

Dear editor and reviewers,

We are happy to resubmit our paper “Direct foliar phosphorus uptake from wildfire ash” (EGUSPHERE-2023-2617). We were glad to see that the reviewers appreciate the importance of the work we have done. We thank the reviewers for the time and effort that the reviewers invested in reviewing our manuscript. The comments provided were insightful and constructive, contributing to the overall improvement of the paper. We have made a lot of effort to change the entire manuscript based on these comments. We conducted an additional experiment and are presenting new results from the sequential extraction of phosphorus (P) in leaves from four local trees. In addition, we have improved the introduction and hypothesizes, better clarified the methods, and strengthened the discussion section and toned down the conclusions. We are confident that the revised manuscript is now ready for publication in Biogeosciences.

Our responses to the reviewers are provided below in **bold**. For your convenience, following our responses, you will find the revised version of the manuscript with a “track changes” to make it easier for the reviewers to follow the changes we have made in the text.

*Both reviewers commented on our comparison to our second paper of Palchan et al which is in review. We were hoping the paper would be published by now but the war in Israel delayed the publication process. We attached the final version of the Palchan et al paper for the reviewers and editor eyes only. We are assured that Palchan et al paper will be published soon.

Reviewer 1

Major issues:

1. I really appreciate the sequential leach done of the wildfire ash, rather than just soluble and total. However, it is unclear how many samples were run to produce Figure S1. If it is only one, then I recommend at least 2 additional samples are run prior to publication to confirm that this sample is representative of P in fire ash. Please show all fire ash sample results in Fig. S1.

R: We acknowledge the reviewer's comment. In response, we have sampled a new set of plants and conducted four additional ashing experiments to demonstrate that different ashed materials exhibit similar P fractionation. These results have been incorporated into Figure 1 in the main manuscript, as suggested by the reviewer.

2. Please include a summary of the P in fire-ash results as Fig. 1 in the main manuscript. The atmospheric community will be interested in the results and including this figure in the main manuscript will expand the impact of the work.

R: We accept this suggestion. Thus, we added the Hedley sequence results of four ashed plant samples to the main manuscript in Figure 1.

3. Similarly, a results and discussion section for fire ash needs to be presented in the main text. Please also discuss how these results compare to previously published P contents and solubilities.

R: Results and discussion on fire ash P are now presented in the main text. Our discussion includes comparisons to two highly relevant manuscripts, both released in the last few months: Wu et al. 2023 and Garcia et al. 2023 (P12 L354-360).

4. The discussion (especially section 4.3) needs clarification and expanding.

R: The entire discussion was revised, better focused, and expanded as the reviewer suggested (changed to section 4.4) (P13-14, L405-432)

Minor issues:

The manuscript contained a few careless errors that a thorough proof-reading would have caught prior to submission. For example, at one point the text refers to a figure that doesn't exist. I recommend thoroughly proofing the text prior to resubmission.

Abstract

Line 17: change particles to ash for clarity.

R: Changed accordingly (P1 L17)

Line 19: change “that reflect” to “which reflect”

R: Changed accordingly (P1 L19)

Line 20: This is a little confusing. Please rewrite for clarity – I think there is a way to only use the word “uptake” once in the sentence.

R: Changed accordingly (P1 L19)

Line 22: add “the” after In a future climate scenario

R: This sentence is changed from its original version to improve clarity (P1 L25)

Line 24: “with fire ash P being the sole nutrient absorbed by the foliage” – This is a very important finding, but it is unclear if it is P only (as opposed to other elements) or if it is fire ash P (as opposed to other aerosol types like dust).

R: The foliage exclusively absorbed P from the fire ash particles. We have adjusted the sentence accordingly. (P1 L21-22).

Line 25: I interpret your data as fire-ash P being a particularly efficient and important source of P. If you agree, please add to the last sentence of the abstract to highlight the significance of the results.

R: We have incorporated the suggested sentence into the text (P1 L31).

Introduction

The intro could benefit from providing some context for the importance of fire as a source of P, particularly to tropical soils that are extremely P-deficient. Even despite tropical soils being depleted in P, they are major carbon sinks, so understanding the biomass response to P deposition to these ecosystems is vital to estimating carbon fluxes accurately. I think a first paragraph around these ideas may highlight the importance of this work's findings and broaden readership.

R: This is an important note. The first paragraph has been revised to acknowledge the impact of fire-derived P deposition on biomass in phosphorus-limited tropical soils (P1 L37-38).

Line 33: P deficiency is particularly prevalent in tropical soils. Is it really prevalent globally?

R: You are correct; P deficiency is widespread, primarily in tropical soils but also in other regions. Several studies have reported global P deficiency, extending across various ecosystems beyond tropical climates. Examples include Vitousek et al. (2010), Hou et al. (2020), and others. We have modified the first paragraph of the introduction to emphasize this important point (P1-P2 L39-L43).

Line 34: It is my understanding that P is low in soils because it is leached from soils by precipitation or has been used by plants. The sentence currently reads as "P deficiency is prevalent globally due to its low bioavailability" which doesn't make sense. Please revise for clarity.

R: P limitation can arise from various factors, including low P concentration in the soil due to insufficient P in the bedrock or slow weathering, high leaching, or increased plant uptake. Additionally, P deficiency may result from its fixation to soil minerals, reducing its biological availability to plants. In tropical soils specifically, P deficiency is attributed to both low total P in the soil due to leaching and biological uptake, as well as high P fixation. We have revised the text to reflect these nuances (P1-P2 L39-L43).

Line 38: Savanna's should not be capitalized and should just be "savannas"

R: Corrected accordingly (P2 L47).

Line 37-39: The sentence that starts with "About 65%..." makes it sound like all fire ash particles originate from Africa. Please revise for clarity. I'm not sure what the authors are trying to say.

R: According to the literature, Africa is identified as the largest source of fire ash. We have revised the sentence based on this observation (P2 L46).

Line 48: Please do not cite a manuscript under review and take out this paper in the rest of your manuscript. It sounds like it may be accepted soon though. Hope that's the case!

R: We acknowledge the challenge of citing a paper that is not yet published. However, the work by Palchan et al. (in review) represents a written paper awaiting publication due to the complex political situation and ongoing conflict in Israel. This paper provides crucial insights that are highly relevant to our results, and it is anticipated to be published soon.

Line 55: There is literature showing that fire ash P is more soluble than dust from Barkley et al., 2019 and references therein). Please update this sentence to reflect this literature.

R: The Berkeley et al. (2019) paper is now included in the text. Also, we have added additional references from the literature that highlight the solubility of fire ash P Myriokefalitakis et al., 2016; Anderson et al., 2010; Wang et al., 2015 (P2 L63,69).

Line 61: These papers are ok to cite, but papers from 2014 and 2010 are pretty old in fire science – please add more recent references.

R: We have added a couple of newer papers, enhancing the content with the latest research findings (P2 L71).

Line 68: Please define eCO₂ conditions. I also don't understand why the abbreviation e was

chosen. Is there a more intuitive abbreviation that could be used? Does e stand for extreme? Define and explain.

R: The “e” is referring to elevated. It is described in the text. Corrected accordingly. (P2 L79).

Line 69: Please remove the comma.

R: Corrected accordingly (P2 L80).

Line 74: What is eCO₂ and aCO₂? This abbreviation should be explained. Is it “actual” and “extreme”?

R: The “a” refers to ambient and e to elevated. This is now clarified in the text and the sentence was corrected accordingly. (P3 L89).

Last paragraph in introduction (line 73):

Please exclude your hypothesis from this paragraph (sentence beginning on line 76 to end). It's confusing to read this because some of it is opposite of your results. To keep things clearer, please just say what the question is. For example: “...applied both directly to the foliage and to the roots to assess how plants use P from fire ash deposition”.

We deleted the hypothesis and changed the paragraph accordingly. (P3 L84-94)

Line 91: Remove “had”

R: Corrected accordingly (P3 L113)

Line 103: Please add “day” instead of
D

R: Changed accordingly (P4 L125)

Line 108: as should say “ash”

R: Corrected accordingly (P4 L130)

Line 107: Please adjust grammar to say “At this stage, fire ash was applied directly on to the

foliage of 12 -P plants...”

R: Corrected accordingly (P4 L129)

Line 111: What is bone-fire burning?

R: Corrected to a “The fire ash used in this study was produced by burning branches and needles of coniferous trees in a controlled bonfire setting”. (P4 L139).

Line 113: Ash is also singular, so please say “Later, the ash was burned again...”

R: Corrected accordingly. (P4 L141).

Line 118: move sentences about Tables S1 and S2 to section 2.3 where you discuss the chemical composition methods.

R: Changed accordingly. (P4 L150).

Line 139: This sentence is repeated above. Remove the above one.

R: The specified sentence has been removed. (P5 L159).

Methods

Section 2.3:

It would be helpful to say give a sentence at the beginning of this section describing why each chemical analysis was chosen. For example, say something like “We performed X analysis to quantify total P and a sequential P leach to estimate the different fractions of P.” Why was XRD performed? Why was ICP-MS performed? I imagine ICP-MS was done to determine a total P concentration while the sequential leaching was done to determine each P phase. Please state as such. What does each step of the sequential leach tell us? Which is most soluble?

R: An explanation sentence for each method has been added as well as the meaning of each step (P4 L156-158, L175).

Line 149: “two separate pulses” is confusing. I think you can just say twice or two times.

R: Corrected accordingly. (P5 L186).

Line 154: I understand following P deposition estimates from Gross et al. 2021 30 g/m², but is this deposition rate reasonable for fires? Discuss why or why not. Even if it's not, I think it's ok because it's still important to be able to compare your results to another study.

R: While reliable data on fire ash deposition is limited, it is well-established that average global dust deposition exceeds that of fire ash (based on geographical location). Leveraging the abundance of reliable data on dust deposition, we opted to use dust deposition amounts as our reference for fire ash. This decision facilitates a meaningful comparison of our results with previous studies. It is essential to acknowledge that this may not precisely represent actual fire ash deposition. Therefore, we have included a brief discussion on this point (P5 L192-193).

Line 158: Please adjust the grammar. "The same amount of ash that was applied to the foliage was applied to the roots."

R: This sentence is changed from its original version to improve clarity (P6 L204).

Line 163: Change to "remaining ash" instead of "ash remains"

R: Corrected accordingly. (P6 L210).

Line 166: Should say "Elemental analysis was performed..." instead of "the elements measurement".

R: Corrected accordingly. (P6 L216).

Line 167: Change "get rid of the" to "eliminate"

R: Corrected accordingly. (P6 L217).

Line 168: Delete "to achieve a clear solution".

R: Corrected accordingly. (P6 L218).

Line 179: Why only the P-deficient plants? Please discuss the reasoning.

R: PH measurements were conducted on P-deficient plants, excluding those treated with fire ash. The presence of the material on the leaf surface interferes with the physical contact between the flat surface of the pH electrode and the leaf itself. Additionally, we measured

the pH of P-sufficient plants, and the results were similar. This is now explained in the text (P6 L234-237).

Line 187: You can say “additional holding capacity analysis was performed at Ben Gurion University”

R: The sentence changed accordingly (P7 L242-L243).

Section 2.6: Reference for pH measurement available? Why was leaf pH measured? What does it tell us?

R: Yes, there are a several studies that reported similar acidic pH of chickpea leaves. References now added to the text (P6 L234). These measurements indicate the acidity of the leaf environment which promotes P dissolution in fire ash (see paper of Tiwary et al. (2022) now added to the text). This can provide insights into the foliar nutrient uptake mechanism as was shown in Gross et al. (2021). An explanation was added in the ‘Introduction’ section (P3 L85-L88).

Results

3.1:

- What is shoot? Is that the whole plant or the same as the root? Please define and explain why shoot biomass measurements are made for.

R: The shoot refers to the aboveground part of the plants excluding the roots. An explanation has been added to the manuscript. (Methods, section 2.5, P6 L212-L214).

- There is no figure 1f or 1e. Please correct so the text refers to the correct figure.

R: Corrected accordingly. (P7 L261-L264).

- Figures 1 and 2
 - These figures need to be explained. Please say that they are violin plots. What does the middle dash represent? What do the other dashed lines represent? It’s not standard dev because they are not the same on either side

of the center dashed line.

R: The dashed lines in the violin plots represent the median and the dotted lines the quartiles. We added this information in the figure legends (P10 L344-L345 and P11 L352-L353).

Please report the significance and what type of significance test was performed.

R: The significance is $P < 0.05$, and the test used was the Tukey test. We added this information in the figure legends (P10 L344-L345 and P11 L352-L353).

3.2: Please make sure the text refers to the correct figures. There is no figure 2f or e.

R: Corrected accordingly (figures 2 and 3, P10, P11).

3.3: This paragraph is confusing. Please revise for clarity.

R: Whole section 3.3 was rewritten and clarified and changed to section 3.4 (P8 L272-283).

Line 208: Replace “Plant’s nutrient status” to “the nutrient status of plant samples”.

R: The sentence is changed from its original version for clarity (P8 L274).

Line 208-209: This is poorly worded and confusing, but a major result.

R: We reworked this section, providing detailed clarification of the calculation and explanations for the results (P8 L269-280).

Figure 3:

Remove interpretation from Figure 3 caption (second the last sentence)

R: Removed accordingly (changed to figure 4) (P12 L361).

The legend on the plot does not match the description of the legend in the caption.

Please revise.

R: Corrected accordingly (figure 4).

Why was P not measured and provided on Fig. 3?

The plants were P-starved; therefore, the increase in P was assessed by calculating total P values. In this scenario, the P levels in the ionome cannot demonstrate changes in

concentration, as there were no variations due to the fact that all available P being directed toward plant growth. This is why figures 1 and 2 represent the total P values.

Discussion

Line 278: I think a better and stronger interpretation of your data is that direct foliar application of fire ash is directly beneficial to plants and increases biomass. The word “emphasizing” makes it sound like the results are not novel. Please link the fact that biomass increase to the plant taking up atmospheric carbon via photosynthesis.

R: We agree. The word 'emphasizing' has been changed to 'demonstrating.' Since the P-deficient plants were unable to grow, our results demonstrate that the increase in biomass is attributed to additional P directly taken up through the leaves from the fire ash particles. This P is the limiting factor for growth. Even the plants grown under elevated levels of CO₂ were unable to grow without sufficient P in their nutrition. The sentence has been modified to: 'Foliar application of fire ash under ambient CO₂ levels increased chickpea biomass and total P content compared to untreated control plants, demonstrating that foliar uptake of P from fire ash has a direct nutritional impact on plants, providing P for biomass growth and boosting photosynthesis' (P12 L373-375).

Line 281: Please delete “... confirming out initial hypothesis that fire ash P is more bioavailable to plants” and remove any mention of the hypothesis. The authors could say here “emphasizing the importance of P for plant growth”.

R: Corrected accordingly. (P12 L379).

Line 281: Please delete “However, despite its projected bioavailability” and replace with something like “because there was no nutritional impact when fire ash was deposited on roots, we conclude the nutritional impact occurred exclusively through foliar uptake”

R: Corrected accordingly. (P12 L379-L380).

Line 282: Please delete the sentence that starts with “This discovery.” You do not need to discuss your initial hypothesis. You should instead refer to published literature – how are your results similar or dissimilar to previously published studies? Do your results challenge these studies?

R: Direct foliar uptake of P from fire ash particles has been overlooked, until now. Our

results represent the first instance in which fire ash particles were directly added to plants, thus definitively challenging the common perception that P is solely taken up through the roots from the soil, even in the case of atmospheric particle deposition. We have changed the sentence accordingly (P13 L394-L399).

Line 286: Imply should be implies.

R: Corrected accordingly (P12 L386).

Section 4.2: Connect to your results again. Do your results agree with other results from the Gross lab?

R: Yes, our results agree with the previous works of Gross et al. 2021 and Starr et al. 2023. We have added a short discussion and connected our results to their findings (P13 L405-408).

First sentence in 4.2: You do not need to repeat the same Gross et al. 2021 citation in the same sentence.

R: Additional citation was removed (section 4.2 changed to section 4.3).

I think you need a sentence like “our data showing low pH on plant leaves supports previous assertions that low pH may help facilitate P uptake on plant leaves”.

R: Additional sentence was added: “As in previous studies, we also measured a highly acidic leaf surface environment (average pH value of 1.15) and a high dust holding capacity (average value of 15%), support previous assertions that low pH and high holding capacity may help facilitate P uptake on plant leaves” (P13 L405-408).

Section 4.3:

Delete discussion of your hypothesis (Line 310). Instead discuss why your results are unexpected based on current literature w/ citations.

R: The discussion of our hypothesis was removed, and the sentence was revised based on your comment (P13 L426-L428, L430-L435).

Line 308: Should contribution be content? I do not understand this sentence.

This section is generally pretty confusing.

R: This section has been rewritten and additional explanations were added (P13 L416-L428).

The results presented in Section 3.3 say that the eCO₂ conditions reduced the conc of various elements, so the discuss section should discuss why. I feel like the discussion here is missing.

R: We expanded the discussion regarding the reasons for the nutritional reduction under elevated levels of CO₂ (P13 L416-L428).

Section 4.4

What is n.d. on line 328?

R: It is a mistake. Corrected accordingly (P14 L453).

Line 326: I think the current state thinking is that soluble nutrients like P are more quickly and easily used by the plants after deposition to the soil. Your results are interesting because they contradict that.

R: Your remark is correct; however, it's important to note that most of the P in fire ash particles is not soluble. Additionally, the soluble portions can interact with other minerals and/or microorganisms within the soil. When particles settle onto plant foliage, they may remain undisturbed and be partially dissolved by foliar organic acids such as oxalic, malic, and citric acids. We have clarified this in the text (P14 L457-L459).

Line 328: Delete “in accordance with the common view”

R: Changed accordingly. (P14 L455).

Line 238: Fire also releases N that contributes to N deposition... There is no current N limitation in terrestrial ecosystems because of anthropogenic emissions.

R: What we aimed to express is that anthropogenic pollution increases the concentration of nitrogen (N) in soils. Consequently, this elevation can lead to an imbalance in plant stoichiometry. The high phosphorus (P) concentration in fire ash could play a partial role in offsetting this anticipated stoichiometric imbalance. The sentence has been revised and clarified in the text (P14 L466-468).

Please discuss how your results inform biogeochemical models. What do the results say about the need for chemical transport model to capture the physics of deposition onto plant leaves? This means that modelers need to have accurate land type model inputs and need to account for surface roughness. Do models currently take deposition onto leaves into account?

R: It is an important observation. We have added a paragraph that underscores the significance of updating biogeochemical models (P15 L470-475).

SI:

1. Please redefine all abbreviations (except elemental symbols) in SI (e.g., XRF, etc.).

R: The abbreviations were redefined.

2. Add longer descriptions of each table.

R: Additional descriptions were added.

3. How many fire ash samples were analyzed? Figure S1.

R: We conducted an additional experiment and analyzed four new samples of tree branches and leaves from four different trees to measure their P concentration and fractionation. See our responses to previous comments.

Reviewer 2

This paper is a nice illustration of the potential P-fertilising effect of ash deposited on plant surfaces. It has been known for a long time that P can be taken up by leaves, but this paper quantifies the importance of this P uptake for a crop species in an experimental setting. While the broader conclusions (that our future world will see more ash deposition and that this may make this biogeochemical pathway quantitatively more important than it has been) is true, I feel that the authors 'over-sell' the idea that it is going to be highly significant for plants. The experiment has done several things that maximise the effect of ash: high ash loads, complete burning of ash to remove organic residues, and importantly, choosing a species that is covered in hairs that contain high concentrations of acids, and that (being a legume) is quite responsive to P fertilisation. I would suggest that the conclusions are toned down.

R: We thank the reviewer for his comments. We have toned down the conclusions throughout the text.

I agree with (most of) the comments provided by Reviewer 1 and have avoided repeating the same points. Whilst this manuscript does not have many major issues, I believe that the cited manuscript (Palchan et al., in review) should have been made available to the reviewers. Everything indicates that this manuscript is a companion paper based on the same (or parallel experiment). The amount of data presented in this paper is not large. Whilst I have ticked the box 'minor revision', it is possible that a major revision that includes combining Palchan's manuscript to publish it as a single paper may be better advice.

We provide here the submitted paper of Palchan et al. for the reviewers and editor eyes only. Our paper describes the impact of fire ash on plants and differs from Palchan et al. which tests the impact of mineral particles like desert dust and volcanic ash which vary in their composition, source material and nature from combustion ash. Thus, merging our results with the data presented in Palchan et al. will generate a substantial amount of data, potentially overshadowing the specific effects of combustion ash on plants. We genuinely believe that the ecological importance and impact of combustion ash will interest a large number of readers, justifying a separate discussion and publication. It's important to note that the publication of the Palchan et al. paper has been delayed

partially due to the war in Israel. We believe that by spring both papers will be published and enable an appropriate comparison between the two papers. Palchan et al. article is expected to be published in the next couple of months. Once Palchan et al. paper will be published, we can ask the editorial committee of 'Biogeosciences' to change the citation status from 'in review' to the actual published paper. We promise that we will update once the paper is published.

L5: I suggest that the species (chickpea) is included in the title.

R: We thank the reviewer for his suggestion, however, we are certain now that the foliar uptake pathway is viable mechanism in other plants as we had published in other papers (Starr et al. (2023) and Gross et al. (2021)), where foliar nutrient uptake from atmospheric particles such as desert dust, was shown to occur in other crop and tree species as well. Thus, foliar nutrition from fire ash is probably applicable to other plant species. We are concerned that if we include the plant's name in the title, it will narrow down the true meaning of our article, which is broader than a single plant. Yet, we acknowledge the reviewer's remark and have added more mentions of the plant specie in the text in several places, and that chickpea is a plant with unique characteristics (P3 L85-L88 , P14 L448-L449).

L18 and L76: ash applied to the roots or rather to the soil surface?

R: The ash was applied to the perlite and gently mixed around the roots to enhance the physical contact between the roots and the particles, thereby increasing the chances of having a more significant impact. This is now explained throughout the text. For example (P1 L17, P3 L90).

L21: You have not demonstrated that plants cannot take up P through their roots. It didn't happen in your experiment, but it is the main pathway under normal circumstances. The way you formulate it here suggests that they don't.

R: You are correct; the primary pathway for nutrient uptake is through the roots. However, our study focuses on the immediate (termed in the paper as "short time scale") impact of fire ash on plants. Our results indicate that in a short timescale, plants may not efficiently uptake P from fire ash via the root pathway, possibly due to low bioavailability or limited contact between fire ash particles and the roots. In contrast, the direct application of fire ash particles

to the foliage enables extended and direct contact, increasing the likelihood of foliar P uptake. We have revised the paragraph to make it clearer based on your suggestion. (P1 L22-23).

L25: This is quite far extrapolated from one unique species to all plants. I'd add the word 'potentially' as a minimum and would suggest to tone this down.

R: The sentence is changed from its original version to town down the conclusions (P1 L21-29).

L68: "impair" is quite a strong word in "... impair plant's mechanisms of nutrient uptake ...". "... reduce plant nutrient uptake ..." may be appropriate?

R: We replaced 'impair plant's mechanisms of nutrient uptake' with 'reduce plant nutrient uptake' (P2 L80).

L68: explain that eCO₂ and aCO₂ are elevated and ambient CO₂.

R: We added an explanation of eCO₂ and aCO₂ (elevated and ambient co2 levels). (P2 L79).

L77: "Fire ash impacts will be higher than that of other atmospheric sources due to the higher P concentrations and increased solubility in comparison to desert dust and volcanic ash". You cannot test this hypothesis as the experimental design does not include desert dust and volcanic ash treatments. This hypothesis seems to be formulated for the combined experiments of this paper and that of Palchan et al (in review) ...

R: We removed this and other hypotheses in the introduction. We mentioned the comparison between fire ash and mineral dust in the discussion and refer to Palchan et al. And other papers. Please refer to our previous comment regarding Palchan et al. paper.

L108: fire ash, not fire as.

R: Corrected accordingly. (P4 L131).

L102: bonfire I assume?

R: You are right. Corrected accordingly. (P4 L139).

L113: further burning at 550 C reduces the ash to mineral-only ash, but is that the type of ash that is dispersed and deposited in the real world, or is that the less-completely burned ash?

R: In the real world, fire ash particles exhibit a wide range of burning completeness and temperatures, along with various types of organic matter, including stems, branches, leaves, fruits, needles, etc. In our attempt to describe and quantify the phenomenon, and recognizing the variability in real-world conditions, we wanted to establish a 'perfect' set of conditions. However, this is an important comment, and we added an explanation in the text (P4 L142-145).

L118: dispersion instead of erosion?

R: Corrected accordingly (P4 L149).

L155: "...whereas the chickpea grown in similar growing conditions." Change to "... in which the chickpea was grown ..."

R: We replaced the sentences according to your suggestion. (P5 L194).

L156: 3 g of ash (not as)

R: Corrected accordingly. (P5 L195).

L157: "the ash was gently applied manually on the leaves". More detail is needed. Was it evenly spread, how did you avoid spillage? Did you touch the leaf or let the ash fall on it? Touching the leaf of chickpea damages hairs which release strong acids ...

R: The application of fire ash particles was performed in the following manner: we placed the ash particles in a sieve with a 63-micron mesh size and spread the ash by gently shaking the sieve above each plant. Some particles were spilled during the process. Afterwards, the plants were left undisturbed with the settled ash particles on their foliage. The top of the pots was covered to prevent percolation of fire ash particles to the substrate. We added this explanation in the text (P5-P6 L196-L200).

L159: "applied to the roots". I strongly request different wording, e.g. soil surface, as I'm sure you didn't apply it to the roots in the way you applied it to the leaves. However, you may not like to use 'soil' for perlite. "Substrate" is an alternative option.

R: We replaced the wording 'applied to the roots' to 'applied to the substrate around the root system'. This is now explained throughout the text. For example (P1 L17, P3 L90).

L162: “The plants were rinsed in tap water, 0.1M HCl and three times in distilled water to remove any ash remains.” The HCl concentration seems very high, do you have evidence that this did not damage the plants? Do you also have (microscopic) evidence that all ash was effectively removed?

R: Before employing this washing method, we tested it extensively in our preliminary experiments. Additionally, this washing method was used in the work of Gross et al. (2021), where they applied desert dust to plants and microscopy was used to ensure that no damage occurred, and no excess of dust particles remained on the leaf surface. We added this explanation in the text (P6 L208-210).

L175: Not dust but ash.

R: Corrected accordingly (P6 L226).

L188: only ash, not dust?

R: Only fire ash. Corrected accordingly (P7 L243).

L189: leaf, not leave.

R: Corrected accordingly (P7 L245).

Figures 1 and 2: I think that these figures can be effectively combined. I would add Root biomass too. And I would prefer P concentration rather than P content. Differences in P content seem simply due to differences in biomass, but this can be verified by showing P concentration.

R: We did not detect changes in P concentration because any additional P was directed to biomass growth since the plants were P starved. Thus, the extra P taken up from fire ash particles is reflected by increased P content rather than P concentration.

The combination of Figures 1 and 2 would create an 8-panel figure, potentially complicating the understanding of the differences. Figures 1 and 2 depict two distinct growing settings with different CO₂ conditions. We believe that presenting them separately is a more representative way of illustrating the results.

Root biomass graph has been added to the supplementary file as figure S1 in the complementary.

L273: “The depletion of the plants nutrient status is caused by the downregulation of the roots system”. This is an interpretation that should not be stated in the figure caption. Lower nutrient concentrations at eCO₂ are also due to ‘dilution’ by carbon-based compounds, including higher concentrations of non-structural carbohydrates.

R: We removed this interpretation from the figure caption. Since the control group, which was grown under elevated CO₂ conditions, did not show an increase in biomass, it indicates that the 'dilution' effect is not responsible for the nutrient reduction in this case. We acknowledge that the dilution affect is a major factor in many cases, and we discuss this in the text based on your suggestion. (P1 L23-L25, P13 L416-424).

L291: These results suggest that solubility tests examined by chemical extractions do not necessarily reflect actual biological availability and emphasize the importance of fertilization experiments with plants.” I agree, but the result remains puzzling, and it’s a pity that no attempts were made to look into this further. What was the pH in the perlite substrate? Was there evidence of the ash dissolving and being transported into the substrate? Were there roots throughout the substrate? Chickpea roots have the capacity to access P from poorly soluble salts, through the same mechanism that you propose for leaves.

R: This is an important observation. The tested plants exhibited an extensive root system, with an average root-to-shoot ratio of 50:50 and the pH of the substrate was around 7. Also, our aim was to study the immediate nutritional impact of fire ash particles right after deposition. Thus, the smaller physical contact between the fire ash particles than that of the leaves is an inherent property in field conditions and in our experimental system. Investigating the physiological response of roots following the application of fire ash and other atmospheric particles is an intriguing question that deserves dedicated research. We clarified this the text (P12 L389-L390).

L296: “ ... promotes the release of P solubilizing metabolites, such as malic citric and oxalic acids”. As far as I know these compounds are contained in gland hairs, and only released when these break, rather than ‘exuded’. Breakge may occur naturally, but I’d suggest that you comment on this rather than suggesting that these compounds are continuously exuded.

R: According to the work of Gross et al. (2021), chickpea plants sequester oxalic, malic, and citric acids from trichomes independently of their breakage. P-deficient chickpea plants increase the granular secretion by activating different strategies, for example increasing the

density of trichomes. However, we agree that fire ash application may physically break the glands and increase the exudate concentration. This is now mentioned in the text (P13 L403-L405).

L321: “Another possible factor could be the elevated pH level of the fire ash particles which may impact the chemical environment of the leaf surface.” But your measurements demonstrate a highly acidic environment ...

R: You are correct. The chickpea leaf environment is highly acidic; however, we did not measure leaf surface pH after the application of fire ash particles as the fire ash interferes with the pH measurements. Thus, we deleted this sentence from the text (P14 L443-L446).

Figure S1: why do the fractions not add up to 100%? Is that the soluble fraction that's missing? Why not include it?

R: We have added Figure S1 to the manuscript and incorporated four additional samples, as requested by Reviewer 1. The figure was changed based on your and reviewer 1 suggestion.