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Reply on EC1

Timo A. Räsänen et al.

Author comment on "High-resolution erosion susceptibility data for agricultural lands of Finland" by Timo A. Räsänen et al., Hydrol. Earth Syst. Sci. Discuss.,
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Dear Christian Stamm (Editor),

Thank you for your thoughtful and constructive comments (EC) – they helped to improve the manuscript. Altogether, the comments from the editor and the two referees prompted major revisions, and we have revised the manuscript accordingly. The major revisions are:

- The country scale results on actual erosion and erosion management index were removed from the revised manuscript due to limitations in the used C-factor data, which was pointed out by Pedro Batista (Referee #2). Correction of the C factor data requires considerable work and we decided to leave it as future work to be published in another publication.
- The LS factor and consequent erosion data were recalculated to account for field borders.
- The results on RUSLE evaluation, potential erosion risk and potential erosion risk near water bodies were slightly restructured to accommodate the changes caused by removal of the two parts in mentioned above.
- New sensitivity analyses were added that provide estimates on
 - the propagation of uncertainties from RUSLE factors to erosion estimates
 - effects of location specific cropping and management practices and temporal rainfall erosivity distribution on C- factor values and the consequent erosion estimates
- The terms "potential erosion risk" and "actual erosion risk" were replaced by terms, "erosion susceptibility" and "actual erosion" to avoid the misuse of the term "risk".

Thus, the new findings of the revised manuscript are:

- New high-resolution (two-meter) country scale erosion susceptibility data for Finland
- New evaluation of RUSLE and its performance in boreal conditions, which considers also different spatial scales and issues related to upscaling from field parcel to larger spatial scales
- Improved scientific understanding of agricultural erosion and its spatial distribution

These findings provide new opportunities for research and erosion management. In the following we provide our comments and responses (AC) to the editor comments (EC) point by point.

Comments and answers:

EC1: [Language:] In general, the text is easy to read. Still, sometimes there are issues with the grammar such as missing articles (e.g., L. 19, 34 - 35). [Typos:] There are few instances with misspellings (e.g., L. 38, 218).

AC1: We will proofread the manuscript and correct the grammar and misspelling issues.

EC2: [L. 48:] Strange sentence. What does "implementation through natural constraints" mean?

AC2: This refers to the national system of paying subsidies for farmers for implementing environmental measures, such as the buffer zones. The discussion on this was removed from the manuscript as it was less relevant after the omissions in the manuscript.

EC3: How was the LS factor linked to the actual parcels? How do upslope fields influence downslope parcels?

AC3: The LS factor was recalculated in the revised manuscript to account for the field parcel borders. We explain this in revised manuscript in a following way: "The LS factor was calculated from a two-meter resolution LiDAR-based digital elevation model (DEM) of Finland (National Land Survey of Finland, 2020), and by using the SAGA-GIS Module LS Factor (Conrad, 2013) and the method of Desmet and Govers (1996) with default settings. The LS calculation was performed in two-meter resolution for agricultural lands in 301 hydrological units that consisted of river basins, sub-basin groups (Finnish Environment Institute, 2010) and groups of islands (Fig. S1). The agricultural lands were defined according to the field parcel data from Finnish Food Authority, which contains over one million vectorized field parcels and accounts almost all agricultural land in Finland. The use of vectorized field parcels treated each field parcel as an isolated hydrological unit (in terms of overland flow) in the LS calculation to account for the effects of varying landcover on surface runoff, as recommended by Desmet and Govers (1996). The approach is considered justified as in Finland the fields are typically well drained and commonly surrounded by open ditches, which advocates for the hydrological isolation of the field parcels. However, adjacent field parcels that shared the same parcel border were treated in the calculation as a single field parcel, since it is common that uniform field areas are divided into separate field parcels for cropping and management purposes." The evaluation of RUSLE at the seven field sites was not affected by the recalculation of the LS. Their LS factors were originally calculated considering the field borders.

EC4: [L. 133:] What is the empirical basis for the claim that sink filling increases the errors? Sinks in a DEM can be real (and should be accounted for) or can be artifacts. Why did you not distinguish between the two situations?

AC4: We removed the statement that it increases errors. Our observation was that sink filling with a two-meter resolution DEM resulted in flattening and raising of the field surface levels to the levels of neighbouring landforms, such as embankments and roads. This significantly distorted the DEM and the original surface characteristics of the fields were lost. Also, as mentioned in the EC4, fields often have natural depressions, and breaching was observed to create artificial erosion areas. We are not aware of research that would provide suggestions for correct treatment of high-resolution DEM for LS calculation on agricultural lands. We revised the justification on treatment of DEM (or lack of) in the manuscript to be clearer.

EC5: [L. 162:] According to my knowledge, the RUSLE model does conceptually not account for sub-surface transport through tile-drains. Nevertheless, you compare RUSLE simulations to empirical data of the sum of surface and subsurface sediment transport. Should that not be reflected in a conceptual modification of the RUSLE model including a model parameter accounting for the split between surface and subsurface transport? Additionally, the subsurface flow can induce mobilisation of soil particles also within the soil profile, especially in the vicinity of subsurface drains because of the disturbances of

the soil profile due to the installation of the drains. How is this accounted for?

AC5: According to Renard et al. (1997) subsurface drainage is considered in the P factor. Bengtson and Sabbagh (1990) suggested an average P factor value of 0.6, which was also recognised by Renard et al. (1997). However, the research on how the subsurface drainage should be considered in the RUSLE is limited, and to our understanding there is no commonly accepted approach for this. Except, RUSLE2 (USDA, 2013) incorporates a method for this, which considers the changes in K factor due to the subsurface drainage, but in our case the data was too limited to consider this. Therefore, we chose to follow the original suggestions by Renard et al. (1997) and Bengtson and Sabbagh (1990). According to our literature review the subsurface drainage reduce erosion 8-90% (on average 38%) (Bengtson et al., 1988, 1984; Bengtson and Sabbagh, 1990; Formanek et al., 1987; Gilliam et al., 1999; Grazhdani et al., 1996; Istok et al., 1985; Maalim and Melesse, 2013; Skaggs et al., 1982), which results to average P value of 0.62. We used the P value of P 0.6 as suggested and used earlier in Finland by Lilja et al. (2017a). Also, the research in Finland showed that substituting of old drainage pipes with new ones reduced erosion up to 15% on a clay soil (Turtola and Paajanen, 1995). The use of sum of surface and subsurface sediment is justified also by research. In Finland, it is observed that up to 50-90 % of the erosion loading from clay soils occurs via subsurface drainage (Finnish Environment Institute, 2019; Turtola et al., 2007; Turunen et al., 2017; Warsta et al., 2014, 2013) and that erosion material in subsurface drainage flow from clay soils originates mainly from the surface soil (Uusitalo et al., 2001). In the Finnish research, the origin of the erosion material was determined by an analysis of Cesium-137 contents of soil layers and eroded soil material in subsurface drainage flow. Also, process-based modelling studies in Finland suggest that majority of the erosion material in subsurface drainage flow originates from the surface soil (Turunen et al., 2017). A study from Norway also reports that soil material in the drain flow originated most likely from the plough layer, and the soil material was transported to subsurface drains via cracks and macropores in the soil (Øygarden et al., 1997). However, we do acknowledge that the consideration of subsurface drainage in the P factor lumps a complex and poorly understood process into a single value and has therefore limitations and is a considerable source of uncertainty. In the revised manuscript we perform a sensitivity analysis which includes the uncertainty in the P value. This justification was added to the revised manuscript. Note also that our modelling approach tests the above assumptions against empirical data and the resulting performance can be considered reasonable.

EC6: [L. 274 (Tab. 4):] Please provide the number of observation years and the standard deviation of the measured erosion.

AC6: These have been added to the revised manuscript.

EC7: [L. 303 - 304:] Are these novel findings?

AC7: To our knowledge these areas have not been identified as high erosion areas earlier, and therefore these findings are novel.

EC8: [L. 318 - 319 (Fig. 4):] The high-resolution DEM only affects the LS factor, doesn't it? Hence, only this map should make any difference to previous estimates, shouldn't it?

AC8: The R (Panagos et al., 2015) and K factor data (Lilja et al., 2017a, 2017b) are based on existing data, but the LS data is new and created in the manuscript. Thus, the LS factor data, and the erosion estimates calculated with the LS data are new. Erosion has not been estimated earlier over the whole Finland with RUSLE at two-meter resolution. Lilja et al. (2017b) started the two-meter resolution modelling work, but it was not finished and not published.

EC9: [L. 349 (Fig. 6):] To which degree are these findings novel?

AC9: According to the Pedro Batista (referee #2), the results in Fig. 6 contain large uncertainties due to limitations in the C factor. After careful consideration and performed sensitivity analyses, we agree with his view. The C factors vary by location and this was

not considered in the submitted manuscript, which caused regional biases in the erosion estimates. Therefore, the results in Fig. 6 were omitted from the revised manuscript, and their correction will be addressed in future research. However, the sensitivity analyses prompted by Pedro Batista's thoughtful comments are a new addition to the revised manuscript. The issues related to the C factor are discussed in more detail in the Batista's comments and in our answers to him. Despite the omissions, the revised manuscript provides still substantial new findings as explained in the beginning of our comments. Reporting the sensitivities in the northern conditions is considered to provide valuable information regarding erosion assessments.

EC10: [L. 353:] Replace "high field area" by "areas with a large fraction of arable land" (or similar).

AC10: This section was removed from the revised manuscript.

EC11: [L. 357 - 358:] Is that statement not trivial given the definition of the EMI index?

AC11: This section was removed from the revised manuscript.

EC12: [L. 445 - 446:] Where is the evidence that it was indeed the lack of high-resolution risk maps that prevented the implemented of targeted measures?

AC12: We have removed this statement from the revised manuscript.

EC13: [L. 448 - 452:] The four bullet points seem rather similar to me. Can you more precisely explain what the differences are?

AC13: These are affected by the omissions and therefore the policy and management implications were thus revised, and they are now as follows: "The developed erosion susceptibility data markedly improves the basis for analysing the agricultural erosion over multiple spatial scales and consequently provides new opportunities for planning the erosion management. For example, the current data showed large areas with high agricultural intensity and high erosion susceptibility (e.g., coastal areas in Southern Finland), and how erosion varies locally (e.g., Karjaanjoki and Paimionjoki basins), including areas where field parcels near water bodies and have high erosion susceptibility. Such information can be used to guide planning and allocation of erosion management efforts. The consideration of different spatial scales is also important as different scales were found to provide different insights to erosion, which can affect the conclusions drawn from the data and the choice of erosion management measures. Larger scales can provide indication of broader areas needing erosion management, and the local scales reveal more exact locations of high erosion field parcels and help in choosing appropriate erosion management measures. Altogether, the developed data can be used to improve erosion management from policy to actual management levels. However, the use of the data requires understanding of the related uncertainties that were also clarified in this research."

EC14: [L. 454 - 456:] Is this a novel result?

AC14: The results from evaluation of RUSLE are novel, and they provide improved understanding of performance of RUSLE in boreal conditions and provide new estimates on the effects of different crop and management practices on erosion.

EC15: [L. 458 - 460:] This seems to be quite standard knowledge, or am I wrong?

AC15: Agreed. Our intention here was to address a broader audience and to underline an important issue, which is sometimes neglected in practical management. Therefore, we wish to keep this sentence in the manuscript.

EC16: [L. 471 - 472:] Given that you have access to actually crop management data, it should be straight forward to assess the effects such modification in practice, shouldn't it?

EC16: Yes, it should be straightforward with appropriate C values, but this work is considered to be outside the scope of the current manuscript.

EC17: [L. 477 - 478:] Where is the evidence for that? It is a frequently used arguments by natural scientists that improved model will enhance management, but which evidence demonstrates the validity of the claim?

AC17: In this particular case the argument originates not only from natural scientists, but from our personal communication with actors involved planning and implementation of the environmental measures in the agricultural sector, such as the Ministry of Agriculture and Forestry and the Finnish Food Authority who are responsible of allocation of environmental measures in Finland. Of course, there is never a guarantee that improved system understanding leads to improved management outcomes as the implementation depends on variety of factors.

EC18: [L. 481:] The previous erosion risk estimates were rather similar (see L. 384 -389). So in which sense has the understanding of erosion risk considerably been improved?

AC18: The current research provides a new spatially explicit data and information on erosion in high-resolution over the whole Finland and such data and information has not existed before. The earlier work does not provide either the same spatial resolution or coverage as the current work, and the spatial distribution of erosion on country scale has not been well analysed and presented in earlier publications.

EC19: [L. 487 - 488:] What do you mean by considering erosion risk across multiple scales? What does it mean from a scientific point of view, what does it mean in practice?

AC19: The manuscript shows how different scales reveal different spatial patterns in erosion. From scientific point of view this means that conclusions drawn from analyses will depend on the analysis scale, and analysis only in one scale provides a limited view on spatial distribution of erosion. From practical point of view this can affect how management of erosion is approached. Broader scales can reveal regions where greater erosion management effort is needed, and local scales can provide insights into efficient location-specific targeting of mitigation measures. We added following to the revised manuscript: "The consideration of different spatial scales is also important as different scales were found to provide different insights into spatial distribution of erosion, which can affect the conclusions drawn from the data and the choice of erosion management measures. Larger scales can provide indication of broader areas needing erosion management, and the local scales can reveal the locations of the high erosion areas within the field parcels, and consequently help in choosing appropriate erosion management measures for a given location."

EC20: [L. 489 - 490:] Which aspect provides new opportunities for analysing the P- and C cycle given the similarity of previous erosion estimates?

AC20: We have decided to simplify the discussion and remove this from the manuscript.

EC21: [L. 491 - 492:] Where can one see this demonstration? The manuscript does not compare how policies or planning has changed due to the new erosion risk map.

AC21: We have removed this statement from the manuscript.

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