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 #1

General comments

The authors analyzed the differences between typical barley cropping, barley cropping with addition of charcoal and typical lupine cropping on runoff amounts for the Anjeni Watershed in the years 2012 and 2013 in a comprehensive study. Additionally, they compare three transects, which differ in degradation severity, and three slope positions. Cropping treatments with barley or lupine did not only differ due to plant morphology but also due to tillage and fertilization. The slope position had no influence on the results, but cropping and degradation severity has.

To my point of view there are many shortcomings which should be addressed. From the fact that runoff was higher for the lupine crops in 2013, the authors conclude that root morphology, root depths and tillage practice affect runoff. Although this is seem likely, the results do not allow this conclusion since the effects of the plant morphology and tillage practice as well as fertilization cannot be distinguished. Thus, I suggest to conclude only that under the commonly applied lupine cropping practice runoff is higher than under the commonly applied barley cropping practice.

Response
We agree with Referee #1 and have incorporated the suggested conclusion.

Under the commonly applied lupine cropping practice runoff is higher than under the commonly applied barley cropping practice

In addition, effect of tillage was also highlighted in the conclusion. Comparing runoff only from lupine plots between 2012 and 2013, where the only difference was that lupine plots were tilled in 2012 while they were not tilled in 2013, there is great increase in runoff from lupine plots in 2013. Even though such increase could be due to several factors (eg. rainfall) it still provides insights how tillage affects runoff responses.

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.

Comment

The effect of charcoal was analyzed and had no effect. This result should also be stated in the conclusions and the abstract.

Response

We agree with the suggested comment and non-significant effect of charcoal on runoff was highlighted both in the abstract and conclusion.

Charcoal tended to decrease runoff but results were not significant.

Comment

In the last section, the only statistically significant result (runoff on lupine plots is greater than runoff on the other plots) is relativized by speculating that in the long term lupine may have the potential to reduce runoff by improving infiltration rates through the creation of biopores. Thus, the reader is asking himself what message can be "taken home" from the study.

Response

The hypothesis presented regarding the long-term effect of lupine roots was based on the root morphology of the lupine crop (Figure F1 in supplementary material F), which eventually would improve permeability of the soil by creating cracks and biopores when these roots decompose.

Figure F1. Lupine crop root morphology

Specific comments

I am not sure but I wonder what a "spatial process "is. It might be better to write about "patterns" instead of "processes". Moreover, the title is misleading since the effect of different crops on runoff is analyzed.

The title is changed to:

Effect of charcoal amendments and a deep rooted crop on spatial and temporal runoff patterns in the degrading humid highlands of Ethiopia

Page 4388
Lines 2-7: I would omit most of the first lines of the abstract since the effect cropping and charcoal on runoff is analyzed and not runoff mechanisms themselves.

Response: The suggested change was made and the first lines of the abstract were omitted

Page 4389
Lines 6-7: "There is no agreement:" I expected some examples for disagreement in the following sentences but did not find any.

Response
Two contrasting arguments (findings) regarding the dominant runoff mechanisms in the sub-humid Ethiopian highlands are presented as follows:

Page 2, line 24-28 and Page 3, 1-10.

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 to 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).

Page 4389

Lines 17-20: This is not a sentence. Just omit the word "which": "Another solution, improving soil acidity and organic carbon pool through the addition of biochar or charcoal, is known to improve soil physical and hydraulic properties (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)."

Response: Suggested change was made and the word "which" is omitted.

Pages 4391 and 4392
It would be interesting to have more specific information about the soils in the plots: texture, organic matter content in topsoil and bulk density. It might also be helpful for the reader to have the information about soil properties, slopes and degradation for the plots in one table.

Response: The suggested information is added in Table 1.

Table 1. Spatial attributes and soil properties of plots

Transect	Position	Plots	Elevation (m.a.s.l.)	Slope (%)	Sand	Silt (%)	Clay	[1]OM	[2]BD (g cm^{-3})	[3]D (m)
One	Upslope	1,2,3	2438	3.0	24.8	35.4	39.8	2.2	1.1	1.15
	Mid slope	4,5,6	2431	2.5	31.7	28.0	40.3	2.1	1.1	1.22
	Downslope	7,8,9	2411	1.5	23.6	36.7	39.6	2.2	1.1	> 1.3
Two	Upslope	10,11,12	2461	2.5	23.8	32.2	44.0	2.1	1.1	0.84
	Mid slope	13,14,15	2426	2.0	17.8	39.0	43.2	2.4	1.2	1.09
	Downslope	16,17,18	2415	1.0	24.7	36.3	39.0	2.4	1.3	> 1.3
Three	Upslope	19,20,21	2455	3.0	21.0	37.7	41.4	1.3	1.4	0.33
	Mid slope	22,23,24	2438	2.0	30.6	37.4	32.0	1.4	1.3	0.72

[1]OM: Organic Matter; [2]BD: bulk density; and [3]D: soil depth

Page 4392
The lupine treatments served as indicator for the effect of deep rooting on runoff. Is it possible that lupine and barley roots have also different effects on the soil hydraulic properties at the upper soil layers? If so, it should be stated.

Response: Yes, lupine and barley crops are expected to have different effects on soil hydraulic properties. This is actually purposely designed for their different purposes. Barley has a shallow root system, but widely has a fibrous root system and grown in the area. In this study we looked at the potential of using charcoal amendment to improve runoff from barley fields. While lupine has a deep rooted system and is widely grown on marginal lands for its leguminous nature. In this study we expected that lupine would

improve soil permeability due to its deep roots and thereby reduce runoff responses. The following sentence is added to section 2.2 (Experimental setup)

Lupine and barley crops are expected to have different effects on soil hydraulic properties. Barley has a fibrous root system, while lupine has deep-rooted system and is widely grown on marginal lands for its leguminous nature.

Page 4393
The difference between the treatment types 1 and 3 is not only the crop but also fertilization and tillage, which is fine because the treatments resemble common practice. However, as not only the crop but also fertilization and tillage might have an effect on runoff, this should be stated more clearly here but also in the discussion.

Response: Differences between treatments and tillage practices are clearly stated both in the methods and discussion section of the manuscript.
While, lupine seedbeds are typically not tilled, tillage was done in 2012 as plots were originally designated to be sown with alfalfa, another deep rooted crop. When alfalfa proved to be unsuccessful, lupine was sown on the tilled soil. The year after, in 2013, only barley plots were tilled and seeded, while lupine seeds were sown on untilled plots, which is a more common practice in the area. Also in line with farmer practices, all barley plots were fertilized with 100 kg/ha Di-Ammonium Phosphate (DAP; 46% Nitrogen, 23% Phosphorous, and 21% Potassium) during seeding, and 100 kg/ha of Urea (100% Nitrogen) one month after sowing. While lupine plots were not fertilized. Both fertilization and tillage are different for lupine and barley treatments during the two year (2012 and 2013) study period. To distinguish treatment effect (barley and lupine crops grown under common practices) and tillage effect, data from the two year study was analyzed separately.

Page 6, line 8-11 and page 13, line 8-10.

Both fertilization and tillage are different for lupine and barley treatments during the two year (2012 and 2013) study period. To distinguish treatment effect (barley and lupine crops grown under common practices) and tillage effect, data from the two year study was analyzed separately.

Page 4395
Line 5: Although it is quite simple, please write the exact mathematical formulation for the runoff coefficient (Rcoef = XX/YY [-]).

Response: The formula used to calculate daily runoff coefficients (R_{coef}) is included in the text.

Page 8, line 1-2.

$$R_{coef} = \frac{runoff}{rainfall} \qquad (1)$$

where runoff is daily runoff (mm/day), and rainfall is daily rainfall amount (mm/day).

Lines 11-12: I cannot find any black arrow in B1-B3.

Response: This is by mistake and the word "black arrow in B1-B3" is deleted from the text

Page 4396
Lines 4 -9: In other sections (page 4395, lines 18-19; page 4397, lines 12ff) the authors argue that rainfall is spatial highly variable and therefore Rcoef can be > 1. Since variability in rainfall might be assumed to be a random error, I do not understand why the authors do not allow Rcoef to be greater than 1 for statistical analysis. If I am not wrong, cutting Rcoef to 1 will produce a bias in the data analysis.

Response: We agree with reviewer #1 that rainfall could be assumed as a random error. But in this manuscript we argued that the only reason that Rcoef can be > 1 is due to high rainfall amounts that rained on some of the plots that we couldn't catch using a single rain gauge at the watershed outlet. Runoff coefficient cannot be > 1 under normal conditions, and by adjusting the runoff data, we are accounting the extra rainfall amount that we could not be able to record using one rain gauge.

Comment
Table D1: Please clarify how total and average 3 day runoff and precipitation are related.
I guess all data represent the time spans from 29 June to 4 October 2012 and 25 June to 8 October 2013. However, in 2012 I calculated 98 days. Total rainfall was 1036 mm and 3 days average was 29 mm. If I simply divide 1036 by 29 I come to roughly 36 three-day intervals, which yields 108 days and not 98 days. I hope my thoughts are not too confusing here. It would be very interesting to have the cumulative runoff for all plots. Thus, I suggest to move table D1 into the paper.

Response
Table D1 is moved into the main manuscript and is now Table 2. The start dates were June 29 to
October 4 in 2012 and June 25 to October 8 in 2013. This results in a total of 98 and 106 days in
2012 and 2013, respectively. We have made the corrections on Table 2.
Page 20, line 1-4.

Table 2. Summary of total runoff during the year (Total runoff), average 3-day runoff in mm (Mean runoff) and Standard error (SE) in mm averaged of the plots in the transect for 2012 and 2013. The annual precipitation in 2012 and 2013 was 1036 and 1528 mm, respectively.

Plot	Rainfall/Runoff (mm)	2012 Transect			2013 Transect		
		1	2	3	1	2	3
Control	Total runoff	438	484	598	300	367	482
	Mean runoff	13	15	18	9	10	14
	SE	2.8	2.5	3	1.7	2.7	2.5
Charcoal	Total runoff	365	468	513	282	365	397
	Mean runoff	11	14	15	8	10	11
	SE	2.2	2.5	2.6	2.1	3	2.3
Lupine	Total runoff	509	495	583	732	670	747
	Mean runoff	16	15	18	21	19	21
	SE	2.8	2.4	2.5	3.3	3.4	3.1
Rainfall	Total rainfall	1036			1528		
	Mean rainfall	32			43		
	SE	0.5			0.8		

*SE: Standard error of the mean

Comment

Figure 4: Rcoef > 1 is mainly given for low rainfall intensities in the long term measurements (left). In the measurement campaign 2012 to 2013 Rcoef > 1 is mainly given for high rainfall intensities. This is interesting as I would have expected the latter to be general since high rainfall intensities are often accompanied by storms, which may lead to greater variability.

Response

In Figure 4, we showed the relation between runoff coefficients with 3-day total runoff amount. In this figure higher runoff amounts does not always mean high rainfall intensity, as runoff intensity also depends on the rainfall urination. We compared our results with runoff coefficients > 1 with the long-term data just to show that our measurements were not due to error.

Page 4397
Lines 21-22: This is only hardly visible in Fig 5. Is this statistically significant?

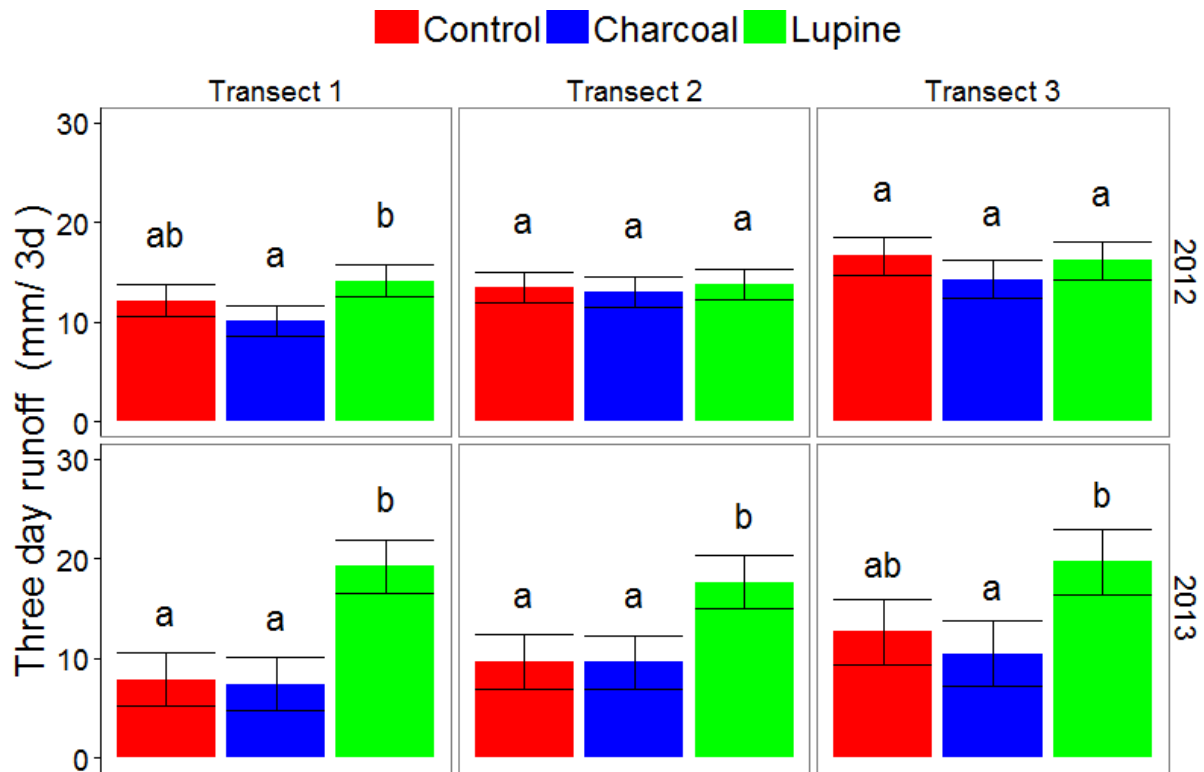**Response:** We have changed Figure 5 and now significant letters are clearly visible.

Figure 5. Effect of charcoal amendment and deep-rooted lupine crop on plot-scale runoff (3-day total) for each transect and year. Treatments not sharing the same letter within an individual transects for a given year are significantly different at p < 0.05.

Page 4398
Lines 6-8: "In general, during the start of the monsoon season (ca. 500mm cumulative rainfall in
Fig. 6), plot scale runoff response generally exceeded watershed-scale discharge response." I guess authors mean until 500mm cumulative rainfall.

Response: Yes, we mean until 500 mm cumulative rainfall.

Lines 11ff: Is it possible that this difference can be explained by the plant growth and thus enhanced root water uptake at the later stage or by increased macro porosity due to root growth?

Response: Yes, this could be another possible explanation for observed differences especially at plot level. However, we believe that the observed increase in discharge at the watershed scale as the rainy monsoon progresses is only due increased base flow.

Line 18ff: Unfortunately, I am not an expert but is it really surprising that tillage increases infiltration capacity? I guess there should be literature about that topic. If not, I apologize.

Response: Yes, tillage increases infiltration rates. Tillage practices in the Ethiopian highlands are employed using oxen pulled plow that disturbs the top soil surface (0-20 cm).

Figure 6: Please use the same colors for treatments as in other figures.

Response: The suggested correction was made and the same color is applied for treatments in all Figures including Figure 6.

Page 4399
Lines 2-4: Please give the SCS-CN equation in the materials and methods section and explain it a bit since not all readers might be familiar with this equation. If I understand it right, the equation was fitted to the data, thus I would not write about prediction in this case.
Page 9, line 3-10.

Response: the SCS-CN equation is given with a paragraph explaining the purpose of fitting the equation.

In addition, to assess the differences in soil storages in plots, the SCS curve number was fitted to three-day rainfall and runoff data for each treatment type and cropping year using the equation (Eq. 2) below. The SCS equation was effectively used in predicting rainfall-runoff relationships in the Ethiopian highlands (Tilahun, 2012) and for different regions in the USA and Australia (Steenhuis et al., 1995).

$$Q = \frac{(P_e - 0.2S)^2}{(P_e - 0.8S)}$$
(2)

where Q is runoff (mm) P_e is three day rainfall (mm) and S (mm) is potential maximum soil storage (Steenhuis et al., 1995).

Figure 7: Please omit the word prediction as the model is simply fitted to the data.
I wonder why the model allows runoff for the charcoal treatment in 2013 even when rainfall is 0. Please explain or better revise the model. I wonder whether this figure and the part with the SCS-CN equation can be omitted. I do not see any benefit here.

Response: the suggested change was made and the word "prediction" was substituted by the word "fitted" in the manuscript

Lines 6-7: I did not find the statistical analysis which underlines the statement that transect
3 (more degraded) produced significantly more runoff than the other two transects. Please clarify.

Response: Statistical tests were performed between transects and results are given in Fig. E1 in supplementary material E.
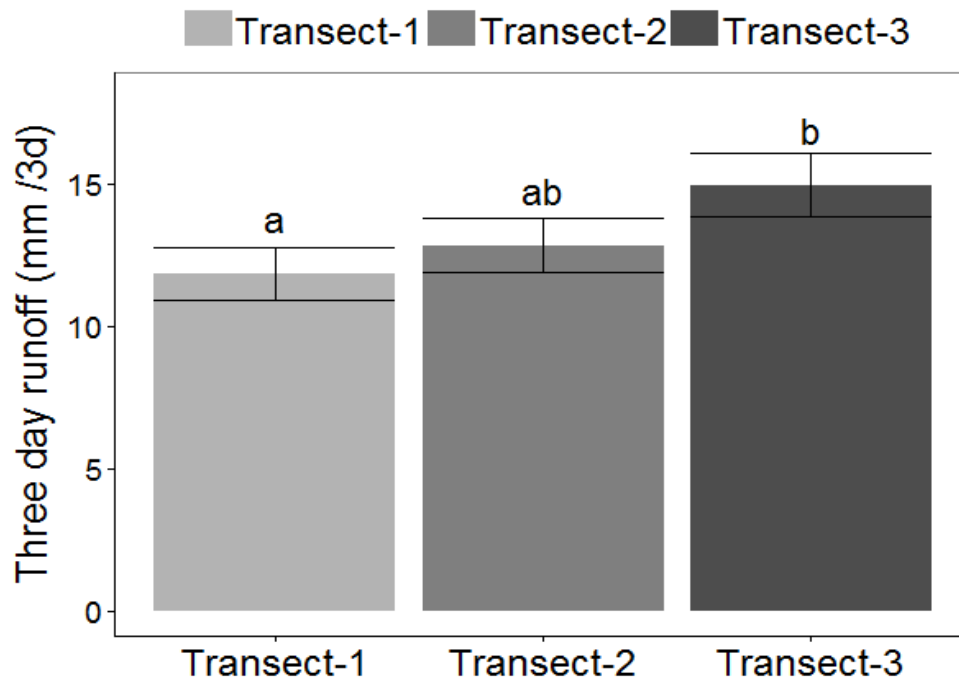
Figure E1. Runoff responses between transects. Transects not sharing the same letter are statically significant at p < 0.05.

Line 7-9: That tillage practice affects storage is already given in the sentence above. I did not find any hint in the paper that root morphology does significantly affect water storage.

Response

Here the difference in root morphology is represented by the different crops: barley and lupine as discussed in the methods and discussion section of the manuscript.

Lines 10ff: At this point I was a bit disappointed. Here, the only significant results (runoff on lupine plots is greater than runoff on the other plots; Fig 5) are relativized by a mere speculation, which is far beyond the results presented here.

Response

We agree with reviewer #1 that our results did support the long term intended effects of lupine. However, our observations of the size and length of lupine roots suggest that when these roots decompose they will create void spaces (cracks) that would serve as preferential flow paths. It is based on our field observation, as shown in Figure F1 in supplementary material E, that we expected the suggested long term impacts of lupine crop.

Technical corrections
All figures: Please increase font size of legends, axis labels and axis tick labels

Response
All figures are are checked for font size of legneds, and asix labels.