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Interactive comment on "The impact of extreme summer drought on the short-term carbon coupling of photosynthesis to soil CO_2 efflux in a temperate grassland" *by* S. Burri et al.

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Response to Anonymous Referee #1

General comments

This paper presents well conducted research on an important topic, that is the response of carbon allocation and carbon storage in grasslands to increased summer drought expected for the near future, using novel techniques (i.e. combined 13C-pulselabeling with online infrared laser isotope analysis of CO2 from soil respiration). Experiments were conducted in the growing seasons of 2010 and 2011 in a Swiss intensively managed lowland grassland ecosystem. Drought was implemented on three

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replicated plots in each of the two years by rainout shelters, equipped with a translucent screen, permeable also for UV-B radiation, for 8–12 weeks in each of the two years. 13C-labelwas applied at high dose (99.9 atom% 13C) with transparent chambers over a period of 90 min once on every plot (both on control and drought plots), a few weeks after installation of the rainout shelters. Soil CO2 efflux and its carbon isotopic composition were monitored online, whereas above- and belowground plant material was sampled at different times, starting with frequent sampling directly after labeling, and increasing the sampling intervals with time after labeling. The major finding was that, albeit drought reduced the total C uptake of the plants and also soil CO2 efflux, it increased the relative C allocation below ground, indicating that the plants were investing relatively more carbon into root growth than under non-drought conditions. The paper is well written and the data presented are in principle of high quality. However, a few issues have to be straightened before the paper should finally be accepted. Among those is the fact that obviously a very high variability of belowground biomass was found between the different plots and sampling times (see Table 2, data for belowground biomass especially in 2010). This was mentioned briefly in the Results section (p. 11685, l. 17-18). However, this fact was not properly addressed in the discussion, especially its potential implications for the interpretation of the data. Was it, for example, due to an inappropriate sampling methodology? As this data, together with the 13C information, form the basis for the quantification of the belowground carbon allocation, it is important to clarify. More specific comments follow below.

Response: We highly appreciate the referee's positive and encouraging evaluation of our manuscript. His/her detailed comments helped a lot in improving the text and describe details more precisely. Most of all, we thank the referee for his/her critical questioning regarding the results of the below-ground biomass. This triggered an in-depth reanalysis of our root biomass data. Although the results for the below-ground biomass in 2010 now have changed compared to the previous version (while the results for below-ground biomass in 2011 have changed only marginally), the results for below-ground biomass under the drought treatment in 2010 and 2011 resemble each other much more and the treatment effect in 2010 has become significant (Table 2 and document “Changes_Table2.pdf”). This also resulted in different 13C excess values for the below-ground biomass in 2010, and a recalculation of the recovery rates in 2010 and 2011. Accordingly, section 3.3 and Fig. 4 have been changed (see adapted Fig.4 as attachment). We agree with the referee’s concern about the high variability of below-ground biomass. Although the variability was reduced due to the re-calculation of the 2010 data, there is still high variability in the below-ground biomass data. However, we do not think that this variability is connected to an inappropriate sampling design/approach. One reason for high variability is probably the high natural and spatial variability in root density. Our setup allowed for three fully independent replicates per sampling point (three replicated plots per treatment), which might be on the low side of replication given the variability expected in the field. However, due to the overall experimental approach (pulse-labelling with laser spectroscopy in the field in a replicated drought experiment) and the dense sampling schedule for our study (please refer to section 2.3, where we added that the samples were weighed before grinding), it was impossible to sample below-ground biomass with higher replicates without disturbing our field site. Since managed grasslands are a highly dynamic system, large variability in standing below-ground biomass seems to be the rule rather than the exception.

Due to the reanalysis of the below-ground biomass data for in 2010, our results now show a more consistent drought response in both years (see section 4.4 which has been rewritten). Moreover, our data now more strongly confirm that the control plots in 2011 were subject to some drought stress as a result of the strong spring drought in 2011. All in all, we think that our data became much more consistent and the story of our manuscript simpler and more straightforward.

Specific comments

p. 11674, l. 6: add “under field conditions”, as e.g. Sanaullah et al. (2012) indeed looked at drought stress effects on carbon allocation, albeit under laboratory (microcosm) conditions (as correctly mentioned in the next sentence).

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Response: We added this as suggested.

p. 11674, l. 25f.: The hypothesis could be more specific, i.e. don't just say that you expect a reduced coupling between above- and belowground carbon allocation under drought stress, but hypothesize in which way the allocation pattern might be altered.

Response: We tried to specify our hypothesis accordingly.

Former text: "We hypothesized a tight coupling between above- and below-ground systems under normal conditions and expected the coupling to be reduced under drought stress, as it had been observed for beech saplings under drought (Ruehr et al., 2009; Barthel et al., 2011).

Adapted text: "We hypothesized a tight coupling between above- and below-ground systems under normal conditions and expected the coupling to be reduced under drought stress. If the latter resulted in a higher residence time of fresh assimilates in the above-ground biomass as observed for beech saplings under drought (Ruehr et al., 2009) or in a higher relative below-ground allocation of recent assimilates as shown under laboratory conditions(Sanaullah et al. (2012) for grasses, Barthel et al. (2011) for beech saplings) remained to be shown. Independent of the exact distribution within the plant, we anticipated the use of fresh assimilates in soil CO2 efflux to be reduced under drought conditions (Ruehr et al., 2009; Barthel et al., 2011)."

p. 11675, l. 7: When was this original seed mixture applied?

Response: The original seed mixture was applied in 2002. We added this to the text.

p. 11675, l. 13: Had always the same plots been subjected to drought stress since 2005, i.e. the plots used for the experiments in this paper?

Response: No, the plots used in this study were newly established in 2009, as the ones used since 2005 were heavily damaged by mice infestation. We added this information to the section 2.1.

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Added text: “The plots used for this study were newly established in 2009, since the ones used since 2005 at the same site were heavily damaged by mice infestation.”

p. 11675, l. 14/15: Already mention here that you had six blocks, and give the size of the plots.

Response: We changed this as below.

Former text: “The experimental setup was organized in a block-design, with each block consisting of a control (ctrl) and a drought-treated plot (tmt) which was covered by shelters during the treatment period. Plots were managed according to the management of the surrounding grassland, however, no fertilizer was applied.”

Adapted text: “The experimental setup was organized in a block-design with six blocks. Each block consisted of a control (ctrl) and a drought-treated plot (tmt) which was covered by shelters (3 x 3.5 m) during the treatment period. The core plots had a size of 1 x 2 m and were managed according to the management of the surrounding grassland, however, no fertilizer was applied.”

Consequently, we also changed a sentence at the end of this section concerning the shelter plots:

Former text: “Underneath the shelters, core plot areas of 1 x 2 m were set up to avoid edge effects.”

Adapted text: “The core plot area was centered underneath the shelters to avoid edge effects.”

p. 11675, l. 23 + 25: Here it is not clear what “two of the three replicates” and “on one replicate” mean. If you have six blocks, you have six treatment replicates. If you refer to the three blocks that were equipped with soil sensors, the wording is misleading.

Response: We changed the text to makes this clearer.

Former text: “On two of the three replicates, air temperature was recorded at 160 cm (ventilated system with the same sensors as for soil temperature records), and relative humidity of air was measured at 60 cm on one replicate (HC2-S3C05, Rotronic, Bassersdorf, Switzerland)."

Adapted text: "On two of the three blocks used for measuring microclimate, air temperature was recorded at 160 cm (ventilated system with the same sensors as for soil temperature records), and relative humidity of air was measured at 60 cm on one of the three blocks (HC2-S3C05, Rotronic, Bassersdorf, Switzerland)."

p. 11765, l. 22: Down to which depth were the soil samples taken?

Response: Down to 15 cm depth. We added this to the text.

p. 11678, l. 16-17: Don't refer the reader to a paper "in preparation". How shouldone get the information? If you can't cite a published or accepted paper, you have todescribe it.

Response: Yes, this is right. We deleted the citation.

p. 11679, l. 19: How were the errors propagated?

Response: By Gaussian error propagation. We added this to the text.

p. 11679, l. 23: What was the error threshold before 13C labeling? Also 35‰

Response: Yes, it was the same threshold for the pre-labeling phase. This is, of course, not ideal for natural abundance values. However, we built our manuscript mainly on the values after labeling. As we wanted to filter the whole data set with the same criteria, namely one that is suitable to filter the measurements after labeling, we decided to set this threshold. If one were to analyze natural abundance values alone, the threshold must have been set a lot lower.

p. 11681, l. 13: Setting biomass to zero after cutting ignores the few cm of standing biomass after a cut. How large is the estimated offset?

Response: We agree that this assumption has a drawback. However, we did not harvest the remaining biomass after the cut during our experiment, as this would have required a destructive sampling down to the ground, thus cutting the grass meristems as well, with no regrowth afterwards. Including an estimate of the remaining above-ground biomass/stubble would add one assumption more to our manuscript. This is why we decided to set the biomass to zero after cutting. However, ignoring the stubble biomass and its potential label in our calculation will rather result in a slight underestimate of the above-ground biomass at the time of labeling. However, this would then be a general offset for all plots, also for the controls, since the majority of stubble biomass is rather old growth, even before our treatment started.

p. 11684, l. 14f.: Make reference to Fig. 3 at an appropriate place also in this paragraph.

Response: We added a reference to Fig. 3.

p. 11685, l. 9-16: The order of the two sentences should be reversed for the sake of a (chrono)logical order (first describe the observations within the shelter period, then after the removal of the shelter).

Response: We reordered the sentences accordingly.

p. 11690, l. 27/pl. 11691, l. 1+2: This sentence should be better hyphenated with the previous sentence, as it appears a bit isolated.

Response: We changed this as follows:

Former text: "Wolf et al. (2013) could show a reduction in gross primary productivity at the same site during the spring drought in 2011 compared to 2010 by eddy covariance measurements."

Adapted text: "This is confirmed by Wolf et al. (2013) who could show a reduction in gross primary productivity at the same site during the spring drought in 2011 compared to 2010 by eddy covariance measurements."

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Table 2: How can the linearly interpolated values for aboveground biomass be lower than the two endpoints of the reference period?

Response: As described in section 2.5 (p.11681, l. 11-15), the interpolated value was estimated by linear interpolation between two cut dates. For the interpolation, the biomass was set to zero after the cuts on 1 July 2010 and 26 May 2011 (as an approximation), as the grass was cut on these days (and the corresponding above-ground biomass was harvested). Therefore, growth started on 2 July 2010 and 27 May 2011 from zero, reaching the values of the 2nd cuts on 25 August 2010 and 15 July 2011.

Table 2: How can belowground biomass decrease by 40 or even almost 60% in control and treatment plots within a period of nine days (between 21 and 30 July 2010)?

Response: As stated above, we re-analyzed the data for below-ground biomass in 2010 (Please see the revised Table 2). Nevertheless, among spatial variations in root biomass, also temporal variability due to management has to be considered. With the cut, above-ground biomass is reduced to a large extent, which probably also impacts the root-to-shoot ratio of the sward (compare ratio at 1st cut: 2010 ctrl: 1.0, 2010 tmt: 4.35; 2011 ctrl: 5.2, tmt: 8.0), to interpolated value: 2010 ctrl: 1.4, tmt: 10.3; 2011 ctrl: 4.3, tmt: 16.6, to 2nd cut: 2010 ctrl: 0.46, tmt: 3.2; 2011 ctrl: 1.39, tmt: 5.04). Thus, while the sward regenerates after each cut, also root biomass is regrown.

Technical corrections

p. 11673, l. 28: Replace "under solar radiation and temperature" with "at higher solar radiation and temperature. Response: We changed this accordingly.

p. 11675, l. 3: Replace "took place" with "were conducted". Response: We changed this accordingly.

p. 11678, l. 6: delete "took place"; "diameter" (singular) Response: We changed this accordingly.

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p. 11679, l. 10: “tracer release with soil respiration” Response: We changed this accordingly.

p. 11682, l. 6 + 16: replace “after label stop” with “after labeling” Response: We changed this accordingly.

p. 11684, l. 23: replace “during which” with “when”. Response: We changed this accordingly.

p. 11685, l. 6+8+13: replace “into the shelter period” with “after shelter installation” Response: We changed this accordingly.

p. 11685, l. 11: delete “2010 and 2011” (it’s clear) Response: We deleted the years in the brackets, as it does not seem to make sense otherwise.

p. 11685, l. 16: replace “were recovered” with “was recovered” Response: We changed this accordingly.

Table 1: replace “Control” and “Treatment” with “ctrl” and “tmt” in the table, as the abbreviations are defined in the table header. Response: We changed this accordingly.

Table 2: Header: replace “at cuts” with “at the time of cutting” and write “interpolated values that were used”. Response: We changed this accordingly.

On behalf of all authors, Susanne Burri

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Former Table 2

Table 2: Mean standing above-ground biomass (at cuts) and below-ground biomass (sampled) for 2010 and 2011 before and after the pulse labeling experiments as well as the linearly interpolated value that was used for calculating ^{13}C excess. SE is given in brackets (n=3). [a] $p \leq 0.01$ denotes significance level.

	Above-ground biomass			Below-ground biomass		
2010	Cut	Interpol.	Cut	Sampled	Interpol.	Sampled
Date	01 July	22 July	25 August	21 July	22 July	30 July
Ctrl [g m^{-2}]	116 (44)	83	218 (21)[a]	635 (382)	607	386 (57)
Tmt [g m^{-2}]	114 (24)	47	123 (24)	1357 (595)	1270	572 (64)
Tmt/Ctrl [%]	98	57	56	214	209	148
2011	Cut	Interpol.	Cut	Sampled	Interpol.	Sampled
Date	26 May	10 June	15 July	06 June	10 June	11 June
Ctrl [g m^{-2}]	44 (11)	79	261 (45)[a]	225 (67)	335	362 (29)
Tmt [g m^{-2}]	41 (8)	19	62 (18)	325 (104)	315	313 (92)
Tmt/Ctrl [%]	89	24	24	144	94	86

Fig. 1. Changes_Table2

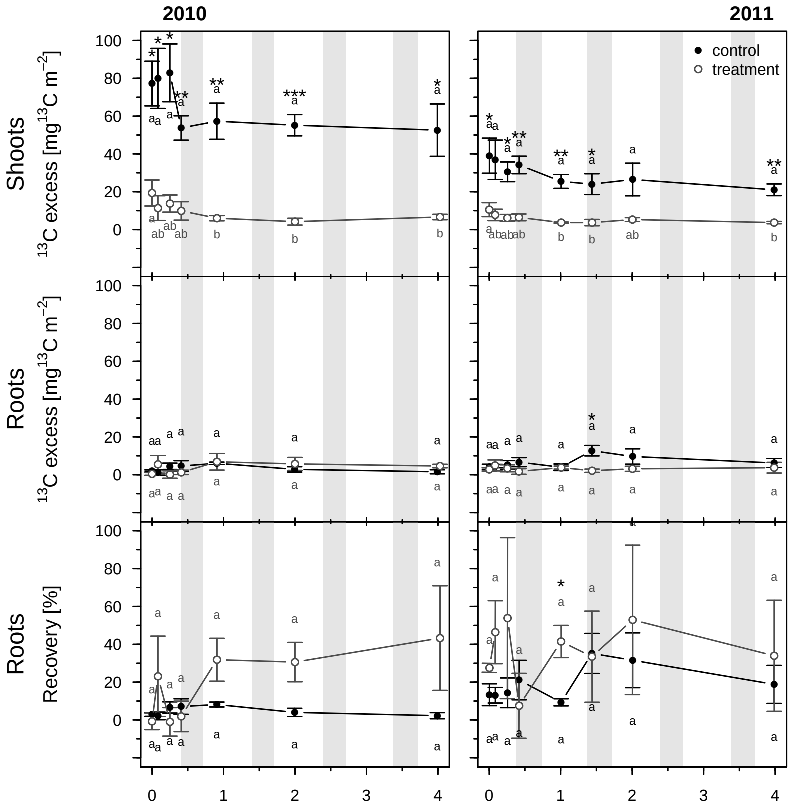

Fig. 2. Changes_Fig4

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