

Authors' response to reviewer' comments on the manuscript bg-2017-322 "*Variations and determinants of carbon content in plants: a global synthesis*" by Suhui Ma et al.

To the editor:

Dear Dr. Akihiko Ito,

Thank you very much for the constructive comments and suggestions from you and the two reviewers. These comments were summarized as two major points: (1) explaining the application of the C content, and (2) adding discussions on the interactive effects of climatic factors and life form on the variation of plant C content. We have carefully addressed these comments in this revised manuscript. Please find our point-to-point responses to these comments as attached at the bottom of this letter. We also attach our updated manuscript with the "track changes" option.

We are looking forward to receiving your decision.

Best wishes,

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To Anonymous Referee #1:

[Comment] General comments

This manuscript describes a synthesis of carbon (C) content measurements in plants i.e., the fraction of biomass that is C. This is quite important, as many researchers assume that this value is, e.g., 45-50%, without measuring it themselves, and systematic errors could bias ecosystem- to global-scale estimates of vegetation C pools. The authors assemble a large dataset from both TRY and the scientific literature and analyze the effects of plant organ, life form, latitude, etc., on reported C values. In general, I think this is a very worthy effort, and the analysis seems solid in most respects.

[Reply] Thank you very much for your encouragement.

[Comment] 1. The text says that “interactive” factors were explored, but there’s no mention of interactive effects in the results, and it’s not clear, for example, whether the latitudinal trends shown are independent of life form. It seems to me really important to report type III SS and interactions, so that readers understand the relative importance and relationships of the tested factors. This would also allow the text to be clearer and more prescriptive about the primary effects and what values or ranges researchers should use.

[Reply] Thanks. Following your suggestions, we have analyzed the interactive effects by using *varpart* function in the revised version. The interactive explanations of climatic factors and life form on the variation of the C content ranged from 0.7% in the stems to 15.7% in the reproductive organs. This indicated that the changes of plant C content along latitudinal or climatic gradient may not be independent of life form. We have added these results in the revised manuscript [Lines 125-127: “The interactive explanations of climatic factors and life form on the variation of C content of the reproductive organs, roots, leaves, and stems were 15.7%, 3.6%, 5.2%, 0.7%, respectively.”].

As you recommended, we have also used the general linear model (GLM) and the *anova* function in the *car* package to report the type III SS. The C content of plant organ was significantly affected by climatic factors ($p < 0.05$ in stem), life form and their interaction ($p < 0.05$ in all cases except for reproductive organ), respectively (Table S3-S6). We added in the section of Materials and methods [Lines 101-103: “Additionally, a linear model and an analysis of variance with the type III were performed to test the variations of C contents explained by climatic factors and life forms.”] and Result [Lines 120-121: “The C content of plant organs was significantly affected by climatic factors ($p < 0.05$ in stem), life form and

their interaction ($p < 0.05$ in all cases, except for reproductive organ), respectively (Tables S3-S6).”] in the revised manuscript.

Table S3. The summary of anova (Type III tests) for plant C content in reproductive organs. Climatic factor includes mean annual temperature (MAT) and mean annual precipitation (MAP).

Factor	Sum Sq	Df	F value	P value
Intercept	4771	1	366.48	< 0.001
MAT	6	1	0.46	0.50
MAP	8	1	0.61	0.44
Life form	3	2	0.10	0.91
MAT: MAP	85	1	6.66	0.01
MAT: Life form	9	1	0.65	0.42
MAP: Life form	29	1	2.25	0.14
MAT: MAP: Life form	2	1	0.14	0.71
Residuals	1172	90		

Table S4. The summary of anova (Type III tests) for plant C content in roots. Climate factor contains mean annual temperature (MAT) and mean annual precipitation (MAP).

Factor	Sum Sq	Df	F value	P value
Intercept	5831	1	359.17	< 0.001
MAT	2	1	0.12	0.73
MAP	4	1	0.27	0.60
Life form	256	3	5.25	<0.01
MAT: MAP	5	1	0.28	0.59
MAT: Life form	328	3	6.73	< 0.001
MAP: Life form	73	3	1.49	0.21
MAT: MAP: Life form	424	3	0.87	0.46
Residuals	28717	1769		

Table S5. The summary of anova (Type III tests) for plant C content in leaves. Climate factor contains mean annual temperature (MAT) and mean annual precipitation (MAP).

Factor	Sum Sq	Df	F value	P value
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Intercept	6517	1	510.08	< 0.001
MAT	22	1	1.72	0.19
MAP	39	1	3.09	0.08
Life form	2829	3	73.81	< 0.001
MAT: MAP	13	1	1.00	0.32
MAT: Life form	371	3	9.68	< 0.001
MAP: Life form	818	3	21.34	< 0.001
MAT: MAP: Life form	471	3	12.29	< 0.001
Residuals	222234	17393		

Table S6. The summary of anova (Type III tests) for plant C content in stems. Climate factor contains mean annual temperature (MAT) and mean annual precipitation (MAP).

Factor	Sum Sq	Df	F value	P value
Intercept	83	1	7.75	0.01
MAT	104	1	9.72	<0.01
MAP	108	1	10.11	<0.01
Life form	286	3	8.92	< 0.001
MAT: MAP	107	1	10.03	<0.01
MAT: Life form	129	3	4.02	0.01
MAP: Life form	136	3	4.25	0.01
MAT: MAP: Life form	108	3	3.36	0.02
Residuals	35321	3311		

[Comment] 2. On a related note, no code or data availability is specified (and please note that “available from the authors” is not, in my opinion, acceptable). It’s 2017, and I expect all code and data (at least that backing the main results) to be included as supplementary info, or posted in a repository. It’s not acceptable to produce results from a black box, and there’s a huge benefit to making the data (for future analyses) and code (so readers can see exactly what was done) available. At the very least, why not contribute your assembled literature data back to TRY?

[Reply] Thanks. We will upload the *R-software* codes and relevant data of this study in the revised manuscript. Following your suggestions, we will contribute our data to TRY to benefit more studies.

[Comment] 3. Finally, while I appreciate the difficulties of writing in a foreign language, the current manuscript has many minor errors and thus frustrating to read. Please work with either an editing service or English-fluent colleague to improve it in this respect.

[Reply] Thanks. We have polished the manuscript writing with colleagues' help.

Specific comments

[Comment] 1. Lines 23-25: unclear ending; more suitable than what?

[Reply] Thanks. Specific C content values from different organs and life forms may be more suitable than the canonical value of 50% to evaluate global vegetation C stock. We have revised this sentence in the revised manuscript [Lines 21-23].

[Comment] 2. L. 44: "ignores"

[Reply] Thanks. We have corrected the writing.

[Comment] 3. L. 136: can you give examples of large-scale studies that have assumed a 50% value?

[Reply] Thanks. According to your comments, we have added some case studies of the large-scale C stock estimations using 50% in Lines 133-135 as following: "the canonical value of 50% which was widely used to convert vegetation biomass to C stock at large-scales, such as in temperate forests (De vries et al., 2006), tropical forests (Lewis et al., 2009; Saatchi et al., 2011), and global forests (Keith et al., 2009).".

[Comment] 4. L. 157-158: "Plant organs: are likely"

[Reply] Thanks. We corrected this in the revision.

[Comment] 5. L. 163: consistent? Inconsistent?

[Reply] Thanks. It is consistent. We have corrected it.

[Comment] 6. L. 198: how specific? Do researchers need to use latitude-weighted values? Life form weighted? It would be good to very clear: what are the most important factors for researchers to consider, if they need a C content value and aren't going to measure one themselves? E.g. "We recommend using the values given in Table 1, which are specific to plant organ and life form."

[Reply] Thanks for your insightful comments. Our results showed that C content varied significantly among plant organs and life forms. Thus, we recommend using the values given in Table 1, which are specific to plant organ and life form. We have revised this in the revision [Lines 185-186: “Thus, specific plant C contents given in Table 1 provided an alternative to IPCC for their guidelines to update the plant C fractions and could improve the accuracy of vegetation C stock estimations.”].

[Comment] 7. L. 356: latitudinal trend after accounting for other factors?

[Reply] Thanks. Similar to the statistical analysis of Han et al. (2011), we did not account for other factors, because we focused our study on exploring the biogeographical pattern of plant C content. We have made modifications in Materials and methods section [Lines 97-98: “A linear model without accounting for other factors was used to explore the biogeographical pattern of plant organ C content along the latitudinal gradient, as well as the relationships between plant organ C content and MAT and MAP (Han et al., 2011).”].

To Anonymous Referee #2:

[Comment] General Comments: This paper reports the findings of an extensive literature review to determine the carbon content of plants with respect to different organs in individual plants, between plant species and along a latitudinal gradient. While the review is comprehensive, I wonder how these results will be applied in any practical way? The authors present a superficial analysis of how their results are different from canonical values typically used for plant carbon content, but the reader is left to wonder how the results reported here will be used in any practical way?

One concern that I have is that this paper seems ill-fitted to the journal *Biogeosciences*. There's no biogeoscientific data provided and the findings are not discussed in a biogeoscientific context.

[Reply] Thanks for your comments. As we know, plant C content is critical to assessment of global C cycle and ecological stoichiometry. The most widely employed C content in plants is 50% both at the regional and global scales for the estimations of vegetation C stock (e.g. Saatchi et al., 2011; Li et al., 2016; Borchard et al., 2017). However, plant C contents varies significantly with different organs, life forms, and biomes, and even across individuals (Elias and Potvin, 2003; Tolunay, 2009; Martin and Thomas, 2011; Yao et al., 2015). Using the default value of 50% as biomass-C conversion factor can lead to biases in vegetation C stock estimations (Zhang et al., 2009; Martin and Thomas, 2011; Rodrigues et al., 2015). To reduce the uncertainty, several studies have used the species-specific organ C contents to evaluate the stand vegetation C stocks (Jones and O'Hara, 2012; Rodrigues et al., 2015; Wu et al., 2017). Nonetheless, it is hard to obtain available data of C content and biomass allocation for every species and organ in practical applications. At large scales, the generalized C contents of specific woody species provide an alternative to the realistic estimations (IPCC, 2006; Thomas and Martin, 2012; Wu et al., 2017). However, the lack of plant C contents of other life forms (such as herb, crop, vine, etc.) still constrains the accurate estimation of vegetation C stocks at large scales.

Therefore, in this paper, we explored the C content of different life forms and organs using the largest C content dataset to date. The dataset covers woody plants, herbs and other life forms plants (i.e. crop, vine, fern, bamboo). Moreover, our result can be an alternative for the IPCC guidelines to update the C fractions. The practical applications of specific C content will improve the accuracy of vegetation C stock estimations and our understanding of terrestrial C cycle. We have added these in the Introduction [Lines 31-60] and the

Conclusion sections [Lines 185-189] .

In addition, accurate estimation of the vegetation C stock can help us to understand the responses of global C cycles and terrestrial ecosystems to global changes, which is one of major scopes of *Biogeosciences*. Many studies focusing on the estimation of vegetation C stocks across the world's terrestrial biomes have been published in *Biogeosciences* (e.g., Fyllas et al., 2009; Petrescu et al., 2012; Guo et al., 2014; Nyirambangutse et al., 2017). Therefore, we believe that our paper is suitable to *Biogeosciences*. Thank you for your understanding.

[Comment] 1. Specific Comments: You point out that C content varies across individuals (line 57), and that your results suggest that overestimating the carbon content of plant organs could introduce errors ranging between 3.77-13.8% in regional C stock. I wonder if this 3-14% is larger than the variance between individuals, and if not, how much uncertainty does the inter-individual variation add to a regional C stock estimation? Are your findings significant compared to the uncertainty due to different C content between individuals?

[Reply] Thanks for your comments. As you pointed out, plant C content from the same organ and the same species in one site varies across individuals (Elias and Potvin, 2003). Compared with the species-specific C content, several studies have showed that the canonical value of 50% could introduce errors ranging from 3.77% to 13.8% in regional C stock (Bert and Danjon, 2006; Tolunay, 2009; Fang et al., 2010; Rodrigues et al., 2015). Following your suggestions, we calculated the mean individual variation of plant organ C contents using the formula of Bert & Danjon (2006). Our result showed that the mean individual variations in roots, leaves and stems were -0.61% (-1.34~2.56%), 0.13% (-0.01~0.23%), and 0.19% (-0.63~1.01%), respectively, implying that variations among individuals of certain species are less than the variations among life forms (e.g. 3.77 – 13.8% in previous studies). Hence, the specific C contents of different life forms in our study could be useful in global and regional C stock estimation.

[Comment] 2. Page 7, line 148: Are the differences between your values and those used by the IPCC significant?

While I appreciate the effort to quantify the plant organ C content, if you were to consider the carbon stock of an entire plant, for example a tree, given the % mass that each organ contributes to the overall C mass of the individual tree, is 50% that far off? It's difficult to decipher this from the text, but I would imagine that this is the number that

would be of most interest to someone trying to apply this data, for example, calculating a regional carbon pool.

[Reply] Thanks for your comments. Following your suggestions, we conducted one sample Student's t-test to determine whether the stem C content of woody plants significantly differed from the default value of 50% and the IPCC values (47%, 48% and 51%). The stem C contents in our results were significantly lower than that of temperate broad-leaved woody species (47.7% and 47.8% vs. 48%; $p < 0.001$ and $p = 0.018$, respectively) and conifers (50.5% vs. 51%; $p < 0.001$), but were significantly higher than those of tropical broad-leaved woody species (47.7% and 47.8% vs 47%; $p < 0.001$ and $p < 0.001$) proposed by IPCC (2006). We have added these results in the new manuscripts [Lines 92-94: “and thus the one sample Student's t-test was used to determine whether the stem C content of woody plants significantly differed from the default value of 50% and the IPCC values (47%, 48% and 51%), respectively.”] and [Lines 140-142:“ However, these data were significantly lower than the values of temperate broad-leaved woody species (48%; $p < 0.001$ and $p = 0.018$) and conifers (51%; $p < 0.001$), but higher than that of tropical broad-leaved woody species (47%; $p < 0.001$ and $p < 0.001$) proposed by IPCC (2006).”].

Additionally, we have not found relevant studies that have reported the detailed biomass allocation of each plant individual in terrestrial biomes. The unclear biomass allocation limited our calculation of the biomass-weighted C contents of each organ of specific individuals. Thus, as we addressed in the Introduction section [Lines 50-51], “the generalized C contents of specific life forms provide an alternative for realistic estimations”. From the perspective of practical application, the organ-specific and life form-specific C contents in our study may improve the accuracy of the estimation of regional and global vegetation C stocks.

[Comment] 3. Page 8, line 177: But your results suggest that life form is more important than climate

I'm having a tough time following your argument. If I have this right, life form is the dominant control on C, not climate. But doesn't climate influence life form, particularly along a latitudinal gradient where climate will influence the length of the growing season, water availability, photosynthetically active radiation, etc... I guess I don't understand how you can talk about life form independently from climate and attribute it to carbon content. Are you suggesting that within the same species that a latitudinal gradient exists with respect to carbon content? If so, it's unclear.

[Reply] Thanks for your comments. Indeed, climate affects plant physiological processes through changing the length of growing season, water availability, photosynthetically active radiation, etc., and shaping life form distribution and the community species compositions. In other words, climate is the key factor driving plant physiological processes and determining species compositions (Araújo et al., 2004; Bertrand et al., 2011). Moreover, the distributions of plant life forms are also affected by phylogenetic evolution, soil fertility, topographic condition, biotic interactions, and anthropogenic activities (Furley and Newey, 1979; Linhartyan and Grant, 2003; Wang et al., 2009).

Our result showed that the independent explanations of climatic factors (MAT+MAP) (0.2 – 8.4%) on the variation of organ C contents (analyzed by pooled data of each organ in all life forms rather than species) were lower than that of life form (7.2% – 21.5%). Thus, life form may directly drive the variation of plant C content. Further, we found that plant C content decreased with increasing latitude, which was consistent with the changes of life forms along the latitude. The proportion of woody plants tended to decrease while that of herbs increased with increasing latitude and decreasing MAT and MAP (Fig. S1). Hence, the compositions of life form of regional vegetation may largely explain the variation of plant C content at the latitude.

Our result was consistent with the previous studies that life form influenced greatly the plant C content (Fyllas et al., 2009; Zhao et al., 2016). Additionally, the universally constrained C:N:P ratios of plants shows the close relationship among C, nitrogen (N) and phosphorus (P) contents (Hessen et al., 2004; Fyllas et al., 2009; Zhao et al., 2016). At large scales, that leaf N and P stoichiometry varies remarkably among life forms also supports our conclusion (Han et al., 2011; Zhao et al., 2016; Tian et al., 2017). According to your comments, we have rewritten our discussion to avoid misunderstanding [Lines 162-180]. Thank you again!

Technical Corrections:

[Comment] Page 3, line 38: biogeochemical cycling? Page 3, line 44: ignores; Page 3, line 49: compared; Page 4, line 66: patterns; Page 4, line 71: literatures; Page 4, line 77: that used; Page 5, line 105: A linear model; Page 6, line 106: latitudinal gradient; Page 6, line 111: A linear model.

[Reply] Thanks for your comments. We have corrected all these wordings.

[Comment] Page 6, line 125: should it be $p < 0.15$ and $p < 0.05$?

[Reply] Thanks. Their p values were 0.147 and 0.053, respectively. We have revised these in the new manuscript [Lines 118-119] as following: “while reproductive and stem C content displayed no significant latitudinal trend ($r^2 = 0.02$, $p > 0.05$; $r^2 < 0.01$, $p > 0.05$; Fig. 3, Table S2). ”

[Comment] Page 8, line 180: Doesn't this belong in the Results section?

[Reply] Yes. Following your suggestions, we have deleted this sentence in the Discussion section and rewritten the Results section.

[Comment] Page 9, line 189: shapes the biogeographic patterns... Page 9, line 199: “Besides”?

[Reply] Thanks. We deleted “Besides” in the revised manuscript.

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