Point-by-point Responses to Reviewers

Note: text in black are the comments, and text in deep blue are our responses.

We appreciate reviewer's constructive comments on our manuscript. We carefully considered each comment and revised the manuscript accordingly.

Responses to Reviewer 1

Comment 1: The manuscript is very well written and presents very interesting and extremely useful data not only for a global soil science community but also for any related field interested in biogeochemical fluxes and pools. As the background, aim, methods and results are clearly and with high quality standards presented, I have only minor comments. One important request from my side would be, that the readme file of the presented data would be extended to make the data tables self-explainable. E.g., looking at the rf.dat.csv file, units are not clear and BIOMES, BEDROCK, SOIL TYPE is not clear what the categorical numbers given represent. Same holds true for the covstack.dat.csv and the raw.data.csv files. The readme.txt does not explain units or legends (e.g. what is a "1" for BIOME or BEDROCK). One option would be to include Table 1 somewhere in the readme file and add information needed on parent materials, vegetation types, bedrock and soil orders.

Response 1: We really appreciate your positive comments. As suggested, the revised readme file (a word file) has included Table 1 in our main text, which includes units of each numeric variables. And we have added three more tables in the readme file to explain the meaning of numbers in each categorical variable. We have uploaded the updated readme file to 10.6084/m9.figshare.14583375.

Comment 2: Another general comment would be that it is not clear how you excluded agricultural land and on which basis you separated between natural – semi natural and extensively used (grass-)land. It is a great idea, to not mask out cropland or other heavily influenced areas in your map and data tables but instead present the predicted "background" or "natural" values. However, I think this also needs to be described in the readme file very briefly to avoid misunderstanding and misuse of data. May be this should also be stated in the abstract, to make very clear, that you give "potential natural background" values of P in these areas.

Response 2: Many thanks for pointing this out. In the previous version, we have described how we excluded data from agricultural and other heavily influenced areas only in the method. In the revision, we have described our criteria to collect data in the introduction to make the criteria clear to readers when reading the introduction (Lines 78-79 in the revised manuscript). To avoid a misuse, in the Fig. 5 of main text, we have marked cropland areas in our predicted maps as a reminder that our predicted values in these grid-cells indicates "potential natural background" values. This has also been described in the introduction (Lines 80-82) and new readme file (Note 1).

Abstract

Comment 3: Very well written indeed!

Response 3: Thanks a lot.

Comment 4: 23: what do you mean "predictions increased"? The predicted amount increased? Or reliability of predictions increased?

Response 4: We meant the predicted concentration increased with latitude. In the revision, we have rewritten the sentence as "predicted soil total P concentration increased significantly with latitude" to avoid this misunderstanding (Line 24).

Introduction

Comment 5: Also very well written and interesting to read.

Response 5: Thanks a lot.

Comment 6: 78: do you mean to say that you explicitly exclude agricultural used soils? This is not clear (was only clear after reading the methods). And if so, on which basis did you do this separation between natural – semi-natural (extensively used grassland?) and agricultural (arable and intensive grassland?).

Response 6: Yes, we explicitly excluded agricultural used soils from our database. We collected data only from (semi-)natural ecosystems, based on sampling description in the original databases and literature. We defined (semi-)natural ecosystems as ecosystems without any documented significant anthropogenic activities such as tillage, fertilization, and heavy grazing. Forests with a stand age greater than 10 years were considered as (semi-)natural ecosystems. We have added these descriptions to the revised introduction (Lines 78-79).

Comment 7: 83: global total P stock including "background values" of agricultural soils? So this would be some kind value of potential P content with no human influence?

Response 7: Yes, we meant "potential background values" without direct human disturbance. We have described this clearly in the revised introduction (Lines 80-82).

Methods

Comment 8: 93-94: which efforts? What are the criteria?

Response 8: We have added one sentence to describe how we excluded soils from anthropogenic disturbance (Lines 94-95). "We carefully checked description of soil sampling in every cited paper to ascertain if the soil sample experienced any documented significant anthropogenic activities such as tillage, fertilization, and heavy grazing." Forests with a stand age greater than 10 years were considered as (semi-)natural ecosystems and included in our database.

Comment 9: 97 why web of science and not google scholar? Web of science often seems exclusive of some journals or data sets which are still peer reviewed.

Response 9: Data in papers included in the databases of Web of Science have been generally strictly peer reviewed, and thus should be generally reliable. Some data or journals that are not included in Web of Science but included in Google Scholar may be still peer reviewed, but could be difficult for us to distinguish them from those not peer reviewed, and may be difficult for us to judge the quality of the data (e.g., while without clear land-use history description). Meanwhile, our aim is to collect a spatially representative database, not a comprehensive one (which is very unlikely to be achieved, given the huge amount of data in literature). There is a trade-off between selectivity (only relevant references are selected) and sensitivity (all the selected references are relevant) here. Google Scholar is excellent for sensitivity, but very inefficient for selectivity. Therefore, we have used the Web of Science to search and collect the data.

Comment 10: Figure 1 and lines 140-141: would it be possible to also give WRB soil types? This might increase understanding (and citation) in the whole of Europe soil science community.

Response 10: Many thanks for this advice. We have added WRB soil type as a variable in the updated rf.dat data frame. Please check the updated rf.dat data frame stored in Figshare (10.6084/m9.figshare.14583375). We also summarized the soil total P concentration in relation to different WRB soil types and added these results in a table in the supplementary file (Table S6). We extracted WRB soil type of each site from a global WRB soil type map (Hengl et al., 2017) based on the geographical coordinates. And we mentioned the method to extract WRB soil type of each site (Lines 148-150) and the result in main text (Lines 227-229).

Reference:

Hengl, T., et al.: SoilGrids250m: Global gridded soil information based on machine learning. PLoS One, 12, e0169748, 2017.

Table S6 Soil total P concentration (mg kg^{-1}) in WRB soil types at 0-100 cm depth. Results based on our database. P10, P25, P75, and P 90 indicate the percentile rank of 10%, 25%, 75%, and 90%. Only WRB soil types with more than 10 observations are shown here.

WRB soil type	Count	Min.	P10	P25	Median	Mean	P75	P90	Max.
Cryosols	59	36.3	282.6	646.5	1078.0	1152.2	1525.0	1968.4	3470.0
Phaeozems	153	43.1	96.3	205.1	641.0	1122.6	987.7	3192.0	9630.0
Leptosols	170	35.0	253.1	390.6	592.9	1114.1	957.3	3155.0	9020.0
Nitisols	24	99.1	398.8	578.3	742.8	766.5	1012.9	1164.7	1367.0
Andosols	258	11.0	111.7	240.9	578.1	656.5	881.6	1362.7	2850.0
Albeluvisols	69	124.8	264.4	401.1	585.1	655.3	808.7	1039.8	2374.8
Cambisols	1010	9.8	171.8	358.5	581.5	650.7	805.0	1110.3	4433.0
Vertisols	56	14.1	175.0	247.5	415.5	634.0	723.8	1259.0	2900.0
Histosols	21	90.6	167.2	184.4	305.3	631.7	1370.7	1450.6	1505.2
Calcisols	107	17.7	88.9	232.7	450.0	630.4	658.5	1317.4	4243.0
Luvisols	534	3.3	99.9	239.1	489.4	585.6	799.5	1187.0	4800.0
Alisols	223	34.0	190.0	319.1	476.0	578.5	665.5	1010.0	3680.0
Chernozems	122	37.0	107.2	238.2	470.9	573.0	654.4	1327.4	3480.0
Podzols	185	14.5	104.3	203.9	327.5	546.7	732.0	1160.5	3444.2
Kastanozems	341	20.3	38.7	222.1	411.9	513.0	604.0	760.0	5520.0
Fluvisols	82	83.5	154.4	245.0	331.5	477.8	516.3	785.0	3320.0
Solonchaks	50	16.7	254.8	329.5	518.0	466.7	641.7	674.6	685.7
Acrisols	916	3.0	105.8	200.0	364.4	443.6	575.4	856.9	3898.0
Gypsisols	34	63.0	176.6	289.3	410.9	384.2	472.3	573.3	664.1
Gleysols	46	58.6	72.4	99.7	147.5	373.6	400.3	900.0	3200.0
Ferralsols	257	16.0	86.9	148.0	254.4	307.7	380.0	537.3	1997.0
Regosols	23	100.0	116.0	155.0	250.0	277.7	315.0	356.0	820.8
Lixisols	106	1.4	11.0	21.3	106.7	258.7	326.2	653.2	3090.0
Arenosols	167	24.3	31.8	38.3	52.9	171.1	267.8	543.5	1355.0

Comment 11: 179-180 this is a great idea, to not mask out cropland or other heavily influenced areas. However, I think this also needs to be described in the readme file very briefly to avoid misunderstanding and misuse of data. May be this should also be stated in the abstract, to make very clear, that you give “natural background” values of P in these areas.

Response 11: We appreciate this advice. As described in Response 2, to avoid a misuse, we have marked cropland areas in our predicted maps (Fig. 5 of main text) as a reminder that our predicted values in these grid-cells indicates “potential natural background” values. This has also been described in the introduction (Lines 80-82) and new readme file (Note 1).

Results

Comment 12: I think it would be very interesting, if you would extend Tables 2 and 3 to the 0-30 cm layer, so give 0-30 and 0-1m, separately.

Response 12: Many thanks for this advice. In the revision, we have extended Table 2 and 3 to give 0-30 cm and 0-100 cm separately (Table 2 and 3 in revision).

Comment 13: 214 – 216 this is surprising as we would expect strongly weathered soils to be significantly lower than intermediate weathered soils, and intermediate soils higher than young, low weathered soils. Any explanation?

Response 13: To our knowledge, as Walker and Syers (1976) conceptual model predicts (Figure 1): soil total P concentration decreases during soil development. At the beginning of soil development, all soil P is in the primary mineral form. With time, P in primary minerals decrease, while organic P and occluded P accumulate, total P declines due to losses in dissolved or particulate form. The decreasing trend of soil total P with soil development (or weathered extent) is well supported by our results and previous studies (i.e., Cross and Schlesinger, 1995; Yang and Post, 2011; Yang et al., 2013) with uplift modulating the evolution of total soil P (Buendía et al., 2011). We didn’t discuss the relationship between soil total P and soil order, because a similar pattern has been discussed in these studies, and soil order is less important than four other predictors we discussed in the manuscript, i.e., parental material, SOC, soil sand content and MAT.

Indeed, as Walker and Syers model predicted, soil available P may peak at intermediate weathering stage, but not total P.

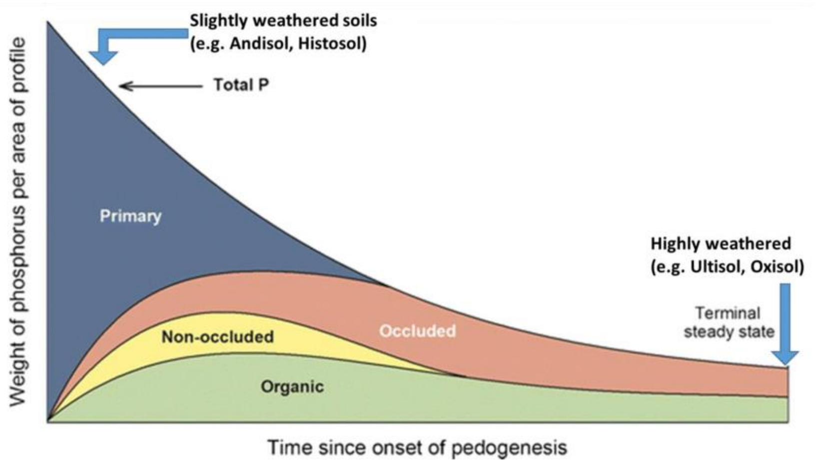

Figure 1. The Walker and Syers (1976) conceptual model of phosphorus dynamics during long-term ecosystem development. Figure adapted from Walker and Syers (1976), Cross and Schlesinger (1995), and Yang and Post (2011).

References:

Buendía, C., Kleidon, A. and Porporato, A.: The role of tectonic uplift, climate, and vegetation in the long-term terrestrial phosphorous cycle. Biogeosciences, 7, 2025-2038, https://doi.org/10.5194/bg-7-2025-2010, 2010.

Cross, A.F. and Schlesinger, W.H.: A literature review and evaluation of the. Hedley fractionation: Applications to the biogeochemical cycle of soil phosphorus in natural ecosystems. Geoderma, 64, 197-214, https://doi.org/10.1016/0016-7061(94)00023-4, 1995.

Walker, T.W. and Syers, J.K.: The fate of phosphorus during pedogenesis. Geoderma, 15, 1-19, https://doi.org/10.1016/0016-7061(76)90066-5, 1976.

Yang, X., Post, W.M., Thornton, P.E. and Jain, A.: The distribution of soil phosphorus for global biogeochemical modeling. Biogeosciences, 10, 2525-2537, https://doi.org/10.5194/bg-10-2525-2013, 2013.

Yang, X. and Post, W.M.: Phosphorus transformations as a function of pedogenesis: A synthesis of soil phosphorus data using Hedley fractionation method. Biogeosciences, 8, 2907-2916, https://doi.org/10.5194/bg-8-2907-2011, 2011.

Comment 14: 252 increase only from equator to high northern latitudes? Any explanation why this increase is seen?

Response 14: We found soil total P concentration increased with decreasing latitude in both northern and southern hemispheres (Fig. 5 and Fig S3K). Explanation for this result has been added to the revised discussion (Lines 341-343), as follows: "Lowland tropical soils are relatively more weathered compared to soils at high latitudes due to warmer climate (Hou et al., 2018). Moreover, the last glaciation could have eroded soils at northern higher latitude and have caused relatively young and P-enriched soils (Vitousek et al., 2010; Reich and Oleksyn, 2004)".

References:

Hou, E., Chen, C., Luo, Y., Zhou, G., Kuang, Y., Zhang, Y., Heenan, M., Lu, X. and Wen, D.: Effects of climate on soil phosphorus cycle and availability in natural terrestrial ecosystems. Global Change Biol., 24, 3344-3356, doi: 10.1111/gcb.14093, 2018.

Vitousek, P.M., Porder, S., Houlton, B.Z. and Chadwick, O.A.: Terrestrial phosphorus limitation: mechanisms, implications, and nitrogen–phosphorus interactions. Ecol. Appl., 20, 5-15, doi: 10.1890/08-0127.1, 2010.

Reich, P.B. and Oleksyn, J.: Global patterns of plant leaf N and P in relation to temperature and latitude. Proceedings of the National Academy of Sciences, 101, 11001-11006, doi: 10.1073/pnas.0403588101, 2004.

Comment 15: 257 African highlands do not show this?

Response 15: Yes, African highlands also show higher soil total P concentration than low African lands in our predicted maps (Fig. 5). We stated African highlands as east Africa in the previous version. To avoid this misunderstanding, we have rewritten east Africa to African highlands in the revision (Line 272).

Discussion

Comment 16: Generally, a very clear and good discussion. Only the above-mentioned points, why younger soils are clearly higher in P than intermediate soils and intermediates soils not higher than strongly weathered (old) soils are missing. This kind of contradicts our text book knowledge of young soils being low in P, then slowly accumulating P to a certain peak (intermediate weathered soils) and finally loosing soil again.

Response 16: Please see our Response 13. In revision, we have added two sentences to discuss this pattern shortly (Lines 223-227). The declining trend of soil total P during soil development supports the Walker and Syers (1976) conceptual model of phosphorus dynamics during long-term ecosystem development. And this pattern is consistent with previous studies (i.e., Cross and Schlesinger, 1995; Yang et al., 2011; Yang et al., 2013).

Comment 17: And may be you should briefly discuss high southern latitudes (no glaciations, so strongly weathered?)

Response 17: Many thanks for this advice. In the revision, we have re-written the discussion of this issue (Lines 341-343). Also see Response 14 above.

Conclusions:

Comment 18: 361: this is not totally correct, as we would have expected highest P contents in medium aged, intermediate weathered soils (e.g. peak of weathering, not so much lost yet).

Response 18: Please check our response 13 above.