Interactive comment on **"Effect of charcoal amendments and a deep rooted crop on spatial and temporal runoff patterns in the degrading humid highlands of Ethiopia" by H.K. Bayabil et al.**

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Anonymous Referee #2

Thank you for the review and the comments. It is excellent review but in some cases the changes proposed on removing some of the results were difficult to implement because we need more than one year of data in hydrological studies.

In the following we give first a general response to the review and then respond to the comments. The comments are copied verbatim. Each comment is followed by our response and we cite the text that is changed. The blue colored text is added. The black text is the original text. For clarity we did not show the text that is omitted

General response:
For clarity, let us first explain the intent of this field experiment and the underlying design. There were eight (8) replicates of the same three treatments. Data was collected for two years. Plots were constructed by us, data collectors hired and storm runoff totals measured for each rainfall event. This is quite an accomplishment for one person in Ethiopia. We expected that the deep rooted crop and the charcoal would increase infiltration through the slowly permeable layer formed as a result of the land degradation processes with the largest differences on the most degraded soils. We planned to have had a really "neat" paper in which we could show statistically that deep rooted crops and charcoal increased infiltration and reduced runoff and these treatment could be used to counter land degradation. Finally, we could have developed some recommendations as suggested by the reviewer

Obviously this is not what happened. Several plots had runoff coefficients that were greater than one, meaning that there was more runoff than runoff. When looking at other experiments in the same watershed, we found that similarly runoff plots had runoff coefficients greater than one. Reading more about monsoon climates, it became obvious that the rainfall was highly variable both in space and time and could explain our results with one rain gage in the middle of the watershed. Surprisingly we found very few studies reporting that they had more rainfall than runoff for the obvious reasons that violating the mass balance is never seen favorable by the reviewers. Since, we had good quality data, we decided to report openly what we found. Our hope is that once we publish these results, others will follow. This would help greatly the development of rainfall runoff relationships for the monsoon climates.

Thus our philosophy is different than reviewer 2, who would like us to remove data to make the results better fitting. Instead we would like to include all results clearly showing the (variable) rainfall runoff relationships. Obviously we did not explain this very well in the manuscript and we offer our apologies

Comment:

Understanding hillslope hydrologic during rainstorms is a prerequisite for improved catchment management. In the past few decades, many experimental hillslope studies have been conducted to understand rainfall–runoff processes. Classically, there are two mechanisms of surface runoff generation: (1) Hortonian flow that occurs when rainfall intensity exceeds infiltration capacity of the soil and (2) saturation excess surface runoff that occurs when the perched water table rises, saturating the whole soil profile and creating a seepage face. Although these mechanisms have been used to classify overland flow (OF) mechanisms throughout the world, there is still a lack of knowledge in terms of their factors that control (Sen et al., 2010; Van de Giesen et al., 2010; Orchard et al., 2013). By focusing on different land uses, it is this gap that the present study aims at investigating. Despite this paper being of main interest, it still requires significant revision before publication in HESSD can be granted.

Response:

We are pleased with the overall evaluation of the manuscript. We have implemented many of the revisions recommended to us and described below.

Comment:

The structure and content of the introduction could be greatly improved and so far the authors' materials and methods are not adapted to the research objectives. Plots with different sizes and followed during different periods are used but can't be compared;

Response:

We changed the objective such that is now in accordance with the material and methods. The objective is stated now as follows

> "The objective of this study was, therefore, to investigate realistically spatial and temporal rainfall-runoff relationships in the Ethiopian highlands by investigating the effects of soil degradation status and landscape position. Soil degradation status was affected by adding biochar and growing a deep rooted lupine crop"

We have used long term data from relatively similar plot sizes 3 m^2-plots (3 m length, 1 m width). In addition, we are very much aware that we used different time periods. However, observed flows from plots are extremely scarce and these are the only ones available to us. We use the data from these additional plots to strengthen the explanation of our observation of the experiment performed and not to compare our results against. The reviewer is correct that this would not be proper

Comment:

The basic assumption in research studies aiming at studying one factor is to hold the other factors constant, which was not valid here (there were at least changes in tillage and possibly landscape position between the plots).

Response:

As described above, it was our intent to keep all factors constant. We did not change the landscape potions. In both years the 24 runoff plots stayed at the same location, but indeed we did not plow the lupine crop unlike the first year when it was planted. We intended to grow alfalfa which require plowing but the seeds failed to germinate and we planted lupine. We followed standard farming practices by plowing the barley plots and not the lupine plots. The effect of plowing on increasing runoff (in all eight replicates) was not expected and therefore interesting, but indeed it makes the interpretation of the results statistically more difficult.

Comment:

The obtained results should be discussed, i.e. confronted to the existing literature. Title. Are the authors investigating runoff "processes"? what processes?. Isn't the paper about land use impact on water losses in the degraded?

Response:

We worded this wrong. We are indeed not interested in the runoff processes but in the runoff rainfall relationships. We also realized that we were not interested in land use but in ways to improve the soil. We changed the text to reflect this. For example, the title is now

> "Effects of charcoal amendments and a deep rooted crop on spatial and temporal runoff patterns in a degrading tropical highland watershed".

And the objective is:

> "The objective of this study was, therefore, to investigate realistically spatial and temporal rainfall-runoff relationships in the Ethiopian highlands by investigating the effects of soil degradation status and landscape position. Soil degradation status was affected by adding biochar and growing a deep rooted lupine crop"

Comment:

Introduction.

First of all, the structure of the introduction should be significantly improved to better account for the different processes of OF and to lead the reader to research gaps and research objectives. There are many different ways of writing an Introduction. This depends on the academic subject involved, the journal itself and the specific topic of the article. It is important for the purpose of the research that authors can follow standard patterns as follows: A. Presenting the background of the subject; B. Indicating the importance of the research on the subject; C. Acknowledging what has be done so far on the subject by referring to existing research studies and reporting ones; referring to methods and ideas associated with other researchers; D. Pointing to a gap in knowledge of the subject; E. Selecting research objectives F. Explaining the organisation of the research The first 3 lines of the existing introduction should be moved at the end of the introduction.

Response:

We have significantly changed the introduction (partly based on reviewers 1 comments as well) and it complies with the structure suggested in the comment and demonstrated in the next section. The sections suggested by the reviewer are bold and in square brackets

"1 Introduction

[**A. BACKGROUND**] Performance of many soil and water conservation structures in the tropical highlands has proven to be challenging due to uncertainty of its placement. Ideally the location of the conservation structures should be directly related where runoff is generated in the landscape. Evaluating the effectiveness of landscape modifications is especially timely in the Ethiopian highlands where in an attempt to increase prosperity and assure food security for the rapidly increasing population (Hurni, 1988a, 1999; Nyssen et al., 2009b), the Ethiopian government is implementing management practices for increased rainwater productivity in the degrading landscape and increase the life of hydroelectric power plants such a as the Grand Ethiopian Renaissance Dam on the Blue Nile near Sudan (MOFED, 2010; MOA, 2013; Dagnew et al., 2015; Chen and Swain, 2014) Most areas in the Ethiopian highlands receive high amount of annual precipitation aiding leaching of the soil and promoting land degradation, however, water scarcity is common for 8-9 months every year (Amsalu and Graaff, 2006; Bewket and Sterk, 2005; Biazin et al., 2011; Hugo et al., 2002). Rainfall distribution is variable both spatially and temporally (Biazin et al., 2011; Bitew et al., 2009; McHugh et al., 2007).

[B. IMPORTANCE OF THE PROBLEM] To counteract this problem, soil and water conservation practices are ubiquitous in the Ethiopian highlands. However, surprisingly, most non-traditional soil and water conservation practices are ineffective because their placement neither addresses drivers of runoff nor considers spatial and temporal variations of runoff in a landscape.

Planning effective soil and water management measures require knowledge of dominant runoff generating mechanisms and factors that controls it (e.g., land use vs topography). There are two mechanisms of surface runoff generation: (1) Hortonian flow that occurs when rainfall intensity exceeds infiltration capacity of the soil and (2) saturation excess surface runoff that occurs when the perched water table rises, saturating the whole soil profile. However, there is still lack of agreement in terms of runoff imitation mechanisms and on the factors that control it in the Ethiopian highlands.

[C. ACKNOLEDGEMENT ON WHAT HAS BEEN DONE] Previous studies highlighted saturation excess as the dominant runoff mechanism (Bayabil et al., 2010; Steenhuis et al., 2009; Tilahun et al., 2014, 2013). A field study by Bayabil et al. (2010) found that in the Maybar watershed, with highly conductive soils, saturation excess runoff was mainly driven by topography by channeling water though the hillsides as interflow and saturating the lower lying fields. Likewise, in Debra Mawi watershed in the northern Ethiopian highlands, saturated lower lying fields contributed most of the surface runoff (Tilahun et al., 2013).

In contrast, (Bewket and Sterk, 2005; Taddese, 2001) reported that infiltration excess runoff mechanism was dominant mainly based on analysis of the hydrograph at the outlet focusing on land use change. Land use is important because it affects soil infiltration capacity. For example, several studies reported land use change from natural vegetation to agricultural lands increased overland flow during the rainy monsoon phase and reduced base flows during the dry phase (Bewket and Sterk, 2005; Feoli et al., 2002; Taddese, 2001; Zeleke, 2000). In other countries as well, cutting down of forests resulted in decreased infiltration rates (Hanson et al., 2004; Mendoza and Steenhuis, 2002; Nyberg et al., 2012; Shougrakpam et al., 2010).

On degraded fields with poor soil infiltration capacity, management practices should aim improving infiltration rates. This can be done by restoring the soil macropore network by improving soil organic carbon pool or disturbing the soil profile either physically (tillage) or biologically (using deep-rooted crops). Deep rooted crops penetrate through the soil profile and thereby increase soil conductivity (Angers and Caron, 1998; Cresswell and Kirkegaard, 1995; Lesturgez et al., 2004; Meek et al., 1992). Moreover, upon decomposition of these roots, channels and bio-pores will be created that could provide a network of macropores with greater vertical and lateral conductivity (Yunusa and Newton, 2003).

Another solution, for improving soil physical and hydraulic by improving organic carbon pool through the addition of biochar or charcoal (Abel et al., 2013; Asai et al., 2009; Bayabil et al., 2015; Glaser et al., 2002; Kameyama et al., 2010; Karhu et al., 2011; Laird et al., 2010; Spokas, 2010). Biochar and charcoal incorporation are reported to improve soil bulk density (Abel et al., 2013; Laird et al., 2010), porosity (Abel et al., 2013; Atkinson et al., 2010), and hydraulic conductivity (Asai et al., 2009).

Although biochar and charcoal amendments can be both effective in improving soil hydraulic properties, (Bayabil et al., 2015) argued that charcoal to be a more viable solution for rural Africa because it is widely produced in most rural areas of Africa (Lehman et al., 2006) and therefore more accessible to smallholder farmers than biochar.

[D. POINTING TO A GAP IN KNOWLEDGE] The review above shows that deep rooted crops and additions of charcoal could ameliorate the effects of a degrading landscape. However, field research on the effectiveness of these two practices in a tropical highland setting with monsoon rainfalls do not exists to our knowledge.

[E. SELECTING RESEARCH OBJECTIVES] The objective of this study was, therefore, to investigate realistically spatial and temporal rainfall-runoff relationships in the Ethiopian highlands by investigating the effects of soil degradation status and landscape position. Soil degradation status was affected by adding biochar and growing a deep rooted lupine crop.

[F. EXPLAINING THE ORGANISATION OF THE RESEARCH] The research was carried out in the Anjeni watershed in the Ethiopian highlands in 2003 and 2004. Twenty-four runoff plots were established in groups of three in three transects going upslope. Each group had one plot in which lupine was planted and two plots with barley of which one was amended with charcoal."

Comment:
The introduction should begin by a description of the OF processes and their controls: what is known and unknown to lead to research gaps and specific objectives. Then the case pf Ethiopia with different land uses. Rooting depth is a key factor that appears at the end of the introduction. If this is really looked at, then the existing literature on its impact on OF should be further introduced.

Response:
We have included the two runoff process early in the introduction. Instead of land use, we are really interested in how we can ameliorate the soil by increasing the infiltration though the subsoil. This is described. An important parameter is the amount of water that can infiltration through the slowly permeable layer. Rooting depth plays a role but more important is if the roots can penetrate the hardpan. See the citation above for more details

Comment:
Note that biochards are produced for being used for cooking, not available for crops.
What are the "soil-water relationships" the authors aim at considering? Please justify why land use controls stream volumes? Soil properties and water table dynamics are other

factors to be considered; high correlation between these and landscape position; Please, inform further ron the previous works in Ethiopia on runoff studies; Different treatments are proposed and need to be better justified

Response:

Charcoal are produced locally for cooking. Increasing the production would be relatively simple since it consists of making piles of wood and covering it with sand limiting the oxygen flow for the fire.

We have added text to justify the treatments. The section “C: **Acknowledgement on what has been done”** (see above) is almost completely new and added for this purpose.

Comment:

Materials and methods. OF in the study seems not only affected by land use and topographic position but also by tillage as some plots have been tilled while others were not. Conclusions on a given factor of control thus become uncertain. I thus strongly suggest not to consider 2013 data for which soils under Lupine have been tilled). It is simply not possible to conclude on a land use impact if different tillage conditions occurred. By keeping the 2012 data, the authors should have sufficient data to test their hypothesis of a land use impact on OF. Furthermore, why so any factors? Why charcoal and why not having Lupin with charcoal?

Response:

As explained in the “**general response”** we are interested in reporting the data as they are. We would have indeed sufficient data in 2012 for testing the effect of our treatment on plot discharge. However, in hydrological studies it is not desirable to draw conclusion based on one year of data. Two years is bare minimum. Our results show why one year is not sufficient because the second year behaved different that the first year.
As explained in the “general response” we expected that either a deep rooted crop or charcoal amendments would increase the infiltration rate. Therefore lupine with charcoal is not logical.

Comment:

There are too many factors here and to little plot replicates. Charcoal data have certainly to be removed. The experimental design should be better presented. A table could help to show the different treatments and replicate per treatment, and together with the landscape positions. Ideally and following standards, there should be 3 plot replicate for each combination between landscape position and land use. Some long term monitoring plots with a different size and with data obtained at different dates are added to the work. Please remove them.

Response:

Twenty four plots in eight replicates for the three treatments (barley with and without charcoal and a deep rooted crop) is a lot for a hydrological study. A factorial experimental design was used during installation of plots. Effects of landscape position were assessed by placing plots at different slope positions: at downslope, mid-slope, and upslope, and upper positions. In addition, due to the nature of our experimental design, we couldn't use ANOVA tests or linear regression models. To account the variability due to (slope position) we used a linear mixed effect model linear mixed effect model was fitted. In this model, crop type, slope position, and transect were used as fixed factors, and individual plots as random factors. In addition, our understanding is that the variation between replicates the two year observations (to tackle difference in tillage practices on lupine plots) is removed by analyzing the data separately. There are few hydrological studies that have more experimental plots. We placed the replicates on different part of the landscape to get more hydrological information and to understand how the treatments would work in the different parts of the landscape.

Comment:

Fig 5: where are the different slope positions? Plots at different slope positions can't be considered as replicates as topography is one of the main OF controls.

Response:

In the results section we have it is presented that "While we expected that slope position affect runoff, results from the linear mixed effect model showed that plot-scale runoff responses between slope positions were not significant". In Figure 5 we only show significant factors (crop type and transect) that affected runoff. We agree with the reviewer that topography controls Overland flow, however, in this watershed, topography had less effect compared with crop cover and transect (which has different soil degradation levels).

Comment:

How different are data displayed in fig 6 than fig 3? Please, focus on landscape position and land use

Response:

The same data was used on both Fig 6 and Fig 3, however, the two figures were included to serve different purposes. Figure 3 shows runoff responses from plots and watershed outlet with respect to the corresponding rainfall amount (on three days basis). However, on Figure 6 we compare how cumulative runoff response from plots and watershed vary as the rainy season progresses. Initially, plots have greater runoff than the outlet, which is due to greater detention storage at the watershed scale, while later in the rainy season, watershed flow exceeds plot runoff which shows contribution of baseflow. This has significant importance in understanding how runoff generation varies between point (plot) scale and larger (watershed) scale.

Comment:

Fig 7: data are too scattered to identify trends. What is the purpose eof this figure?

Response:

The main purpose of Figure 7 was to show differences in fitted soil storages (using the SCS-CN equation) due to treatment effect and differences in tillage practices on lupine plots during 2012 and 2013.

Comment:

Results.

The presentation of the results should be improved: The data from the catchment outlet are not really used: should be deleted;

Response:

Upscaling plot data to watershed scale is of current interest. So comparing plot data with outlet is important. We used, therefore the outlet data.

The following paragraph refers to the outlet data

> "Comparison of plot-scale cumulative runoff (color lines, Fig 6) and cumulative river discharge (black line, Fig 6) observed at the watershed outlet with cumulative rainfall indicated that approximately 100 mm of cumulative rainfall was needed before runoff was initiated from all plots. In general, during the start of the monsoon season (until 500 mm cumulative rainfall in Fig. 6), plot-scale runoff response generally exceeded watershed-scale discharge response. Nevertheless, as the rainy season progresses, starting from the middle of August and at approximately 500 mm cumulative rainfall, watershed-scale discharge starts to exceed plot-scale runoff depths (with the exception of the lupine plots in 2013, see below). The difference between plot runoff and outlet discharge at early season of the monsoon indicates that detention storage at a watershed scale; while the difference during later the monsoon season represents base flow at the watershed outlet. This is consistent with previous observations by Tilahun et al (2013 a, b); Bayabil et al. (2010) where initially the runoff from the hillsides infiltrate on the lower slope position and then later in the season these bottom lands start to contribute both subsurface flow and surface runoff"

Comment:

Historical data are not necessary; Data should be presented by land use and by landscape position with ANOVA to test the impact of both land use and landscape position.

Response:

The historical data are shown to convince the reader of the unusual fact that the runoff coefficient is greater than 1. We prefer therefore to keep it in the paper. We changed long term plot data and now we used long term data from relatively similar plot sizes 3 m^2-plots (3 m length, 1 m width).

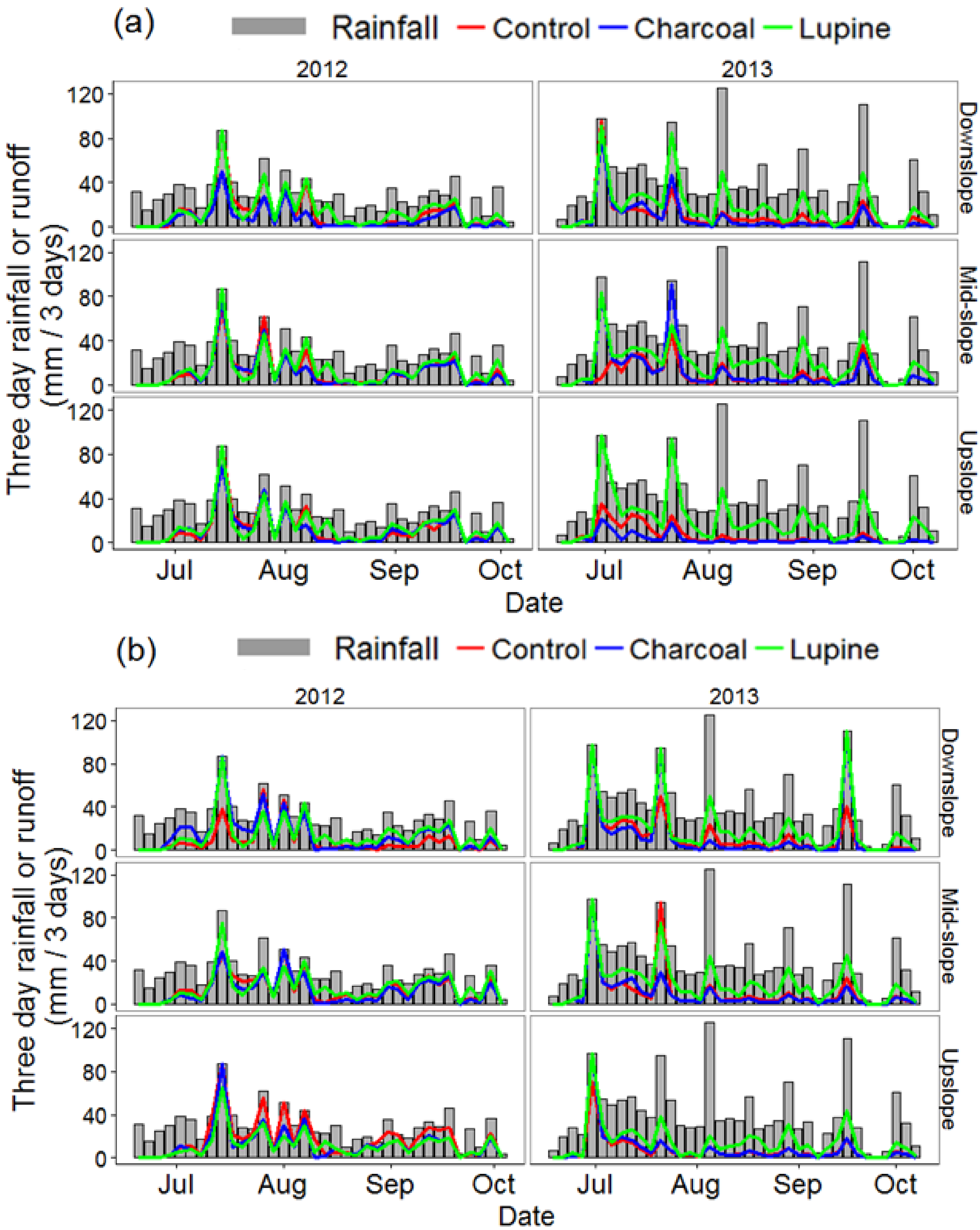
Our data violates ANOVA test assumptions (e.g., independence, normality, equal variance etc.) and therefore are not applicable. As a result we used linear mixed effect model that is applicable for our data.

Comment:

Figure 3 can't be read, too small. can't see treatments, can't see runoff, where are the different slope positions? Discussion.

Response:

Figure 3 is replotted as follows


(a)
Rainfall
Control
Charcoal
Lupine
2012
2013
Downslope
Mid-slope
Upslope
Three day rainfall or runoff (mm / 3 days)
0
40
80
120
Jul
Aug
Sep
Oct
Date
(b)
Rainfall
Control
Charcoal
Lupine
2012
2013
Downslope
Mid-slope
Upslope
Three day rainfall or runoff (mm / 3 days)
0
40
80
120
Jul
Aug
Sep
Oct
Date

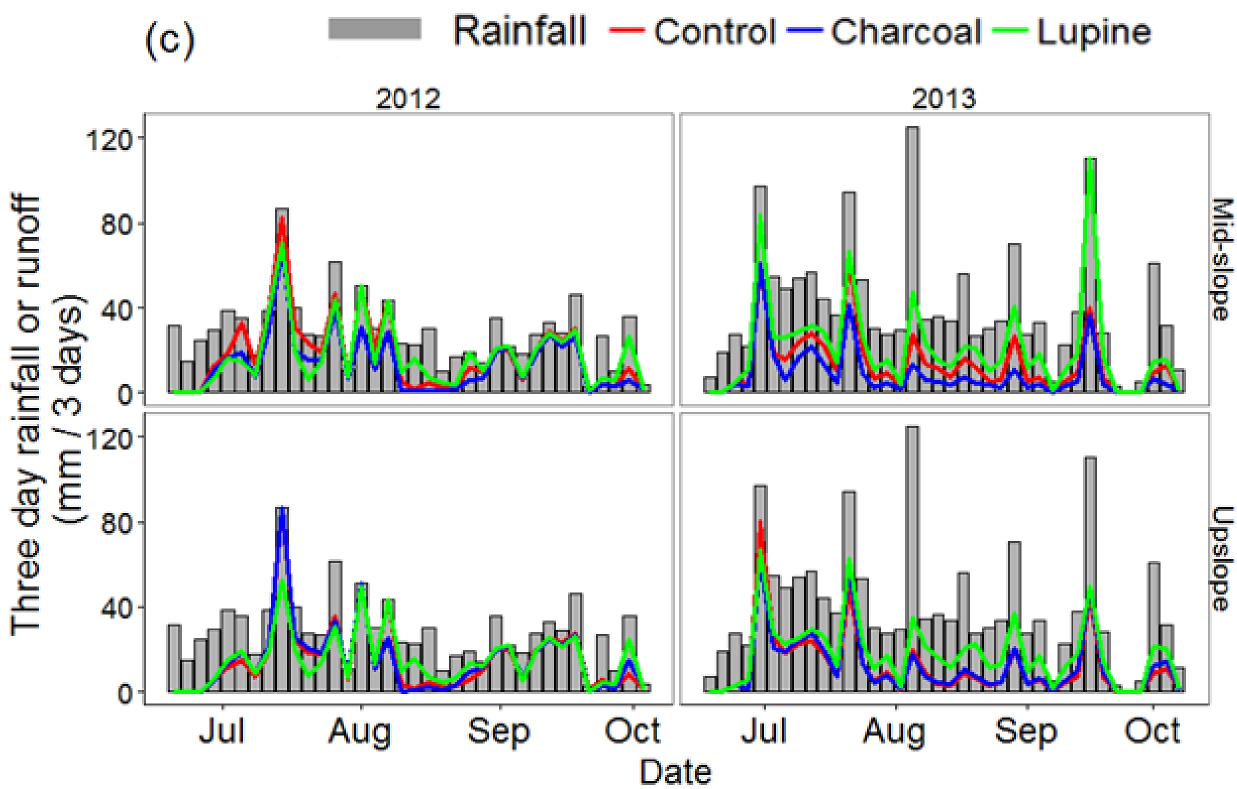


Figure 3. Three day rainfall and adjusted three day runoff depths (aggregated over 3 days) from individual plots at different slope positions along Transect 1 (a), Transect 2 (b), and Transect 3 (c)

Comment:

To be generated Discussion section may fulfil one or more of the following functions: A Presenting background information B Summarising what was (not) done C Explaining why it was (not) done D Evaluating the method(s) or model used E Statement of result(s) F Explanation of result(s) – why and how it happened G Implication of the result(s) – what it does, or does not, imply H Making reference to previous research I General statement of interpretation J Elaboration of interpretation K Discussing implication(s) of the interpretation L Rejection of interpretation M Acceptance of interpretation N Making a recommendation O Stating the limitations of the data P

Response:

This is an unusual paper and we decide to combine the results and the discussion section. SO the outline suggested above really does not apply to our manuscript.

Moreover, in our case statistics is a tool not really the purpose of the paper. It was used to indicate what differences were significant and which need. We had planned a paper in which we would test hypothesis, but as explained in the beginning our results were different than expected. Writing it as a hypothesis based paper did not convey what was important to us.

Comment:

Conclusion

A. Remind of research objectives B. Statements of general findings C. Statements of specific and significant finding D. Statement of overall trends with respect to what was known prior to the study E. How well do results respond to initial gaps, research questions F. Making predictions; recommendations

Response:

We added several sentence to make it adhere to the topics listed above although not quite in the order listed. In addition, in our opinion the Conclusion should also state shortly B' research was performed.

The conclusions are now as follows with in square brackets the categories specified by the reviewer in bold

[A. OBJECTIVE] We set out to investigate the factors that control runoff initiation by investigate the effects of soil degradation status, landscape position, different land uses (barley with and without charcoal, and deep-rooted lupine crop) on spatial and temporal rainfall-runoff relationships. **[B' CONTENT]** We observed and analyzed the discharge of 24 runoff plots installed in groups of three in three transect over a 2 year period. Each group consisted of a plots grown with lupine a barley control and barley with a charcoal amendment. **[B. GENERAL FINDING]** In general we found first that detention storage increased during the first half of the rainy phase and plot runoff was greater than discharge at the outlet. The opposite was true later in rainy phase due to base flow at the outlet. Second, overall, under the commonly applied cropping practice runoff was greater for lupine than barley. Especially, greater runoff was observed during smaller rainfall events (approximately < 20 mm) in 2013, for lupine plots that were not ploughed compared to the tilled plots. Charcoal tended to decrease runoff but results were not significant. Third, plot-scale rainfall-runoff relationships are greatly affected by root-zone soil storage capacity, which is directly affected by soil degradation and the amount of water than can percolate to deeper soil layers tillage practices and fertilization that were different for lupine and barley treatments and root morphology of crops (e.g. root length and density).

[C. SPECIFIC FINDING] Overall, under the commonly applied cropping practice runoff was greater for lupine than barley. Especially, greater runoff was observed during smaller rainfall events (approximately < 20 mm) in 2013, for lupine plots that were not ploughed compared to the tilled plots. Charcoal tended to decrease runoff but results were not significant.

[D. STATEMENT OF OVERALL TRENDS WITH RESPECT TO WHAT WAS KNOWN PRIOR TO THE STUDY E. HOW WELL DO RESULTS RESPOND TO INITIAL GAPS, RESEARCH QUESTIONS F. MAKING PREDICTIONS] In the near term, decreased soil water storage for lupine implies smaller rainfall threshold for runoff initiation. In the long term however, lupine may have the potential to actually reduce runoff by improving infiltration rates through the creation of bio-pores once its large taproot decomposes (Figure F1 in supplementary material F). [The long-term impact of lupine growth on runoff processes therefore requires further investigation. Understanding the drivers of hardpan formation and permeability is essential for the development of management approaches that can effectively tackle hardpan occurrence and its hydrologic impacts, in order to ultimately reverse the land degradation trend.

Our findings are in agreement with other studies that show that rainfall runoff relationship at a small plot scale are different than at the outlet and that better use of green water (rainfall) for smallholder agriculture systems in the Ethiopian Highlands can be achieved by decreasing runoff by increasing the storage of water in the root zone. However, more research has to be done how best to achieve the latter.