Biogeosciences Discuss.,
doi:10.5194/bg-2017-79-RC1, 2017

Biogeosciences Discussions
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EGU

Interactive comment on "Spatially variable soil water repellency enhances soil respiration rates (CO_2 efflux)" *by* Emilia Urbanek and Stefan H. Doerr

Anonymous Referee #1

Received and published: 5 April 2017

General comments:

This study focused on the impact of water repellency (SWR) dynamics on soil respiration. During the growing season of three consecutive years the authors monitored water content, temperature, SWR and CO2 fluxes in topsoils of a grassland and a pine forest site located in eastern England. SWR was quantified in field-moist state with the commonly used water drop penetration time (WDPT) test. In order to parameterize the heterogeneity in SWR distribution the authors derived a parameter representing the relative fraction of extremely water repellent soil (i.e. WDPT > 3600 s). The results revealed a variable distribution of SWR with large temporal changes during the growing season which was explained by variation in soil moisture and temperature. The main

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outcome of the study is that the derived SWR distribution parameter was found to be associated with the measured CO2 fluxes, where the highest respiration rates were measured for variably water repellent soil.

There is a couple of studies emphasizing the potential role of SWR in explaining lag-effects of soil respiration observed after experimental droughts, but so far there is no study in which these effects were directly investigated in the field. In this regard the study by Urbanek and Doerr is timely and would be of potential interest to the readers of Biogeosciences.

However, in its current state, there are several issues with this generally well-written manuscript that need to be addressed. The most important concern I have with the manuscript is that due to the strong co-correlation between soil temperature, soil water content and SWR it is not clearly distinguishable whether the observed effects on CO2 efflux were due to temperature/soil moisture or SWR. This is, of course, a general problem with field studies and the reason why investigations on this issue are usually performed in the lab where the temperature and soil moisture effects can be controlled for.

Another crucial problem with this study is that SWR was determined only for the topsoil while soil respiration arises from the whole soil, making it hardly possible to directly relate these parameters. It is questionable what effect a heterogeneous distribution of SWR in the topsoil (0-10 cm depth) would have in the subsoil. So speculation about possible formation of preferential flow paths is not warranted, particularly when no information on subsoil SWR is available. Even if topsoil SWR is very heterogeneous it might have only a low impact on subsoil water distribution when the subsoil is completely wettable. It would therefore be necessary to investigate both SWR and soil moisture dynamics also in the deeper soil to be really able to infer their impact on soil respiration, consisting of both microbial and root respiration. Although SWR certainly affects the soil moisture pattern, it is soil moisture that actually controls soil respiration. There are several assumptions that are not justified based on the experimental findings

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of the study as well as inconsistencies in the discussion. Therefore, I would not support publication of the manuscript in its current form but encourage its resubmission after a substantial revision according to the points given below. It would certainly help to improve the manuscript if the results are treated and presented as being the outcome of a case study, meaning that a generalization of the observed effects is not necessarily possible.

Specific comments:

Title: The title states that spatially variable water repellency enhances soil respiration. This is not correct because it is not SWR itself but rather the (SWR-affected) soil water content (and temperature) that actually controls soil respiration. Replacing 'enhances' by 'is associated with high' would therefore be more appropriate. Moreover, using the term 'spatially' in the title is somewhat misleading as it suggests that the study was focused on the spatial distribution of SWR at the study sites. However, deriving conclusions about the spatial distribution of SWR is simply not possible based on the investigation of only six soil cores per site.

P1L7: Here, hydrophobicity is used as a synonym of soil water repellency. This is not correct because SWR covers the entire range of states where soil repels water, while hydrophobicity explicitly denotes a state where water is not able to penetrate the soil (often defined as having a soil-water contact angle above 90 degrees).

P1L18: The authors discuss preferential flow as a possible mechanism to explain their results. This is fine in the main text, however, as this was not proved in the study it is conjecture and should not be in the abstract.

P4L6: What is meant by 20-m transect here? Is 20 m the distance between the plots on the left and the plots on the right? If yes, then including a scale would certainly help the reader because it is not immediately intelligible from Fig. 1 that the plots are arranged along a transect.

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P7L18-20: Given the total number of measurement events (n = 16) I was wondering whether the removal of soil material approx. 10 cm away from the flux collars would not influence the moisture distribution and hence CO2 efflux. Could you please comment on that.

P8L7-8: The determination of WDPT frequency distribution and the SWR distribution parameter was based on measurements carried out on material from 4 depths at 6 plots. While SWR distribution with depth could be reasonably described, this is clearly not possible for the horizontal distribution as the plots were located several meters away from each other, not allowing to draw meaningful conclusions regarding the spatial dependence and spatial structure of SWR. Moreover, considering that the material for the SWR determination was extracted at some distance from the flux collars, it seems very difficult to directly relate the measured CO2 fluxes to the measured SWR distribution.

P12L18: What is meant by 'surrounding'? As the plots are several meters away from each other, it is not possible to draw any conclusion about the conditions of the surrounding soil (i.e. in close proximity).

P13, Figure 4: What is the rationale for using the standard error here (and in Figures 6, 7, 8 and Table 2)? Using the standard deviation (as in Table 1) is more appropriate to get an idea about the variation of the water content.

P20L5: The authors assume that the SWR distribution parameter can be used as a proxy of heterogeneity in soil moisture distribution in the flux collars, however, the validity of this assumption was not proved in this study and seems highly questionable considering the points mentioned above.

P20L8: The assumption that uniformly water repellent soil (SWR distribution = 1) is necessarily associated with homogeneously distributed low moisture content is not valid. This becomes immediately evident when considering that the calculation of this parameter is based on core material extracted from plots that were located several me-

ters away from each other. Considering the dimension of the soil cores (5 cm diameter, 9 cm length) it becomes clear that the SWR distribution parameter is not representative of the site and not even representative of the individual plot. In other words, it is easily conceivable that the wetting properties and thus the moisture distribution of the surrounding soil is different from that measured for the soil cores.

P22L21-22: Such detailed statements regarding SWR distribution at the sites are not justified (see comments above).

P23L3-5: Apart from the fact that spatial heterogeneity was actually not investigated in the present study (this is simply not possible by investigating only six soil cores per site) this statement is difficult to understand and in contrast to the assumption that SWR is the cause of preferential flow and a heterogeneous water distribution as stated, for instance, at P26L9-11. What is the authors' opinion? Is spatial variability of SWR caused by a spatially uneven infiltration into the soil which, in turn, is affected by preferential flow, or is SWR itself the cause of an uneven water infiltration and preferential flow phenomena?

P23L10-12: The statement in this sentence is not clear (see comment above). It is not proper to state that the preferential flow paths caused by SWR resulted in a high spatial variability of SWR.

P24L18-20: The statement in this sentence (high CO2 flux at high water content) is in contrast to the findings presented in Figure 7 and the conclusions and are not consistent with the 'model' presented.

P24L25: What is meant by 'severity of SWR'? Is it different from 'persistence of SWR'?

P25L8-10: The use of 'response' is not justified in this context because it is not SWR itself but rather the SWC (influenced by SWR) that actually influences soil respiration. Using 'associated' would be more appropriate ('... different CO2 fluxes were associated with different patterns of SWR ...').

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P25L11: Please check this sentence. What is meant by '... the more realistic effect of SWR ...'? (more realistic than ... ?).

P25L12: I have some issues with the 'conceptual model' presented in Figure 9. According to the model, wettable soil (Figure 9a) represents a condition where soil moisture is too high or soil temperature is too low for SWR to develop. The CO2 efflux associated with this particular state was found to be low. However, it was not SWR that caused the low CO2 efflux but rather the high water contents or the low temperatures (as was correctly stated by the authors). Hence, it is not justified to state that the model is accounting for the complex effect of SWR as both SWR and CO2 efflux are simply co-correlated and controlled by soil moisture and soil temperature. In addition, Figure 9c, which represents the 'water repellent state' with uniformly water repellent soil suggests extremely low water contents (near zero) as compared to the other states. Apart from the general problem of relating the measured parameters in the present study (please see comment to P20L8), the results presented in Figure 4 show that this is not necessarily the case. As shown in Figure 4a, there was a transition from a uniformly water repellent soil (on 19/7/13) to a variably water repellent soil (on 29/8/13 and 8/10/13), while the corresponding water content remained fairly constant around 10 vol-%, which is far from being completely dry (as suggested in Figure 9c). There is also some ambiguity about the intermediate (variably water repellent) state illustrated in Fig. 9b. What do the authors really think? Is SWR the cause of an uneven water infiltration and causes preferential flow phenomena, or is it the spatially uneven infiltration into the soil which, in turn, is affected by preferential flow that causes the high spatial variability of SWR (as stated at P23L3-5)? Generally, the proposed 'model' would only be valid for the specific conditions of the sites investigated. For instance, it is well conceivable that a wettable soil is characterized by an intermediate water content (particularly in case of sandy soils). And the occurrence of such a situation is also possible in summer as shown in a study by Buczko et al. (2007, Ecological Engineering 31: 154–164). Under such conditions (i.e. intermediate water contents and high temperature) microbial activity and CO2 efflux can be expected to be high (and might be even higher than for

variably water repellent soil). Overall, given the lack in general validity and explanatory power, using the term 'model' seems not appropriate, although the given explanations and the illustrations in Fig. 9 are valuable for understanding the observed effects on CO2 efflux at the investigated sites.

P26L16-19: Again, it is not reasonable to state that the intermediate state of SWR enhances soil respiration. It is indeed conceivable that CO2 efflux of a wettable soil, which is characterized by an intermediate and homogeneously distributed water content, is even higher than of a variable water repellent soil, provided that the temperature is high enough (see comment above and comments to P25L8-10 and the title)

P29L10-19: The conclusions presented here are not justified (see comments above).

Other minor points:

P1L12: SWR is introduced at P1L7 and should subsequently be used instead of 'soil water repellency' throughout the text. This should be checked carefully as there are many instances where 'soil water repellency' or 'water repellency' is used.

P2L5-7: The statement that soil moisture controls pore-water connectivity is self-evident and should be removed.

P3L4: SOC is introduced at P2L6 and should subsequently be used instead of 'soil organic C' throughout the text.

P3L18: Please check the style of the sentence (..., which ....., which).

P4L8: Please replace 'for' by 'at' (At each study site ..., and at each ...)

P6, Table 1: Please replace 'for' by 'of' (Selected soil properties of samples ...)

P7L6: Please replace 'for' by 'at' (At each study plot ...) and 'was' by 'were' (... soil collar were temporarily removed ...).

P7L12: I would suggest to replace the sentence by: '... was determined by fitting an

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exponential function to the evolution of CO2 concentration over time ...'.

P7L13-14: Please check the style of this sentence. In addition, could you please add information about the overall percentage of fittings with R^2 <0.95.

P7L19: Can you please specify what is meant by 'further soil measurements'.

P8L3: Was bulk density really determined after each field visit?

P8L7-8: Could you please state how many replicate measurements per plot and depth were carried out.

P8L18: Please check this sentence ('... to reduce oxides of N, CO2 and N2 were determined...')

P8L20: 'distilled' or rather 'deionized' water?

P8L22-23: Please use SWC instead of 'soil water content'. This should be checked carefully throughout the text.

P9L2-3: Could you please state the post-hoc test used in conjunction with the ANOVA.

P10, Figure 2: Please replace 'Air Temp' by 'Air temperature'.

P11, Figure 3: Consistent labeling should be used ('Soil temperature', 'vol-%'). Please use either 'Sampling event' or 'Soil sampling' in the legend. Is it correct that Fig. 3a begins with June 2013 while Fig. 3b begins with July 2013?

P12L6-7: Please use the same rank order for text and numbers (from low to high), i.e., '... slight to moderate (WDPT 6 to 600 s) ...' and '... slight to extreme SWR (WDPT 6 to >3600 s).

P13, Figure 4: Please be consistent with the labeling used in Figure 3 (vol-%) and use the same labeling for a and b (either 'Soil sample collection date' or 'Sample collection date'). Please use site designations consistently throughout the text and figures. Currently there are several variants, e.g., forest (T-f), forest site (T-f), Thetford-forest (T-f),

etc.

P14L10: Is 14°C correct? Figure 6 shows the highest fluxes at the forest site to be around 16°C. Is there any explanation for the large difference in temperature where the maximum CO2 fluxes were found?

P17, Figure 7: Please insert '(°C)' after 'Soil temp.'. 'temperature ranges' -> 'temperature bands'. Please replace '... for SWC's grouped into 10% SWC ...' by '... for SWC grouped into classes of 10 vol-% ...'.

P18, Table 2: The case '**p<0.01' does not appear in the table and should be removed.

P19, Table 3: Using * for referring to the footnote is not appropriate here as * is also used in the interaction term 'SWC * Temp'.

P19L18-21: This paragraph is not adequate in the Results section and should be moved to the Discussion.

P21, Figure 8: Please insert '(°C)' after 'Soil temp.'. Please use a consistent description of the temperature bands in Figure 8 and Figure 7 (P17).

P22L6 and L15: These statements here are inconsistent ('SWR was present for most of spring, summer and autumn' vs. 'SWR was observed from early summer until late autumn').

P22L23: Please delete 'and' in this sentence to read: '... frequent change between sufficiently dry and wet periods, ...'.

P22L24: Please change to '... which allows development ...'.

P23L3: Please replace the comma by 'and' to read: '... higher than 2013 and 20% higher than 2015.'.

P23L19: What is meant by C fluxes here? Referring to soil respiration would be sufficient here as no other C fluxes (e.g. transport of dissolved organic matter) were

investigated in the present study.

P24L13: The reference is lacking: what is meant by ‘this forest type’? This needs to be specified.

P24L16: Using ‘but’ in the context of this sentence is not appropriate.

P25L5-7: Please check the style of this sentence (‘... wettability conditions with uniformly low (wettable) and high (extreme) water repellency ...’ as well as ‘... when soil is dominated either by wettable soil ...’).

P25L12: Please check this sentence (‘Wettable soil ... represents a condition observed when a soil water repellency is absent . . .’).

P29L6: Please add an ‘s’ to read ‘... becomes severely ...’.

P29L10: Please change to ‘... were indeed associated ...’.

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