Interactive comment on "Reconstructing long-term gully dynamics in Mediterranean agricultural areas" by Antonio Hayas *et al.*

Referee #4

General comments

This paper is a very interesting study of gully erosion in a wide agricultural area, cultivated with important crops. Information from a wide time period is analyzed. The scientific questions addressed are within the scope of HESS. The complexity of gully erosion phenomenon in agricultural areas is highlighted and discussed in detail. The Monte Carlo-based approach proposed for reconstructing gully erosion rates from orthophotos is original and helps to get the most of the available information. The paper is well written and both methodology and analysis of the results are correct. Thus, the paper could be published after moderate revision.

We thank Referee #4 for his time in reviewing this manuscript and for his positive feedback.

Specific comments

Introduction is particularly good: concise but including all the key aspects, with well selected and suitable references. It would be desirable to explain in more detail the degree of representativeness of the selected study area.

We appreciate the positive evaluation of the introduction. In terms of representativeness, this area is typical for agricultural landscapes in Southern Spain, both in terms of topography, crops, as geology:

-The area is typical of the rolling landscapes of the Guadalquivir river valley (57 000 km^2), called "Campiña" (more explanation on this term and its extension can be found in Spanish- on https://es.wikipedia.org/wiki/Depresi%C3%B3n_del_Guadalquivir). The mean slope of our study area is 13%. The mean slope of all olive orchards in Southern Spain is between 8 and 16% according to official reports (Consejería de Agricultura y Pesca, 2002. El olivar andaluz).

- Main crops in our study area are herbaceous crops and olives. For Andalucía (S Spain), herbaceous crops and olives are respectively the 3rd and 1st most important crops, together covering almost 50% of the agricultural surface area. They are not just representative for Southern Spain, but also at the national level. According to a classification based on CORINE data, herbaceous crops and permanent crops (olives) are respectively the 1st and 4th most frequent crops (38.6% and 14.2% of the total agricultural area in Spain). Olives are probably one of the most typical crops of Mediterranean hilly areas in general.

-Geology and soil type are typical for the rolling landscapes of the Guadalquivir river valley, or Betic depression, where Vertisols are dominant. Vertisols occupy 9% of the total land surface of Southern Spain (Andalucía region) and possibly a much higher percentage of the agricultural soils (no estimate available).

Therefore, we expect that the observed gully dynamics are representative for other areas of the Guadalquivir or Betic depression.

We have added a more detailed explanation on the representativeness of our area to the manuscript, at the end of paragraph 2.1:

The study area can therefore be considered representative for agricultural landscapes in Southern Spain in terms of land use, topography and geology. Herbaceous crops and olives cover almost 50% of the total agricultural surface area of Southern Spain. Large parts of the Guadalquivir depression are characterized by rolling hills, geomorphologically similar to our study area, and similar soils dominated by clays and marls.

P5. "In order to measure gully width in a representative way, 35 stretches were selected: : :". "Gully top width and depth were measured at 27 representative sections: : :" It seems to me that the number of measurements of these key variables is too low. Please, justify.

This is an excellent question and was also raised by reviewer 1. However, we argue that the amount of measurements is not too low as it is specifically the objective of the Monte Carlo technique to diminish the number of observations in order to optimize sampling cost and time.

Really the central question is to what extent we can correctly characterize the probability distribution functions (pdf) of those key geomorphic parameters. Our own data and a similar study by Istanbulluoglu *et al.* (2002) indicate that the number of observations made should be enough to adequately represent the pdfs. We have added explanation in the text to clarify this issue (see also reply to Referee #1):

With regard to the reduced number of sample points commented by the Reviewer, we are aware of this limitation.

However, the objective of the Monte Carlo method is exactly to reduce the number of observations and avoid having to measure the cross section of each gully section. We do think that the gathered information is enough to develop a Monte Carlo method. Hammersley and Handscomb (1964, section 1.1) appositely explain that one of the reasons for adopting such a method is the inherent difficulty and high economic cost to get field information. In any case, the Monte Carlo simulates in the area occupied by gullies, not the entire catchment, which is less than a 5% of the total catchment area (20 km2). As noted above, Istanbulluoglu et al. (2002) used a similar Monte Carlo approach to estimate channel incision locations in a catchment of about the same size as ours. For the different input parameters they have a similar amount of field measurements, between 19-25 (see their Table 1), which they use to fit a theoretical probability distribution, similar to our method. As long as the field measurements allow to characterize the probability distribution function (pdf) of the variable in question, we are confident that the Monte Carlo method gives a reliable estimate of the uncertainty. We believe that the results shown in Table 4, where we quote the fit between the observations and the theoretically fitted pdfs, with p-values of 0.64-0.98 demonstrate the good fit of these relations.

We have added to the discussion section some more explanation on this topic at page 7 line 39:

Although more field measurements of gully sections would be advantageous in order to reduce uncertainty, time and money spent on ground truthing will increase accordingly. However, the high p-values of 0.64-0.98 obtained here for the fit between the theoretical probability distribution function and the experimental data suggests satisfactory results can be obtained, even with a limited field sample. Moreover, also Istanbulluoglu et al. (2002) successfully used a Monte Carlo approach to estimate gully incision locations using a similar amount of field data.

The Monte- Carlo approach selected is very interesting. However, the authors should explain why they dont consider other methods (such as photogrammetry from stereoscopic pairs, etc.) to estimate gully depths.

This is a good point. The motivation is twofold. Firstly, this study is part of a larger project, whose objective it is to calculate gully volumes over large areas. In order to use photogrammetry for that, we would need to measure all gullies, which would imply a lot of processing time. Monte Carlo allows to obtain a gully erosion rate estimate from a limited sample and obtain a measure of uncertainty. Secondly, we wished to establish a methodology to estimate gully volume using publicly available data that are available under the form of orthophotos. Eventually, our future goal is to extract gully networks automatically from these photos (or use existing algorithms for that), so our MC method would then allow for gully volumes to be rapidly calculated for larger regions without the need of a technician to process stereopairs.

Although this explanation exceeds the objectives of the manuscript, we have added more explanation to the text to clarify the usefulness of MC to the reader:

The advantage of this new Monte Carlo method over traditional photogrammetry is twofold. Firstly, a measure of volume can be obtained from a limited number of measurements whereas traditional methods required the entire area to be processed. Secondly, this allows us to use freely available orthophotos and opens new possibilities towards automatic gully volume determination, as extraction of two-dimensional gully networks using image classification techniques has already been implemented successfully in a variety of environments (e.g. Shruthi et al., 2014).

Shruthi, R.B.V., Kerle, N., Jetten, V., Stein, A., 2014. Object-based gully system prediction from medium resolution imagery using Random Forests. Geomorphology 216, 283-294.

P6. Field observations suggested that a triangular section is a reasonable approximation of most gully sections, so a shape factor k=0.5 was adopted in order to compute the simulated sections". It is not enough just to say that "field observations suggest". The shape factor k is very important for the results obtained and the considered value of 0.5 has to be justified.

We have based this statement on: i) field observations during the measurement of the sections; ii) field measurements made with terrestrial LiDAR (results not shown here) and iii) from other studies in similar environments. From the field mapping, all 27 measured sections were classified as triangular. From the LiDAR data, the same conclusion was drawn (see for example figure 1).

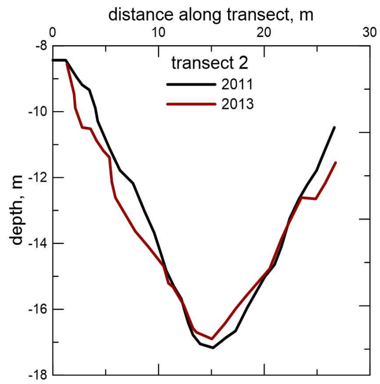

Fig. 1. Cross-section of a representative gully in the study area based on terrestrial LiDAR data in 2011 and 2013.

We however agree that the explanation was not clear on this, and have now explained this better in the text, under section 2.5: "...Field observations suggested that a triangular section is a reasonable approximation of most gully sections, so a shape factor k = 0:5 was adopted in" was replaced by:

During the field mapping, all 27 measured cross sections were classified as triangular, so a shape factor k=0.5 was adopted"

P7L9. I wonder if "extreme annual" makes sense:

The comment is correct. The text has been changed to:

"a big number of high annual rainfalls"

P7. I think that the meaning of the expression "anomalous" used in this paper deserves deeper explanations.

In order to avoid imprecision we have made the following changes:

In section 3.1, at the end of the first paragraph:

can thus be taken as a severe rainy period.

And in section 3.3, in the middle of the first paragraph:

and to severe rainy periods in 2009-2011.

P8. "From 1984 to 1999 and 2009 to 2011 there was an increment of 14.6 $m\,ha^{-1}$ and 23.6 $m\,ha^{-1}$ respectively, which account for 84% of the total drainage density growth". The duration of the two periods is very different, what has to be considered in the discussion.

This is a very good point and was also raised by referee #1. With respect of the different duration of the periods between photos, we have considerably extended the discussion. As commented also by referee #1, at the beginning of the time series the temporal resolution is lower than during the last years, which has an impact on uncertainty.

We agree that these 1956-1980 and 1984-1999 periods are longer and are aware of the limitations. We have noted this already in the Discussion section, on page 6 line 77-82:

However, given the length of this periods and since there are some particular years (i.e. 1961-1962) with extreme rainfalls it is likely that positive gully growth occurred during this period that was later masked by infilling.

We have added to this discussion:

This shows that longer periods, such as 1956-1980 and 1984-1999, are subject to a higher uncertainty with respect to the post-1999 period, when a higher temporal resolution is available.

P10, paragraph 3.7. When calculating the erosion rates in ton ha^{-1} yr^{-1}, is the considered surface area constant or varies from year to year? Please explain.

Again, this is a very good point and was also raised by referee #1. We always calculate erosion rates with respect to the total area of the study area (the motivation being that we are characterizing gully erosion rates in this area; if there would be only one gully in the entire area, calculation with respect to the gullys catchment area would overestimate gully erosion rates in the study area that in this hypothetical case would be largely ungullied).

We have now clearly indicated this throughout the text.

Line 46 to 47 has been modified to clarify this point:

The average gully erosion rate of 39.7 $t\,ha^{-1}yr^{-1}$ for the total catchment area obtained in this study,...

Correction in Line 54 to refer it to the total catchment area:

The highest gully erosion rate of 331 $t\,ha^{-1}yr^{-1}$ referred to its catchment was found...

P10, L27. Is not the Mediterranean climate temperate?

Again, this is correct. See also reply to referee #1

Both climates are temperate, what makes the sentence very unfortunate. Using the revised version of the Kppen-Geiger world climate types of Peel *et al. 2007*, we are rewritten the sentences in the text. We agree and have modified the original version, Line 83 now says:

Moreover, the data presented here clearly show than in Mediterranean-climate areas (Csa type in the Köppen classification) the gully growth dynamics are different than in Temperate Oceanic west-European areas (Cfb type) for instance.

And now Line 89 states:

Data for this study was from the Temperate Oceanic (Cfbn type) loess belt...

Technical corrections

P2L16: "New"

P3L11: remove comma

P7L1: "difference"

P8. "In most of the analyzed period variations on drainage density occurs are small. However, there are two significant periods where the increase". Please rewrite.

All technical corrections were adapted following the indications of referee #1