nature portfolio

Peer Review File

Decision support systems reduce fungicide use by half compared to calendar-based strategies without increasing disease risk

Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality.

23rd Jun 21

Dear Dr Lázaro,

Your manuscript titled "Reducing the use of fungicides in agriculture by 50% with decision support systems. A meta-analysis" has now been seen by 2 reviewers, and I include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a decision on publication.

We therefore ask that you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file. In particular, we ask that you provide an in depth discussion of the advance provided by the present study beyond the existing literature (including ref. 35) and that you include yield impact data, weather and climatic variables (where available) to further demonstrate DSS efficacy, as per the reviewers' recommendations.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter) and the completed checklist:
[link redacted]
** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We understand that due to the current global situation, the time required for revision may be longer than usual. We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning. Of course, if you are unable to estimate, we are happy to accommodate necessary extensions nevertheless.

Please do not hesitate to contact me if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Clare

Dr Clare Davis
Associate Editor
Communications Earth & Environment

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EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

Editorial Policy: Policy requirements

Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:
Communications Earth & Environment formatting checklist

and also in our style and formatting guide Communications Earth & Environment formatting guide .

*** DATA: Communications Earth & Environment endorses the principles of the Enabling FAIR data project (http://www.copdess.org/enabling-fair-data-project/). We ask authors to make the data that support their conclusions available in permanent, publically accessible data repositories. (Please contact the editor if you are unable to make your data available).

All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More information on this policy, is available at http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf.

In particular, the Data availability statement should include:
- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)
- Accession codes where appropriate
- If applicable, a statement regarding data available with restrictions
- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at http://www.nature.com/sdata/policies/repositories.

If a community resource is unavailable, data can be submitted to generalist repositories such as figshare or Dryad Digital Repository. Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Reducing the use of fungicides in agriculture by 50% with decision support systems. A meta-analysis

Lazaro et al.

In general, fungicide use on agricultural crops is increasing perhaps due to the increased disease incidence and/or fungicides are also being used for physiological benefits. As a result, several plant pathogens have already developed resistance against major fungicide classes and are less effective for managing diseases. Fungicides can still be used to protect yield however the frequency of fungicides need to be reduced to minimize the negative impact that can be caused by the irrational use of the fungicides. This manuscript has synthesized data from fungicide studies conducted for several years and compared calendar-based approach vs disease support systems. They found that decision support systems were as effective as calendar-based approach. When fungicides spray was reduced by half the DSS reduced disease incidence more than the calendar-based approach. This indicates the DSS based supports the targets of EU reducing chemical use by half by 2030. This manuscript is written well and easy to follow. It can be accepted with minor revisions.

My comments
1. Explain more about the disease support systems with some examples how DSS was applied on the crops that are analyzed in this manuscript.
2. If possible, include economic analysis to show the shavings by DSS compared to calendar-based approach.

3. Currently, farmers are applying fungicides on crops not only to manage the disease but also for physiological benefits. They hope the fungicides, especially the QoIs, increase yield even in the absence of disease due to the physiological benefits provided by fungicides. I am curious how the DSS and calendar-based approach spray compared for yield response to fungicides. Did these experiments report yield data? Is it worth to look the yield data in some crops?
4. You mentioned that none of the moderator influence the results. Did they explain among study variability? Any other moderator variables that can be included to test if they influence the variability?

Reviewer #2 (Remarks to the Author):

The manuscript had the objective to assess the feasibility of reducing fungicide sprays and maintaining disease control efficacy, by means of adopting Decision Support Systems (DSSs). With the 'from farm to fork' (FFF) strategy of the European Green Deal, as a framework, which set the goal of a 50% reduction in the number of fungicides for the 2030, the authors performed a joint analysis of 80 experiments from Europe, North America and South America, including two crop types (woody and non-woody crops) and five classes of pathogens.

Overall, a very thorough and robust analysis of the dataset was conducted. All the information is very well documented (data and codes are available for reproducing purposes). The scientific interpretation and assumptions made within the study are co

The main highlights obtained from the analysis is that:
The goal of a 50% reduction in the number of fungicide sprays may be possible. When the number of sprays was reduced by 50% with DSSs compared to recommended calendar strategies, the increase in disease incidence never exceeded +5%.

This paper provides a robust confirmatory of DSSs efficacy for managing crop diseases. The manuscript is a complement of their own work: "Lázaro, E., Makowski, D., Martínez-Minaya, J., & Vicent, A. (2020). Comparison of Frequentist and Bayesian Meta-Analysis Models for Assessing the Efficacy of Decision Support Systems in Reducing Fungal Disease Incidence. Agronomy, 10(4), 560; in which it is stated that "calendar-based and DSS-based programs provided similar reductions in disease incidence, further supporting the efficacy of DSSs." Now, authors added an evaluation of halving fungicide sprays in concordance with the 'from farm to fork' strategy.

Once the following concerns have been addressed, this reviewer will support the publication of this work.

L52: there's a lacking bracket

L149-153. As a general question I have: is replacing calendar-strategy to DSS-based strategy the main way of reducing the use of synthetic products for the next agriculture? I mean, this paper provides support for reducing sprays in the currently established systems (monogenic, input dependant), but, should we redesign the cropping systems (intercropping, cultivar mix, etc.) for minimizing the dependency of fungicides? I felt the lack of some lines regarding this idea. On the other hand, 2030 is just around the corner, so the confirmation of DSSs efficacy, can aid conventional farmers to move gradually to less fungicides-dependent crops.

Which are the units in Fig 4 in the y-axis? I suppose absolute difference in proportion scale?. Not clear for me.

I wonder if it could be a good idea to include some weather/climatic variables. For instance, in the tropics, may the difference in DSSs-Cal be the same size as in temperate zones? I understand that the purpose of the manuscript is to arrive to a robust conclusion, however, the framework “FFF” is to be applied in Europe.

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Moncada, 9 August 2021

Dear Reviewer 1,

We appreciate the time and effort spent by you, providing valuable feedback on our manuscript and we thank the opportunity to submit a revised version. We have included below your comments and our responses, indicating how we addressed each concern/suggestion and describing the changes we have made. All three authors have approved the revisions. For clarity, text additions in the revised version of the manuscript and supplementary files are marked in blue and text deletions crossed out in red.

Reviewer 1 (Remarks to the Author):
Reducing the use of fungicides in agriculture by 50% with decision support systems. A meta-analysis
Lazaro et al.

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My comments
1. Explain more about the disease support systems with some examples how DSS was applied on the crops that are analyzed in this manuscript.

The type of DSSs included in our study are now described in the manuscript

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from line 40 to line 47. Additionally, the name of the core DSSs evaluated as well as their corresponding environmental variables: air temperature (C), leaf wetness duration (hours), relative humidity (%), rainfall (mm), solar radiation (KJ.m-2) and wind speed (m.s-1), have been incorporated in the database (data.xlsx and readme_data_supp.pdf supplementary information files). All this information is now summarised in the Supplementary Table S2.

2. If possible, include economic analysis to show the shavings by DSS compared to calendar-based approach.

We acknowledge the relevance of the economic dimension derived from our study. At first sight, economic savings might be inferred from the reduction in the number of fungicide sprays. Nevertheless, economic analyses are more complex that this and they should consider depreciation costs of the spraying machines and farm infrastructures, fixed personnel costs, changes in prices due to the trade-off between offer and demand, among a number of other factors (e.g. `https://library.wur.nl/WebQuery/wurpubs/359933`).

Providing a reliable economic analysis will require additional data and specific modelling techniques. We thus believe that this aspect falls outside the scope of this manuscript. Our data are open and fully available (data.xlsx file supplementary information file) as well as the code to reproduce the whole analysis. This could help research groups in agricultural economics to follow up on our study, providing a full economic appraisal of the use of DSSs in disease control.

3. Currently, farmers are applying fungicides on crops not only to manage the disease but also for physiological benefits. They hope the fungicides, especially the QoIs, increase yield even in the absence of disease due to the physiological benefits provided by fungicides. I am curious how the DSS and calendar-based approach spray compared for yield response to fungicides. Did these experiments report yield data? Is it worth to look the yield data in some crops?

We thank the reviewer for noting this. The physiological effects of QoIs are well documented since the seminal work by Grossmann and Retzlaff (Pest Sci 50,11) and were also mentioned in the books by H.G. Hewit (the sec-

ond edition is quoted in our manuscript). While potentially benefiting farm revenues, the current EU legislation (e.g. Regulation (EC) No 1107/2009; Directive 2009/128/EC) does not allow for off-target fungicide sprays. Applications can be only justified by the presence or the risk of disease, and potential yield increase is considered as a side effect of disease-driven sprays. When assembling the dataset, we carefully explored the information available and, unfortunately, we found very few papers reporting yield data. Although certainly interesting, analysis of yield data was not possible even focusing on a particular crop.

-Grossmann, K. & Retzlaff, G. Bioregulatory effects of the fungicidal strobilurin kresoximmethyl in wheat (Triticum aestivum). *Pest Sci*, **50**, 11-20 (1997).

4. You mentioned that none of the moderator influence the results. Did they explain among study variability? Any other moderator variables that can be included to test if they influence the variability?

We assessed the influence of four moderator variables (experiment location, crop type, pathogen class taxonomic rank and fungicide type) and the interaction of each one of these variables with the baseline covariate (fungicide treatment) by fitting several additional meta-analytic models.

The strength of the effect of each moderator variable was analysed by comparing the predictive accuracy of the fitted models with and without each moderator, as described in the Methods Section (Model evaluation and model selection). Based on that criterion none of the moderator-based models showed an improved behaviour and the moderator effects were considered not relevant. Thus, in accordance with the parsimony principle the two baseline models (MI_0 and MIS_0) were selected. Additionally, we also checked/compared model adequacy and performance of baseline and moderator meta-analytic models to support our model selection decision.

In relation to the question of including any other moderator variables, we explored the Köppen-Geiger (KG) classification as a moderator variable in the statistical analysis, with the aim of addressing whether climate was influential in the performance of DSSs. Countries usually have several KG climatic zones, thus, the variability of climate types was substantial resulting in

very low numbers of data in the KG categories, limiting any further inferential statistical analysis. Nevertheless, we have updated the database (data.xlsx and readme_data_supp.pdf supplementary information files) including KG classification for each experiment and describing it in the manuscript from line 49 to line 52. Two references have been added (refs 17-18) on this aspect.

Ref 17: Köppen, W., Volken, E. & Brönnimann, S. The thermal zones of the earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world (Translated from: Die Wärmezonen der Erde, nach der Dauer der heissen, gemssigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet. *Meteorol. Z.* **20**, 351360 (2011)

Ref 18: Rubel, F. & Kottek, M. Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification. *Meteorol. Z.* **19**, 135141 (2010)

We would also like to point out several minor corrections in the supplementary information files:

- Supplementary Figs. S1S12, Tables S1S8 and references. The changes made correspond to the addition of Table S2. The numbering of the Tables was updated accordingly.
- Data.xlxs. The changes made correspond to the addition of 10 additional columns describing the main characteristics of the experiments: location (country, state, locality, longitude, latitude), Köppen-Geiger category, DSS treatment/s in relation to the environmental variables considered to predict disease risk (air temperature, leaf wetness duration, relative humidity, rainfall, solar radiation and wind speed).
- readme_data_supp.pdf. This file contains Data.xlxs description and it has been updated reflecting the changes done in the database. In this file we have added a reference (ref 1).

  Ref 1: Bryant, C., Wheeler, N. R., Rubel, F. & French, H. kgc: Koeppen-Geiger Climatic Zones. R package version 1.0.0.2.`https://CRAN.R-project.org/package=kgc(2017)`

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Yours faithfully,

Dr Elena Lázaro

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Moncada, 9 August 2021

Dear Reviewer 2,

We appreciate the time and effort spent by you, providing valuable feedback on our manuscript and we thank the opportunity to submit a revised version. We have included below your comments and our responses, indicating how we addressed each concern/suggestion and describing the changes we have made. All three authors have approved the revisions. For clarity, text additions in the revised version of the manuscript and supplementary files are marked in blue and text deletions crossed out in red.

Reviewer 2 (Remarks to the Author):

The manuscript had the objective to assess the feasibility of reducing fungicide sprays and maintaining disease control efficacy, by means of adopting Decision Support Systems (DSSs). With the from farm to fork (FFF) strategy of the European Green Deal, as a framework, which set the goal of a 50% reduction in the number of fungicides for the 2030, the authors performed a joint analysis of 80 experiments from Europe, North America and South America, including two crop types (woody and non-woody crops) and five classes of pathogens.

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The main highlights obtained from the analysis is that: The goal of a 50% reduction in the number of fungicide sprays may be possible. When the number of sprays was reduced by 50% with DSSs compared to recommended calendar strategies, the increase in disease incidence never exceeded +5%.

We thank the reviewer for the useful comments which certainly improved our paper. Below is a point-by-point response addressing the suggestions to our manuscript. For clarity, text additions are marked in blue and text deletions crossed out in red.

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This paper provides a robust confirmatory of DSSs efficacy for managing crop diseases. The manuscript is a complement of their own work: "Lzaro, E., Makowski, D., Martnez-Minaya, J., & Vicent, A. (2020). Comparison of Frequentist and Bayesian Meta-Analysis Models for Assessing the Efficacy of Decision Support Systems in Reducing Fungal Disease Incidence. Agronomy, 10(4), 560; in which it is stated that calendar-based and DSS-based programs provided similar reductions in disease incidence, further supporting the efficacy of DSSs." Now, authors added an evaluation of halving fungicide sprays in concordance with the from farm to fork strategy.

Following the suggestion of the editor, we have reworded the paragraph from line 272 to line 276 in the Methods Section highlighting the major differences/novelties provided by the present study beyond the existing literature, particularly considering our previous study (before ref 35 and now ref 30). Compared to on our previous study, here we used a different modelling framework (based on beta-binomial mixed regression model) more suitable to analyze our dataset, providing a more robust analysis. Moreover, the new models allowed us to assess the effect of the number of sprays - which is relevant to evaluate the effect of halving the use of fungicides - but also the effect of 4 important moderator variables (location, crop, pathogen, fungicide type). To our knowledge, this is the first time that a global synthesis of DSSs has been conducted in terms of reduction of fungicide sprays, which is the cornerstone of the FFF strategy in the EU.

Once the following concerns have been addressed, this reviewer will support the publication of this work.

L52: theres a lacking bracket We have fixed it. Line 64.

L149-153. As a general question I have: is replacing calendar-strategy to DSS-based strategy the main way of reducing the use of synthetic products for the next agriculture? I mean, this paper provides support for reducing sprays in the currently established systems (monogenic, input dependant), but, should we redesign the cropping systems (intercropping, cultivar mix, etc.) for minimizing the dependency of fungicides? I felt the lack of some lines regarding this idea. On the other hand, 2030 is just around the corner, so the confirmation of DSSs efficacy, can aid conventional farmers to move gradually to less fungicides-dependent crops.

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We thank the reviewer for highlighting this issue, on how the next generation agricultural systems will be redesigned to cope with the FFF strategy. We have included a sentence from line 164 to line 170 about this integrated disease control perspective. A reference (ref 20) has been added. In relation to the last point, we really hope that our study will be broadly communicated and will persuade growers to embrace the use of DSSs more widely. As we indicated in line 232, perceived rather than actual risks are likely driving growers cautiousness regarding the adoption of DSSs.

Ref 20: Jeger, M. et al. Global challenges facing plant pathology: multidisciplinary approaches to meet the food security and environmental challenges in the mid-twenty-first century. *CABI Agric. Biosci.* **2**, 118 (2021)

Which are the units in Fig 4 in the y-axis? I suppose absolute difference in proportion scale?. Not clear for me.

As noted above, disease incidence difference (DID) is a measure of absolute effect which assesses differences in disease incidence for two groups. It can range from -1 to 1 in probability scale (-100% to 100%). Specifically, for Figure 4, we computed DID between "DSS50%-Cal" and "Cal50%-Cal" under the following specifications of number of sprays (nspdss50%=nspdcal50%= (1,2,3,4,5,6,7,8,9,10) and nspdcal= (2,4,6,8,10,12,14,16,18,20)). We have clarified this question in Methods section (lines 344 and 355 and from line 373 to line 376).

I wonder if it could be a good idea to include some weather/climatic variables. For instance, in the tropics, may the difference in DSSs-Cal be the same size as in temperate zones? I understand that the purpose of the manuscript is to arrive to a robust conclusion, however, the framework FFF is to be applied in Europe.

Actually, we explored the Köppen-Geiger (KG) classification as a moderator variable in the statistical analysis. Even in the same country, either in the EU or abroad, the variability of climate types was substantial resulting in very low numbers of data covering the different KG categories, limiting any further inferential statistical analysis. Nevertheless, we have updated the database (data.xlsx and readme_data_supp.pdf supplementary informa-

tion files) including the KG classification for each experiment and describing it in the manuscript from line 49 to line 52. As we did for the FRAC classification, we think this descriptive information will help to contextualize our results showing that the dataset of experiments comprised a broad range of climates. Two references have been added (refs 17-18) to support the new text.

Ref 17: Köppen, W., Volken, E. & Brönnimann, S. The thermal zones of the earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world (Translated from: Die Wärmezonen der Erde, nach der Dauer der heissen, gemssigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet. *Meteorol. Z.* **20**, 351360 (2011)

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Yours faithfully,

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13th Aug 21

Dear Dr Lázaro,

Your manuscript titled "Reducing the use of fungicides in agriculture by 50% with decision support systems. A meta-analysis" has now been seen by our reviewers, whose comments appear below. In light of their advice I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table". Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Clare

Dr Clare Davis
Associate Editor
Communications Earth & Environment

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REVIEWERS' COMMENTS:

Reviewer #2 (Remarks to the Author):

Dear auhtors,
thanks for addressing each of my comments.
Now, this reviewer supports the publication of this manuscript.