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Cyanobacteria highly active during the wet season: A long-term study at Boodjamulla National Park, north-west Queensland.

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Abstract

This research is based in far north-west Queensland at Boodjamulla National Park, a dryland savannah dominated by *Eucalyptus* and *Melaleuca* woodlands and floodplains. The interspaces between the perennial tussock grasses are dominated by cyanobacterial soil crusts. The wet season is governed by monsoonal troughs and in the dry season there is often no rain at all. This two-year project has focused on; establishing the diversity of the different crust ecosystems, net carbon uptake annually, and seasonal eco-physiological function. Crust communities can be divided into three main types: flood plain crusts dominated by *Scytonema, Simploca* and *Nostoc,* with abundant liverworts and some areas of moss; dry savannah and elevated crusts dominated by *Scytonema* and *Stigonema* with lichens and liverworts and; rock crusts dominated by cyanobacteria and cyanolichens. CO_2 exchange is measured with an automated cuvette system that records the CO_2 difference over three minutes on a thirty-minute cycle, continuously. Data from the first wet season has shown that CO_2 uptake by cyanobacteria is tightly linked to light intensity but at a considerable temperature range, of 23-36°C. During the wet season, ground water levels were maintained for many weeks. Throughout this time net CO_2 uptake peaked, significantly outweighing respiration. This translates to highly productive cyanobacterial crusts for almost the entire wet season. In contrast, during the dry

season a series of tests showed that cyanobacterial crusts were completely inactive. At the commencement of the wet season new cyanobacterial soil crusts are formed at the expense of last season's crusts. In the growth stage cyanobacteria reach extremely high net photosynthetic rates coupled with N_2-fixation. This constitutes the first wide-ranging eco-physiological report on crust function of its kind. The information will provide a comprehensive daily database for the calculation net productivity on an annual basis for cyanobacterial crusts in these ecosystems.

Introduction

The Gulf Falls and Plains bioregion of northern Queensland are characterised by broad expanses of perennial grasslands and woodlands on alluvial plains, extensive freshwater and estuarine wetlands along with ancient mountain ranges, rocky outcrops and deep palm lined gorges. In the wet season rainfall is governed by monsoonal troughs, tropical lows and cyclones. The wettest months occur over a four-month period between December and March, and rainfall gradients vary greatly between coastal and inland regions. The dry season can extend for several months at which time there is often no rain whatsoever.

This study is based in the far north-west at Boodjamulla National Park. The research site is located in an open woodland flood plain dominated by *Eucalyptus* and *Melaleuca*, typical of the savannah. It is bordered by Lawn Hill Gorge and surrounded by sandstone cliffs and rocky ridges. The interspaces between the perennial tussock grasses on floodplains are dominated by an almost continuous cover of cyanobacterial crusts. These crusts often referred to as biological, microbiotic, cryptogamic or cyanobacterial crusts include an assortment of cyanobacteria, lichens, liverworts, mosses, algae and bacteria (Belnap *et al.* 2003).

Clearly cyanobacterial crusts are an important part of the savannah ecosystem however, no previous research has been carried out as to the functional characteristics and contribution made by the cyanobacterial soil crusts. This research project has focused on establishing: (1) biodiversity of the different crust ecosystems, (2) the net carbon uptake annually, (3) seasonal eco-physiological function and, (4) seasonal biomass and nitrogen inputs.

Methods and Results

Initial biodiversity assessments have revealed complex crust communities that can be divided into three main types: (a) flood plain crusts co-dominated by *Scytonema* and *Nostoc* with abundant liverworts (*Riccia* spp.), (b) dry savannah and elevated crusts dominated by *Scytonema*, *Stigonema* with lichens (mostly *Peltula patellata* and *Diplochistes*) and liverworts, (c) rock crusts dominated by cyanobacteria and cyanolichens (*Peltula* spp.). Primarily, CO_2 exchange is measured with an automated cuvette system (Walz, Germany, Fig. 1). This records the CO_2 difference (three times at 20 sec intervals) over three minutes on a thirty-minute cycle (24 hours).

Fig. 1 Cuvette measuring chamber for CO_2 exchange of cyanobacterial crusts that remains open 90% of the time exposing the crust to natural environmental conditions.

Data from the first wet season has shown that CO_2 uptake by cyanobacteria is closely linked to light intensity but at a considerable temperature range (23-36°C). Predictably, over-saturation with water reduces CO_2-uptake but does not halt it unless cloud cover is heavy enough to severely limit photosynthetic active radiation (PAR). Peak CO_2 uptake frequently exceeded the equipments measurement capacity and further adjustments to cater for this environment were necessary. During the wet season, ground water levels were maintained for several weeks. Throughout this time net CO_2 uptake outweighed respiration on a basis of at least 2:1 but on most days exceeded this by a considerable amount (Fig. 2). In real terms this meant that cyanobacterial crusts were highly active for almost the entire wet season (3-4 months).

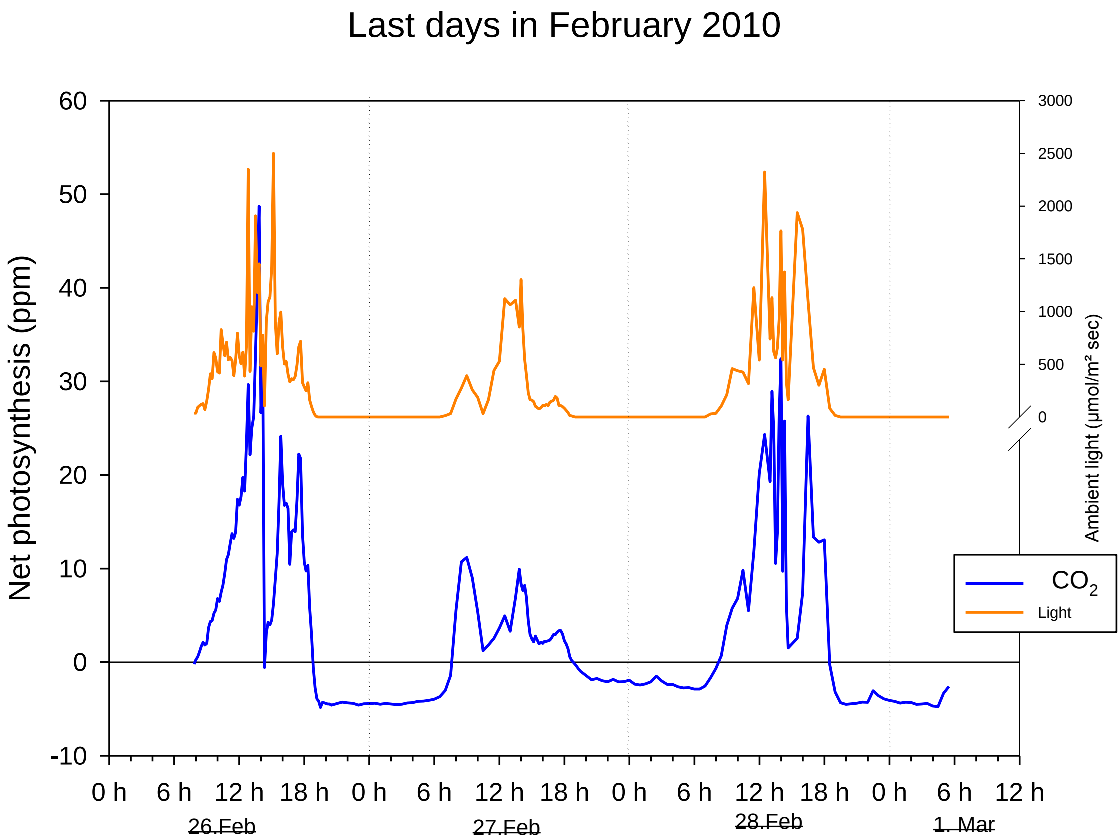

Fig. 2 Carbon dioxide uptake by the cyanobacterial crust.

In contrast during the dry season a series of tests showed that after 125 days with no rain and within eight days of rewetting (artificially) there was only new cyanobacterial growth. At the commencement of the wet season fresh cyanobacterial soil crusts grow over the previous seasons crust. There is a clear peak in biomass yield demonstrated within a few days of significant rain events. This is maximal at the start of the wet season but occurs periodically throughout the season as well. In the process cyanobacteria reach extremely high rates of photosynthesis and N_2-fixation.

Discussion

The data collected to date reveals a complex crust ecosystem that drives a considerable net carbon uptake annually. One of the most influential factors in sustained productivity was the maintenance of ground moisture in between rain events. At this time it was warm, often with high humidity and sunny. Due to high light intensities and optimal moisture, the cyanobacterial crusts performed at their peak. For the first time it was clear that the majority of the crust system from the previous wet season disintegrated and broken down into organic matter (presumably bacterially mediated), as new crusts rapidly covered the soil surface. Observed rates of growth exceeded any previous laboratory studies including observed life cycles of individual cyanobacteria. The challenge now is to measure annual growth and nitrogen inputs over next year's wet season. There is additional experimental work being undertaken at the University of Kaiserslautern to measure net CO_2 exchange of crusts from this site under controlled laboratory conditions across temperature, moisture and light gradients.

As this is the first long-term experiment of its kind it has presented a number of challenges. During the first wet season the data far exceeded expectations however a number of problems were encountered by installing sensitive scientific equipment in the field. The extreme heat leading into the wet season, where daily temperatures averaged 45°C and soil surface temperatures peaked at >70°C pushed the capacity of equipment to its limit. The cuvette itself had to be placed in a miniature water bath in order to prevent invasion by ants looking for safe wet-season nesting sites. A problem currently being resolved is the rapid drying of the sample. Water was artificially added to the sample to maintain moisture equivalent to ground water levels but this does not replicate the natural environment we wish to achieve. Aside from the many challenges the equipment has performed well in a harsh environment.

Elbert *et al.* (2010) have now provided a global context to the significant contribution of microbiotic crusts to terrestrial ecosystems. They have deduced that global annual net uptake of carbon by biological crusts is now estimated to be in the vicinity of ~4.4 Pg a^{-1} which corresponds to ~7% of the estimated global net carbon uptake by terrestrial vegetation (net primary production, NPP: ~60 Pg a^{-1}). This is of the same magnitude as the global annual carbon turnover due to biomass burning. They also estimated that the rate of nitrogen fixation by biological crusts (~45 Tg a^{-1}) amounts to ~40% of the global estimate of biological nitrogen fixation (107 Tg a^{-1}). Importantly, these figures do not incorporate any Australian data. Elbert et al. 2010 conclude that in light of earth's system dynamics, the large contribution of microbiotic crusts to nitrogen fixation is likely to be important also for the sequestration of CO_2 by terrestrial plants, because the latter is constrained by the availability of fixed nitrogen.

Currently, soil respiration and carbon is measured without taking into account the surface crusts that photosynthesise and therefore sequester carbon. Over 70% of Australia is arid or semi-arid and it is probable that microbiotic crusts represent at least 300 million tonnes in biomass. These crusts are an important yet often underestimated component of the natural ecosystem. This long-term study is focused on defining the net ecosystem productivity (in relation to carbon uptake) on a seasonal basis of cyanobacterial soil crusts. However, this research needs to be broadened to include the nitrogen fertilisation that seemingly drives a great deal of growth in the dryland savannah ecosystems of the Gulf Plains and Cape York. This project will be continuing at the site for two years with the aim of providing the first comprehensive eco-physiological report on cyanobacterial soil crust function of its kind.

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