospheric water potential was too low for water vapour uptake by exposed lichen. In all there were only 351 h during which water vapour uptake could have occurred, most of this falling in November. The results indicate that water vapour uptake by exposed lichen will occur during the period of snow melt at the beginning of summer, but only rarely at other times.

Keywords: Antarctica, lichen, photosynthesis, water vapour uptake, water potential, microclimate

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1. Introduction

It has long been acknowledged that lichens with green algal photobionts can absorb sufficient water from a humid atmosphere to photosynthesise. Numerous observations from both the field (Lange et al., 1989) and laboratory (Lange and Killian, 1985) have established that this trait is almost universal amongst green algal lichens but absent from cyanobacterial lichens. A mechanistic interpretation for this phenomenon, which involves differential reversibility of a functional interruption of energy transfer between LHCII and the PSII reaction centre, has been proposed by Bilger et al. (1989). All known lichens from continental Antarctica have green algae as photobionts so one might expect that they will photosynthesise as a result of water uptake from the atmosphere. Measurements of antarctic lichen photosynthesis in the field have indicated that lichens in equilibrium with the atmosphere rarely photosynthesise as a result of water uptake from the air (Gannutz, 1967; Hovenden et al., 1994). These studies have been relatively short-term and have focused on the dry summer period.

Measurement of the relative humidity of air has become commonplace and can be logged by automated instruments. Data for humidity in the microclimate of antarctic lichens have been available for some time. The measurement of air temperature at the point of humidity measurement allows the calculation of the water potential of the air according to a derivation of Raoult's law such that

$$\Psi_{air} = -1.06\, T \log_{10}\, (100/RH) \qquad \text{Eqn. 1}$$

where Ψ_{air} is water potential of the air in MPa, T is temperature in kelvin and RH is relative humidity in percent.

A lichen will absorb water from a humid atmosphere when its water potential is lower than that of the air. Let us assume, as did Bölter et al. (1989), that a lichen in thermal equilibrium with an atmosphere of 80% RH can absorb sufficient water to re-initiate photosynthesis. Then we can calculate the lowest water potential of air from which lichen water uptake occurs, Ψ_{WU}, if we know the thallus temperature of the lichen. Thus, by substituting $RH = 80$ into Eqn. 1 we have

$$\Psi_{WU} = -1.06\, T_l \log_{10}\, (100/80)$$
$$\Psi_{WU} = -0.103\, T_l \qquad \text{Eqn. 2}$$

where T_l is the thallus temperature of the lichen.

Thus by measuring the temperature of the lichen thallus, the relative humidity of the air in the lichen microhabitat and the air temperature at the point of humidity determination, it is possible to compare the actual water potential of the air with that required to provide the lichen with water for photosynthesis, assuming that the lichen can photosynthesise when in equilibrium with 80% *RH*.

This paper investigates lichen uptake of atmospheric water by modelling the atmospheric water potential and comparing it with that calculated as the minimum for lichen water uptake during spring at a well vegetated site in continental Antarctica.

2. Materials and Methods

Study site

All measurements were made on the crest region of a small rounded knoll on Clark Peninsula, Windmill Islands, continental Antarctica (66° 17' S, 110°32' E). This region of Antarctica is dominated by extreme cold and aridity and is classified as frigid-antarctic (Longton, 1988). To the east and south of the Windmill Islands lies the ice plateau of greater Antarctica. Approximately 120 km to the east is Law Dome, an ice mount some 1,100 m in height, which dominates the area's weather. The northern region of the Windmill Islands receives an average of 96 days of gale force winds per year, predominantly from the east while moderate winds come largely from the south (Melick et al., 1994).

The vegetation of the site is dominated by the bipolar macrolichens *Umbilicaria decussata* (Vill.) Zahlbr., *Pseudephebe minuscula* (Nyl ex. Arnold) Brodo & Hawksw. and *Usnea sphacelata* R.Br. These lichens form extensive turves on Clark Peninsula, which is a particularly species rich area with a total of 25 lichen species in this study site alone. Clark Peninsula is the site of some of the most complex and well developed plant communities in continental Antarctica (Melick et al., 1994).

Microclimate measurements

Lichen thallus temperatures were measured using six miniature thermocouples which were logged every three hours by an Aanderaa 3010 automatic weather station. Thermocouples were placed amongst lichen thalli in six sites in the study area all of which were dominated by *Usnea sphacelata – Umbilicaria decussata*. Microclimate humidity was measured with two

Vaisala humidity probes and logged every 90 minutes using a Grant squirrel data logger. Data were collected for the entire spring period from mid-August until early January.

The actual Ψ_{air} was calculated according to Eqn. 1. The minimum water potential of the air necessary for lichen water uptake, Ψ_{WU}, was calculated according to Eqn. 2. Water vapour uptake was assumed to be sufficient to sustain lichen photosynthesis whenever Ψ_{air} was greater than Ψ_{WU}.

3. Results and Discussion

During the period of 21 August 1992 until 5 January 1993 the minimum air water potential for water vapour absorption by a lichen, Ψ_{WU}, varied from –23.7 MPa to –31.1 MPa while the atmospheric water potential of the lichen microhabitat ranged from –5.82 MPa to below –300 MPa. Figure 1 shows the range of Ψ_{air} which is enormous compared to the range of Ψ_{WU} values. The lichen thallus temperatures during this period ranged from –42.8°C to 28.5°C and the ambient temperature in the microenvironment from –31.6°C to 6.6°C. For approximately 351 h during this period Ψ_{air} was greater than Ψ_{WU}, and therefore lichens in equilibrium with the atmosphere could absorb sufficient water to photosynthesise. This figure corresponds to 10.7% of the total time. The temporal distribution of this time during which photosynthesis from water vapour uptake was possible is given in Table 1.

Table 1. Monthly potential for water vapour uptake by lichens on Clark Peninsula exposed to the atmosphere for the period of 21 August until 5 January. The % uptake time is the total number of hours of potential uptake divided by the number of hours in the month.

Month	h uptake	% uptake time
August	45	17.9
September	6	0.8
October	9	1.2
November	267	37.1
December	24	3.3
January	0	0
Total	*351*	*10.7*

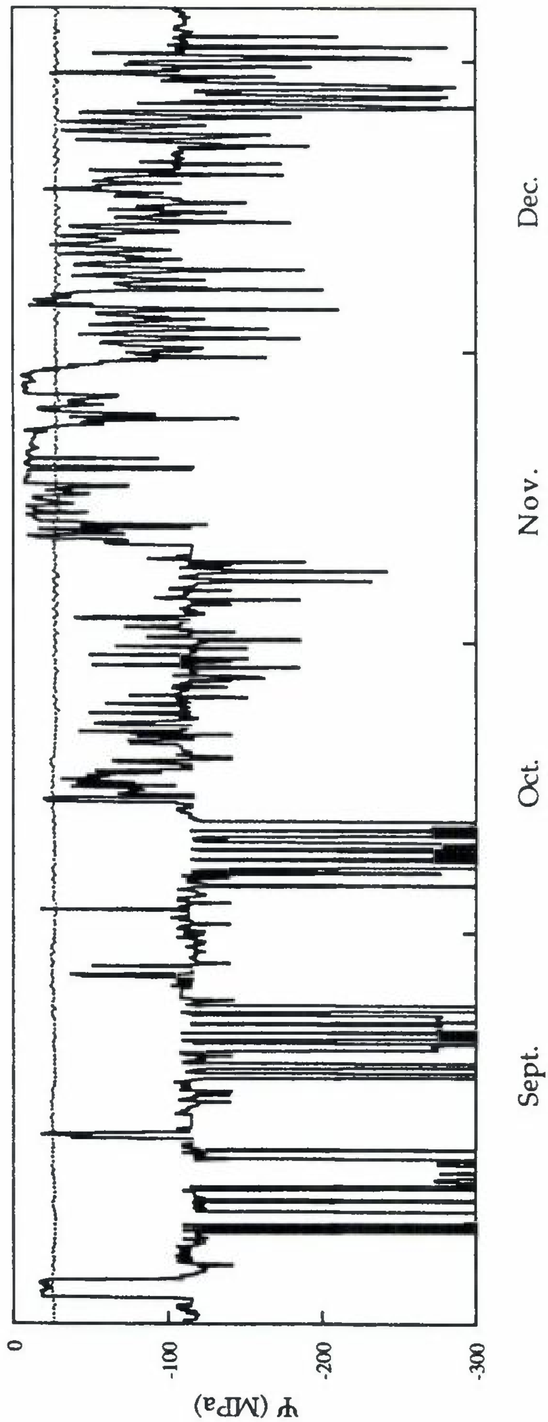

Figure 1. The time course of Ψ_{air} (solid line) and Ψ_{WU} (dotted line) during the spring of 1992. Abbreviations are defined in text.

From both Fig. 1 and Table 1 it is obvious that November is the spring month when water uptake from the atmosphere is most likely with conditions being favourable for approximately 37% of the month. This is undoubtedly linked to the onset of the summer thaw and the increase in atmospheric humidity due to the presence of free water in the lichen habitat. During this period the levels of photosynthetically active radiation are generally high enough to permit photosynthesis since the days are long and bright. This was the only extended period during which uptake of water vapour from the atmosphere was likely. Rare events further into summer such as snow showers and fogs provide periods of high atmospheric humidity and such events are even more scarce during the winter. Therefore, over the spring as a whole, the potential for lichen photosynthesis as a result of water uptake directly from the atmosphere is low. It must be stressed, however, that this is the case for lichens exposed to the atmosphere. Lichens which are blanketed by snow during the winter and early summer would have a much greater potential for photosynthesis due to water vapour uptake since the air in the sub-nival space is considerably moister than that where snow is absent (Kappen, 1993). Water uptake directly from melting snow is also a very important source of water (Schroeter et al., 1994) and late-lying snow may even lead to lichen death (Benedict, 1990). Lichens covered by snow are also sheltered from the extremes of temperature which occur during the spring and are completely protected from desiccating winds.

The extremely low values of Ψ_{air} during the winter are not surprising given the climate. Not only are air temperatures low but the predominant easterly winds mean that the air comes from across the antarctic plateau which is up to 4 km high and extremely cold resulting in what must be nearly the driest air on earth. Exposed lichens therefore are unlikely to absorb water from this air. The microclimate humidity increases during snow falls and at times of summer melt and at these times exposed lichens are able to absorb sufficient water to photosynthesise.

The onset of the summer melt is obvious from Fig. 1 where a marked change in Ψ_{air} can be seen to occur in mid-October. Although it is unlikely that exposed lichens could absorb water vapour from the atmosphere during the second half of October and the first half of November, it is possible that lichens covered with snow were metabolically active during this phase. From approximately 10 November even completely exposed lichens were likely to be photosynthetically active. The first instance of photosynthetic activity after the winter was observed on 5 October, a day with high humidity, high light and relatively high thallus temperatures, on which *Umbilicaria decussata* thalli were observed to be hydrated and evolving oxygen during the early hours of the afternoon. A spike can be observed on Fig. 1 at this date, hence field observations support the model.

The osmotic potential of a non-ideal solution such as cell-sap can be estimated from its freezing point (Salisbury and Ross, 1985). Melick and Seppelt (1994) gave freezing points for *Umbilicaria decussata* from Clark Peninsula of approximately –16°C which corresponds to an osmotic potential of –19.5 MPa. Since our values of Ψ_{WU} are more negative than this, consideration should be given to the assumption that 80% is the minimum relative humidity for a dry continental antarctic lichen to absorb water. If we were to substitute RH = 85% into Eqn. 1 we would receive Ψ_{WU} values from –22.6 MPa to –17.3 MPa which are more similar to the osmotic potential calculated from freezing point. Needless to say, such an elevation of the minimum RH value for water uptake would reduce the potential for photosynthesis from absorption of water vapour even further.

Earlier field work has shown that exposed lichens in continental Antarctica are metabolically inactive for most of the summer period (Hovenden et al., 1994). This study indicates that the early part of the summer melt is probably the most important period for lichen photosynthesis and growth.

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