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Interactive comment on "Annual net primary productivity of a cyanobacteria dominated biological soil crust in the Gulf savanna, Queensland, Australia" *by* Burkhard Büdel et al.

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Anonymous referee 2 GENERAL COMMENT: This is a very nice study providing some data on a topic for which data is quite scarce: a high-temporal-resolution examination of isolated biocrust C exchange on an annual time scale in natural conditions. My main recommendation is to work on the framing of the study and improving the context of the results. These could be more compelling in a couple ways. First, the setting up at the beginning of a "mystery" that some crusts take up C and others don't does not work for the structure of this paper. I already knew the answer before seeing the results that it was a difference in methods among the studies (isolated crusts vs. whole soil

column) so the results did not resolve this part of the narrative. Instead of taking this 'source vs. sink' approach to framing the study, I recommend more directly addressing the contribution of isololated crusts vs. other components of the ecosystem, which though not measured here, are measured much more often than isolated crusts in other studies. This brings me to the context of the results. The order of magnitude of one of the main results here, the 1.72 g m-2 is quite interesting (a very significant finding for which it is hard to come by data). It would be worth putting this in the context of eddy flux tower-measured NEE values, which tend to be on the order of 10s to 100s of g C m-2. For example, a recent study of drylands showed NEP varying from 350 to +330 g C m-2 (Biederman et al. 2017 http://dx.doi.org/10.1111/gcb.13686).

Answer: Yes, you are right and we agreed to take a somehow other framing. With the comments of the two other referees, we now used two clearly addressed aims (as also suggested by you): 1) how do the cyanobacterially dominated biocrusts of Boodjamulla respond to the pronounced seasonality of water availability? and 2) are they sources or sinks for carbon at an annual timescale? We also discussed our results in relation to the outcome of the Biederman et al study: "In a recent study using the Eddy co-variance method, Biederman et al. (2017) found a wide range of carbon sink/source function with mean annual net ecosystem productivity (NEP) varying from -350 to +330 g C m-2 across sites with diverse vegetation types in the dryland ecosystems of south-western North America using evapotranspiration (ET) as a proxy for annual ecosystem water availability. Gross ecosystem productivity (GEP) and ecosystem respiration (Reco) were negatively related to temperature, both interannually within sites and spatially across sites and sites demonstrated a coherent response of GEP and NEP to anomalies in annual ET. Their investigation sites included one region having a noteworthy biocrust cover not accompanied by a dense vascular plant vegetation, the La Paz region of Baja California with an annual C-uptake (NEP) of roughly 90 g m-2. Approximating annual C gain based on the maximal CO2 uptake rates of four biocrust types composed of cyanobacteria, cyanolichens and chlorolichens measured by Büdel et al. (2013) from Baja California, we approach an annual C gain of those biocrusts of 11 ± 4 g m-2 (calculation based on 90 active days per year with 34 of them having a sub-optimal CO2 uptake rate of only 25% of maximum due to suprasaturation. Daily rates were calculated by maximum NP for 5 hours per day minus 10 hours R + DR). This is 6.5 times more than our pure cyanobacterially dominated biocrust from Boodjamulla but still 8 time less than found for the Baja California site in the study of Biederman at al. (2017). It could well be that later successional biocrusts with a wealth of different species groups, including bryophytes, lichens and green algae besides of cyanobacteria, might reach even higher annual carbon fixation rates".

Furthermore, the other cited studies that do not isolate crusts report values on the order of 50 g C m-2 losses, and these losses likely come from plant roots (which the authors should discuss).

Done

The results in this study suggest that net exchange from these biocrusts are 1-2 orders of magnitude below the flux magnitudes of plants, possibly suggesting they are not a huge part of the total ecosystem C budgets. The Elbert et al review claims global NPP by cryptogamic covers to be 7% globally but that seems hard to reconcile with this type of result. Regardless of whether the authors totally agree with my reasoning here, this kind of context is worthy of more exploration in lieu of the source vs. sink issue.

Answer: We added the following paragraph: "Considering the Boodjamulla biocrust as a mid-successional type, where an increase in carbon gain might be expected in the future when lichens and bryophytes establish to form a later successional soil crust. Dealing here with a cyanobacterially dominated biocrust of a mid-successional type might explain the low C-uptake rates and also the seeming discrepancy to the values calculated for the global NPP by cryptogamic covers of Elbert et al. (2012)".

The true strength of this study, the knowledge gap it fills, is in helping to understand the annual fluxes of an isolated crust into our overall understanding of ecosystem C exchange in systems that contain biocrusts. For that, it is a great study and certainly

worthy of publication. The exploration of seasonality and environmental effects on flux rates are also quite nice and well done.

Thank you very much for this nice comment

SPECIFIC COMMENTS abstract: "Of the metabolic active period, 48.6% were net photosynthesis and 51.4% dark respiration." 48.6% of what? measurement timepoints?

Answer: we rephrased that sentence for more clarity

typo: "above a relative humidity above 42%"

Done

Abstract: "This must be taken into consideration for future analyses and modelling of carbon balances in comparable biocrust ecosystems." I think a much more solid conclusion can be given here. It's not clear what comparable biocrust systems are being referred to and "it might be helpful for modeling" is never very compelling. I would end with direct and clear answers to the questions and what the results mean to the larger study of biocrust C exchange.

Answer: You are right, we omitted this sentence and tried to give a more meaningful outlook in the conclusions: "From the magnitude of values it is clear that the observed C fluxes are not at all close to what a plant community can do. Methodological approaches analysing the carbon cycling of biocrusts need to critically reflect, that including or excluding sub-biocrust partitions might influence the status of the biocrust as being either considered as a sink or a source. There is an urgent need for more long-term measurements on different biological soil crust types and developmental stages from all climatic regions of the world".

Take a look at the significant digits throughout the manuscript. eg 31.66 nmol feels unrealistically and unnecessarily precise. This will make it easier to read too.

Done

P6 L5: missing close parenthesis?

Done

I'm not wild about the reporting of WC as mm precip equivalent. Wouldn't moisture levels depend on both precip in as well as evapotransipiration and drainage out? Why not report as something intuitive such as g water g-1 wet soil (ie % water by mass)? If kept, include an explanation of why this approach was used.

Answer: We added the following sentences in Material and Methods to explain why we use mm water column instead of g water per g biocrust: "Water content of samples of the experimental manipulations and those of the field monitoring is always expressed as millimeter water column. As it was impossible to remove the sample after each measurement from the monitoring cuvette system to determine the fresh weight corresponding with the measured value by weighing it with a balance (measurements every half an hour, nobody of us could stand at the site for the whole period), the only method getting matchable values between field monitoring and controlled experiments is to express it like rainfall in millimeters water column".

I like figures 1 and 2. I wish more papers would include nice methods photos like this.

Thanks for the nice comment

Figure 3 caption needs to define what the codes on the horizontal axis (x axis?) mean. I think it should say x axis and it says sample signature, which I didn't understand. Does that mean an individually collected sample? I counted them and see 21 so I am guessing that's what it means. The codes are a bit cryptic.

Answer: we omitted figure 3 as it was by far too unclear. All three referees had problems with it and we no replaced by the much easier to understand table 1.

P2 L 23. what is meant by "carbon deposition"

Answer: should be C-uptake, we changed that in the sentence.

P2. L25. Part of the issue here is that studies are being mixed in which the biocrusts are by themselves or sitting on top of intact soil in which other fluxes like sub-crust respiration and root respiration contribute. This study uniquely looks at an isolated crust with very high temporal resolution. It is quite interesting that net uptake is on the order of 1g m-2 year. This is quite meaningful when comparing with eddy flux values from drylands and many ecosytems that show NEE values on the order of 10s or 100s of g C m-2 year. This suggests that cyano crusts alone are not huge contributors to C uptake, even in dryland ecosystems. (Note: I jotted this paragraph down before reading the results and discussion) I'd phrase the crucial question part of the intro more clearly and flag them as such with numbers and questions marks. Something like: This led us to two questions: (1) How do Boodjamulla biocrusts respond to the pronounced seasonality of water availability? and (2) Are they sources or sinks for carbon at the annual timescale?

Answer: thank you for this really good suggestion that we accepted and included.

"So far, it is unclear what is triggering a biocrust as either a sink or a source of C." I'm not sure this is conceptually accurate. If the biocrust itself, isolated as you have done here" is a persistent source, it dies. If it's a sink, it is growing or at least building SOM. I think what's unclear is the role of the crusts in the larger ecosystem and THAT'S what this study shows probably better than any previous study.

Answer: we agree and changed this part too.

P8 L10. A key point here though is that that top soil chamber still includes plants because there are plant roots below those crusts. The same is true for all the chamber approaches, and is one of the key reasons studies of isolated crusts like this one is valuable and needed. Those numbers (48.8 and 62) are likely large because they are catching the flip side of plant photosynthesis via roor respiration, which is a lot higher than what the crusts are doing. Chamber depth is more or less irrelevant because they are not closed on the bottom. Any root or microbe from anywhere below the measurement area would contribute to surface fluxes.

Answer: we agree and tried to express this in the Discussion.

In conclusion, some key take-homes from this study I'd like to see emphasized more are that the cyano crust alone is capable of being a small but consistent sink of carbon as it grows and possibly contributes a bit to SOM. However, it's clear also from the magnitude of the values that we are not seeing C fluxes that are anywhere close to what the plant community can do. A more complete discussion of these quantities would greatly improve the presentation of this excellent data set.

Answer: Again, we fully agree and tried to express that accordingly.

Thank you for your helpfull comments

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Table 1: Samples used for monitoring (only those listed used during the active period).

1. Sample A10	Sep. 23st – Dec. 12th 2010 (80 days)
2. Sample C5	Dec. 13th – Dec. 22nd 2010, Jan. 4th – Jan. 8th, Jan. 12th – Jan. 14th 2011 (18 days)
3. Sample S1	Dec. 23rd – Dec. 29th 2010 (7 days)
4. Sample SC	Dec. 30th – Dec 31st 2010 (2 days)
5. Sample S4	Jan. 1st – Jan. 3rd, Jan. 9th – Jan. 11th 2011 (6 days)
6. Sample S7	Jan. 15th – Jan. 17th 2011 (3 days)
7. Sample 2B	Jan. 18th – Jan. 25th 2011 (8 days)
8. Sample BS1	Jan. 26th – Feb. 1st 2011 (6 days)
9. Sample BS2	Feb. 2nd – Feb. 13th 2011 (12 days)
10. Sample BS4	Feb. 14th – Mar. 13th 2011 (28 days)
11. Sample BS7	Mar. 14th – Mar. 24th 2011 (11 days)
12. Sample BS3	Mar. 25th – Apr. 4th 2011 (11 days)
13. Sample C14	Apr. 5th – Apr. 17th 2011 (13 days)
14. Sample C11B	Apr. 18th – Apr. 20th 2011 (3 days)

Fig. 1. Table 1