Reproducibility, open science and progression in soil erosion research. A reply to "*Response to 'National-scale geodata describe widespread accelerated soil erosion' Benaud et al. (2020) Geoderma 271, 114378*" by Evans and Boardman (2021).

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1. INTRODUCTION

To address Evans and Boardman's (2021) critique of Benaud et al., (2020), our response focuses on the following three points:

1. Our definition of tolerable soil erosion;
2. Methods for quantifying soil erosion;
3. Transparency, collaboration and data sharing within the soil erosion community

First, however, there appears to be a need to clarify the scope of the original research paper. The remit of the paper was not to provide an historical review of soil erosion research within the UK. This has been reported on numerous times by Evans and Boardman (for example, see Boardman, 2013, 2002; Evans, 2010, 2005). Our work instead sought to advance understanding of the extent to which all available existing data describing soil erosion, and the methodological approaches used to capture such data, can be used to develop an empirically-derived understanding of soil erosion in the UK (Benaud et al., 2020, p. 2). Through providing an alternative and independent perspective on the existing body of work, we were able to make suggestions on how research could be conducted in the future to ensure that greater reproducibility, transparency and collaboration can be achieved within the soil erosion research community, matching progress and discourse within other fields of scientific research (Christensen and Miguel, 2018; "Journals unite for reproducibility," 2014; Powers and Hampton, 2019).

While Evans and Boardman are correct in their assertion that some of the issues presented "*have been discussed in the past literature*" (p. 2), it is always appropriate to apply fresh thinking when attempting to address wicked environmental problems, which includes soil erosion (Banwart, 2011; Bouma and McBratney, 2013; Duckett et al., 2016). Monitoring approaches and technologies that were not cost-effective 5 years ago, let alone over 30 years ago, are now relatively affordable (both in terms of monetary and time cost) and have the potential for greater reproducibility and could allow the quantification of uncertainties (e.g. Cândido et al., 2020; Fawcett et al., 2019; Glendell et al., 2017; James et al., 2020) which is essential to the advancement of scientific knowledge and understanding. Furthermore, tackling environmental challenges in the Anthropocene requires interdisciplinary thinking. To this end, it is appropriate to consider how monitoring approaches and results in general can also be used to improve model accuracy and efficiency (Batista et al., 2019; Carr et al., 2020; Evans and Brazier, 2005). Through building a platform for sharing data and a criterion to increase reproducibility and transparency, our paper (Benaud et al., 2020) also aspired to be a stepping stone in the evolution of scientific and methodological process in this capacity.

2. DEFINITION OF TOLERABLE SOIL EROSION

Broadly speaking, Evans and Boardman critique our definition of tolerable soil erosion, suggesting a tolerable rate of 1 t ha^{-1} yr^{-1} may "*not be noticeable to the farmer*" (p. 4) within a field. In addition to this, they questioned our use of rates of soil erosion rather than extent and frequency when describing soil erosion occurrence.

In response to the former, we reply by stating that establishing tolerable levels for farming were not a major focus of our research – our perspective was more distanced from land use practices. Soil erosion is the process of soil being detached and then transported, most frequently by water in the UK context, but also by tillage, wind and co-extraction crop harvest (Owens et al., 2006), and then deposited. Soil erosion and runoff carrying pesticides, nutrients and sediment are therefore not exclusive processes or problems. As highlighted in our original introduction in Benaud et al., (2020), discussion about tolerability of soil erosion should not be limited to on-farm soil loss. Here, in response to Evans and Boardman, we further emphasise that any discussion on 'soil erosion' in our original piece does not simply refer to short-term and on-site soil loss, but also to the off-site and long-term impacts. All negative environmental consequences of accelerated soil erosion are important when defining a 'tolerable' rate of soil erosion. Furthermore, we reiterate that 1 t ha^{-1} yr^{-1} may not be environmentally 'tolerable' if we consider rates of soil formation (Evans et al., 2020, 2019) and the impacts of sediment on riverine ecosystems (Bilotta and Brazier, 2008; Jones et al., 2012; Naden et al., 2016), for example. Framing tolerable rates of soil erosion in the context of on-site soil loss is, however, important. It is after all within farms that changes to land management practices can be implemented and enforced to mitigate off-site effects, reducing or ideally eliminating soil erosion at source, before it causes either on- or off-site problems. In the UK, and globally, new agricultural land management practices, such as regenerative agriculture and precision farming are gaining momentum, suggesting there is a desire both within the farming community and by policy makers to use the land more sustainably (as per the ambitions of the UK Government's 25 Year Environment Plan, https://www.gov.uk/government/publications/25-year-environment-plan). This needs policy support and robust scientific evidence to encourage wider integration into legislation.

We agree with Evans and Boardman that extent and frequency are also important metrics for understanding the prevalence of erosion. However, we respond by asserting that rates of soil loss from fields (standardised per unit area, per unit time) represent the most useful and consistently measurable metric for comparing the occurrence of soil erosion locally and globally. Rates are also useful for understanding soil erosion in context of soil depth, and more explicitly rates of soil formation, for pairing with ecosystem thresholds, and for evaluating and validating models. In addition, soil erosion data sets are rarely long enough to develop robust magnitude-frequency relationships, therefore reporting of magnitude and frequency of erosion become merely a function of the time period over which the monitoring occurs.

3. METHODS FOR QUANTIFYING SOIL EROSION

Evans and Boardman suggest that visual observations, which target locations known to erode should be used in preference to the criteria we put forward in Benaud et al., (2020), which includes the use of a statistically unbiased sampling strategy. They also question the viability of consistently collecting environmental condition data.

We suggest that neither approach is more correct than the other – these approaches are borne from different questions and epistemological frameworks for 'understanding' and 'quantifying' soil erosion. Critically, our study (Benaud et al., 2020) was borne out of a project funded by the UK's Department for Environment, Food and Rural Affairs (Defra), who required a quantitative evidence basis for soil erosion rates in the UK. We approached this study as a team of interdisciplinary environmental scientists – experts in the fields of soil erosion, remote sensing, environmental modelling, catchment science, and water quality – committed to promoting the use of methods that can quantify environmental variables and uncertainties, with transparent workflows, that can be readily understood and applied by others. As a result, the criteria we have put forward were chosen due to their suitability to deliver that information rigorously. Visual observations, as proposed by Evans and Boardman, could potentially deliver the answer to the question does erosion occur in the UK. However, such an approach, as previously practiced by Evans and Boardman, will not be able to provide a quantification of magnitude or frequency, because it remains a statistically biased approach that focuses on sites of known soil erosion. Such data will also not support legislative change, as they simply present a snapshot of soil erosion frequency in certain localities.

We agree that there are difficulties in using a ‘statistically sound’ approach, but we believe that does not mean it should not be attempted. Without a statistically sound sampling design, the results can only be used to describe erosion presence or absence under a particular set of conditions, thereby removing the cost effectiveness of the approach and transferability of the results. As scientists, it is therefore inappropriate to use biased data to draw broad conclusions such as “*Erosion rates across landscapes is probably very low, equivalent to sheet wash i.e. a background very low rate*” (Evans and Boardman, p.4). Nor can we justify “*giving a higher priority to monitoring landscapes vulnerable to erosion*” (Evans and Boardman, p.1) to reduce costs or establish the scale of the problem, without first carrying out an unbiased national-scale assessment. If we only target locations that are known to erode (presumably identified by experts with prior but imperfect knowledge), we will miss the opportunity to build a complete understanding of frequent but smaller scale events, and we cannot be certain that all problematic landscapes have been identified for a more targeted study (should unbiased data point us in that direction).

Recent advances in remote sensing technologies and computing have the potential to improve the efficiency of statistically unbiased monitoring schemes through providing information on environmental conditions such as rainfall, slope, aspect, land cover, ground cover and soil condition, at super-fine spatial resolutions (e.g., centimetric grain from drones to tens of metres from satellites) and high temporal resolutions (e.g., 5 minute rainfall radar and as frequently as one satellite image per day from Planet Labs). In the UK, rainfall datasets such as CEH-GEAR (Tanguy et al., 2016) as used in Benaud et al., (2020), or rainfall radar data derived from the NIMROD system (Met Office, 2003) are freely available to researchers. Processed rain radar data availability is also increasing globally, and datasets such as TerraClimate (Abatzoglou et al., 2018) also present global, open-access climatic data. Data derived from the Sentinel-1 and Sentinel-2 missions can be used to monitor vegetation cover, globally, where, for example a recent application by Denize et al., (2018) demonstrated the value of this resource for monitoring arable vegetation cover in winter, highlighting the potential for the integration of these resources into soil erosion monitoring programs. In addition, satellite technology offers promising potential for quantifying antecedent soil surface properties (Anderson and Croft, 2009; Babaeian et al., 2019; Mohanty et al., 2017). The availability of these, and other resources, do not negate the difficulty in correlating environmental conditions with soil erosion observations, as demonstrated with our precipitation concentration index analysis, for example (Benaud, et al. 2020). To this end, greater quantities of quantitative data on soil erosion rates under different soil, land use/management, slope and climatic conditions are needed, and can be collected, adopting the approaches and principles that we outline in Benaud et al. (2020). We must be aware that technology does not stand still. We expect that there will be further developments in remote and proximal soil sensing that will open up further possibilities for soil erosion monitoring, and the community should be ready to open their minds to the possibilities that these technologies will offer.

Soil erosion monitoring techniques and experimental designs that promote reproducibility i.e. consistent and comparable results between different research groups and projects, with quantifiable uncertainty, are essential if we are to progress our understanding of soil erosion and improve model accuracy. Monitoring approaches that rely on the skills and long-term experience of a limited few, such as visual estimates of erosion rates (Boardman and Evans, 2020; Evans, 2017), will not efficiently collect the volume of data needed, and promotes a research culture that does not encourage inclusivity and increase diversity (Berhe and Ghezzehei, 2020; Marín-Spiotta et al., 2020). Furthermore, data bias will occur if the reproducibility of a method is tested using estimates made by the same researcher (Boardman and Evans, 2020). As an example of an alternative approach that could be taken, drones offer a low-cost platform to collect imagery for structure-from-motion (SfM) photogrammetry, which allows spatially explicit topographical change to be quantified. Clear data collection protocols can be developed (see Cunliffe and Anderson (2019), for one such example) alongside reproducible data processing workflows and uncertainty analysis (Graham et al., n.d.; James et al., 2020, 2019, 2017). Published examples have demonstrated that SfM photogrammetry can be used to quantify rill and gully erosion in the field (Eltner et al., 2014; Glendell et al., 2017; Kaiser et al., 2014; Ouédraogo et al., 2014), and the implementation for quantifying sheetwash looks promising (Cândido et al., 2020). The rapid advances we have seen in digital photogrammetry over the past two decades (Fawcett et al., 2019) provides a robust example of how recent technological developments, and techniques based on reproducible workflows and interdisciplinary thinking, could be progressed and implemented globally at relatively low cost, to quantify soil erosion objectively.

4. TRANSPARENCY, COLLABORATION AND DATA SHARING IN THE SOIL EROSION COMMUNITY

The third and final major point raised by Boardman and Evans to which we respond here is that they declared our "*search of the literature for databases and sites with quantitative information*" to be "totally inadequate" (p.5). This is an unsubstantiated and poorly evidenced critique of our paper. In the paper, we never claimed that this new database was the *de facto* repository of ALL soil erosion studies ever undertaken – the time constraints of this research project mitigated against us doing that. It is correct that on page 2 of the original paper we state that this database aimed to collate "*all available, empirically-derived soil erosion datasets*", and to the best of our knowledge, this was achieved. However, we accept that it is indeed possible that the data set that we amassed from our exhaustive search of the literature was not complete. We found, when searching for data from past soil erosion studies, that in many cases it is very challenging to access datasets previously collected by researchers, who are now reluctant to share their data, and to identify which are novel data. We respond to Evans and Boardman's point about data inadequacy by highlighting the lack of data openness as a general problem within the soil erosion community in the UK. To provide one example, we contacted Boardman in the spirit of open data sharing in 2015. We requested the data that underpinned published papers on soil erosion in the South Downs, in order to include these data in our database. Boardman declined to contribute to the repository or collaborate in the data sharing experiment arguing that "*the idea of a national database is about 30 years too late*" and that "*if Defra were willing to make him a decent offer for the data*" he "*would consider the request*". Evans demonstrated that he shared the same view. This is by no means an isolated example – many soil erosion studies and publications fail to share their data alongside their publication, and whilst we accept that doing so is a relatively new endeavour within science, we argue that within UK soil erosion there is an urgent need to reverse this trend.

Transparent data sharing allows for the reproducibility of results, and in turn, methods, to be assessed and increases the value of the research by opening the data to other users. Furthermore, faced with the impacts of the Anthropocene, it is arguably no longer appropriate to withhold evidence of wicked environmental problems to the benefit of a select few (Mann, 2014). Shared data has allowed the sensitivities of British landscapes to increased erosion under climate change to be explored and articulated, for example (Ciampalini et al., 2020). To foster scientific development, greater collaboration between researchers is needed, and the diversity of those doing the research needs to increase. It is inappropriate for the conversation to be dominated by a small group of researchers, and for the voices of those open to progression, especially early career researchers, to be met with hostility; we need to be critically and actively open to new ideas to allow the field to progress (Azoulay et al., 2019). As highlighted by Evans and Boardman, the last large-scale soil erosion monitoring data in the UK was collected over 20 years ago now, and we argue this is in desperate need of refreshing.

The online database is openly available here www.tinyurl.com/SoilErosionMap and a persistent record will remain here https://zenodo.org/record/3759157. The website contains instructions on how to contribute further datasets to the database. As curators of that database we would welcome any future submissions from the soil erosion community – in fact, to imagine this database as an evolving source of information upon which we can guide optimal soil erosion research and conservation practices, would indeed be ground-breaking.

5. CONCLUSION

Research is meant to be dynamic, not stagnate, and while it is important to acknowledge and consider the research methods historically used, it is limiting to halt progress to novelty from yesteryear. Soil erosion is a globally important issue with destructive ecosystem impacts. Transdisciplinary approaches, alongside reproducible research methods and data sharing is needed if we wish to change harmful land management practices. Benaud et al., (2020) presents one such approach, and re-opens the discussion in that regard. Critically, more funding and policy support, along-side progressive science is long over-due in this area.

6. REFERENCES

Abatzoglou, J.T., Dobrowski, S.Z., Parks, S.A., Hegewisch, K.C., 2018. TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958-2015. Sci. Data 5, 1–12. https://doi.org/10.1038/sdata.2017.191

Anderson, K., Croft, H., 2009. Remote sensing of soil surface properties. Prog. Phys. Geogr. 33, 457–473. https://doi.org/10.1177/0309133309346644

Azoulay, P., Fons-Rosen, C., Zivin, J.S.G., 2019. Does Science Advance One Funeral at a Time? Am. Econ. Rev. 109, 2889–2920. https://doi.org/10.1257/aer.20161574

Babaeian, E., Sadeghi, M., Jones, S.B., Montzka, C., Vereecken, H., Tuller, M., 2019. Ground, Proximal, and Satellite Remote Sensing of Soil Moisture. Rev. Geophys. 57, 530–616. https://doi.org/10.1029/2018RG000618

Banwart, S., 2011. Save our soils. Nature. https://doi.org/10.1038/474151a

Batista, P.V.G., Davies, J., Silva, M.L.N., Quinton, J.N., 2019. On the evaluation of soil erosion models: Are we doing enough? Earth-Science Rev. https://doi.org/10.1016/j.earscirev.2019.102898

Benaud, P., Anderson, K., Evans, M., Farrow, L., Glendell, M., James, M.R., Quine, T.A., Quinton, J.N., Rawlins, B., Jane Rickson, R., Brazier, R.E., 2020. National-scale geodata describe widespread accelerated soil erosion. Geoderma 371, 114378. https://doi.org/10.1016/j.geoderma.2020.114378

Berhe, A.A., Ghezzehei, T.A., 2020. Race and racism in soil science. Eur. J. Soil Sci. https://doi.org/10.1111/ejss.13078

Bilotta, G.S., Brazier, R.E., 2008. Understanding the influence of suspended solids on water quality and aquatic biota. Water Res. 42, 2849–61. https://doi.org/10.1016/j.watres.2008.03.018

Boardman, J., 2013. Soil Erosion in Britain: Updating the Record. Agriculture 3, 418–442. https://doi.org/doi:10.3390/agriculture3030418

Boardman, J., 2002. The Need for Soil Conservation in Britain: Revisited. Area 34, 419–427. https://doi.org/10.2307/20004273

Boardman, J., Evans, R., 2020. The measurement, estimation and monitoring of soil erosion by runoff at the field scale: Challenges and possibilities with particular reference to Britain. Prog. Phys. Geogr. Earth Environ. 44, 31–49. https://doi.org/10.1177/0309133319861833

Bouma, J., McBratney, A., 2013. Framing soils as an actor when dealing with wicked environmental problems. Geoderma 200–201, 130–139. https://doi.org/10.1016/j.geoderma.2013.02.011

Cândido, B.M., Quinton, J.N., James, M.R., Silva, M.L.N., de Carvalho, T.S., de Lima, W., Beniaich, A., Eltner, A., 2020. High-resolution monitoring of diffuse (sheet or interrill) erosion using structure-from-motion. Geoderma 375, 114477. https://doi.org/10.1016/j.geoderma.2020.114477

Carr, T.W., Balkovič, J., Dodds, P.E., Folberth, C., Fulajtar, E., Skalsky, R., 2020. Uncertainties, sensitivities and robustness of simulated water erosion in an EPIC-based global gridded crop model. Biogeosciences 17, 5263–5283. https://doi.org/10.5194/bg-17-5263-2020

Christensen, G., Miguel, E., 2018. Transparency, reproducibility, and the credibility of economics research. J. Econ. Lit. https://doi.org/10.1257/jel.20171350

Ciampalini, R., Constantine, J.A., Walker-Springett, K.J., Hales, T.C., Ormerod, S.J., Hall, I.R., 2020. Modelling soil erosion responses to climate change in three catchments of Great Britain. Sci. Total Environ. 749, 141657. https://doi.org/10.1016/j.scitotenv.2020.141657

Cunliffe, A.M., Anderson, K., 2019. Measuring Above-ground Biomass with Drone Photogrammetry: Data Collection Protocol. Protoc. Exch. https://doi.org/https://doi.org/10.1038/protex.2018.134

Denize, J., Hubert-Moy, L., Betbeder, J., Corgne, S., Baudry, J., Pottier, E., 2018. Evaluation of Using Sentinel-1 and -2 Time-Series to Identify Winter Land Use in Agricultural Landscapes. Remote Sens. 11, 37. https://doi.org/10.3390/rs11010037

Duckett, D., Feliciano, D., Martin-Ortega, J., Munoz-Rojas, J., 2016. Tackling wicked environmental problems: The discourse and its influence on praxis in Scotland. Landsc. Urban Plan. 154, 44–56. https://doi.org/10.1016/j.landurbplan.2016.03.015

Eltner, A., Baumgart, P., Maas, H.-G., Faust, D., 2014. Multi-temporal UAV data for automatic measurement of rill and interrill erosion on loess soil. Earth Surf. Process. Landforms 40, 741–755. https://doi.org/10.1002/esp.3673

Evans, D.L., Quinton, J.N., Davies, J.A.C., Zhao, J., Govers, G., 2020. Soil lifespans and how they can be extended by land use and management change. Environ. Res. Lett. 15, 0940b2. https://doi.org/10.1088/1748-9326/aba2fd

Evans, D.L., Quinton, J.N., Tye, A.M., Rodés, Á., Davies, J.A.C., Mudd, S.M., Quine, T.A., 2019. Arable soil formation and erosion: a hillslope-based cosmogenic nuclide study in the United Kingdom. SOIL 5, 253–263. https://doi.org/10.5194/soil-5-253-2019

Evans, R., 2017. Factors controlling soil erosion and runoff and their impacts in the upper Wissey catchment, Norfolk, England: A ten year monitoring programme. Earth Surf. Process. Landforms 42, 2266–2279. https://doi.org/10.1002/esp.4182

Evans, R., 2010. Runoff and soil erosion in arable Britain: changes in perception and policy since 1945. Environ. Sci. Policy 13, 141–149. https://doi.org/10.1016/j.envsci.2010.01.001

Evans, R., 2005. Monitoring water erosion in lowland England and Wales—A personal view of its history and outcomes. Catena 64, 142–161. https://doi.org/10.1016/j.catena.2005.08.003

Evans, R., Brazier, R.E., 2005. Evaluation of modelled spatially distributed predictions of soil erosion by water versus field-based assessments. Environ. Sci. Policy 8, 493–501. https://doi.org/10.1016/j.envsci.2005.04.009

Fawcett, D., Blanco-Sacristán, J., Benaud, P., 2019. Two decades of digital photogrammetry: Revisiting Chandler's 1999 paper on "Effective application of automated digital photogrammetry for geomorphological research" – a synthesis. Prog. Phys. Geogr. 43, 299–312. https://doi.org/10.1177/0309133319832863

Glendell, M., McShane, G., Farrow, L., James, M.R., Quinton, J., Anderson, K., Evans, M., Benaud, P., Rawlins, B., Morgan, D., Jones, L., Kirkham, M., DeBell, L., Quine, T.A., Lark, M., Rickson, J., Brazier, R.E., 2017. Testing the utility of structure-from-motion photogrammetry reconstructions using small unmanned aerial vehicles and ground photography to estimate the extent of upland soil erosion. Earth Surf. Process. Landforms 42, 1860–1871. https://doi.org/10.1002/esp.4142

Graham, H.A., Puttock, A.K., Cunliffe, A.M., Benaud, P., Elliott, M., Anderson, K., Brazier, R.E., n.d. Using aerial photogrammetry to detect dynamic canopy height change resulting from beaver (Castor fiber) foraging. In prep.

James, M.R., Antoniazza, G., Robson, S., Lane, S.N., 2020. Mitigating systematic error in topographic models for geomorphic change detection: accuracy, precision and considerations beyond off-nadir imagery. Earth Surf. Process. Landforms 45, 2251–2271. https://doi.org/10.1002/esp.4878

James, M.R., Chandler, J.H., Eltner, A., Fraser, C., Miller, P.E., Mills, J.P., Noble, T., Robson, S., Lane, S.N., 2019. Guidelines on the use of structure-from-motion photogrammetry in geomorphic research. Earth Surf. Process. Landforms. https://doi.org/10.1002/esp.4637

James, M.R., Robson, S., D'Oleire-Oltmanns, S., Niethammer, U., 2017. Optimising UAV topographic surveys processed with structure-from-motion: Ground control quality, quantity and bundle adjustment. Geomorphology 280, 51–66. https://doi.org/http://dx.doi.org/10.1016/j.geomorph.2016.11.021

Jones, J.I., Murphy, J.F., Collins, A.L., Sear, D.A., Naden, P.S., Armitage, P.D., 2012. The Impact Of Fine Sediment On Macro-Invertebrates. River Res. Appl. https://doi.org/10.1002/rra.1516

Journals unite for reproducibility, 2014. . Nature. https://doi.org/10.1038/515007a

Kaiser, A., Neugirg, F., Rock, G., Müller, C., Haas, F., Ries, J., Schmidt, J., 2014. Small-Scale Surface Reconstruction and Volume Calculation of Soil Erosion in Complex Moroccan Gully Morphology Using Structure from Motion. Remote Sens. 6, 7050–7080. https://doi.org/10.3390/rs6087050

Mann, M.E., 2014. Opinion | If You See Something, Say Something - The New York Times. New York Times.

Marín-Spiotta, E., Barnes, R.T., Berhe, A.A., Hastings, M.G., Mattheis, A., Schneider, B., Williams, B.M., 2020. Hostile climates are barriers to diversifying the geosciences. Adv. Geosci. 53, 117–127. https://doi.org/10.5194/adgeo-53-117-2020

Met Office, 2003. Met Office Rain Radar Data from the NIMROD System [WWW Document]. NCAS Br. Atmos. Data Cent.

Mohanty, B.P., Cosh, M.H., Lakshmi, V., Montzka, C., 2017. Soil Moisture Remote Sensing: State-of-the-Science. Vadose Zo. J. 16, vzj2016.10.0105. https://doi.org/10.2136/vzj2016.10.0105

Naden, P.S., Murphy, J.F., Old, G.H., Newman, J., Scarlett, P., Harman, M., Duerdoth, C.P., Hawczak, A., Pretty, J.L., Arnold, A., Laizé, C., Hornby, D.D., Collins, A.L., Sear, D.A., Jones, J.I., 2016. Understanding the controls on deposited fine sediment in the streams of agricultural catchments. Sci. Total Environ. 547, 366–381. https://doi.org/10.1016/j.scitotenv.2015.12.079

Ouédraogo, M.M., Degré, A., Debouche, C., Lisein, J., 2014. The evaluation of unmanned aerial systems-based photogrammetry and terrestrial laser scanning to generate DEMs of agricultural watersheds. Geomorphology. https://doi.org/10.1016/j.geomorph.2014.02.016

Owens, P.N., Rickson, R.J., Clarke, M.A., Dresser, M., Deeks, L.K., Jones, R.J.A., Woods, G.A., Van Oost, K., Quine, T.A., 2006. Scoping study of soil loss through wind erosion , tillage erosion and soil co-extracted with root vegetables. Final report to Defra for project SP08007.

Powers, S.M., Hampton, S.E., 2019. Open science, reproducibility, and transparency in ecology. Ecol. Appl. 29. https://doi.org/10.1002/eap.1822

Tanguy, M., Dixon, H., Prosdocimi, I., Morris, D.G., Keller, V.D.J., 2016. Gridded estimates of daily and monthly areal rainfall for the United Kingdom (1890-2015) [CEH-GEAR].