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Spatial and temporal runoff processes in the degraded Ethiopian Highlands: the Anjeni Watershed

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Abstract

As runoff mechanisms in the Ethiopian highlands are not well understood, performance of many soil and water conservation measures is inadequate because of ineffective placement outside the major runoff source areas. To improve understanding of the runoff generating mechanisms in these highlands, we monitored runoff volumes from 24 runoff plots constructed in the 113 ha Anjeni watershed, where historic data of rainfall and stream discharge were available. In addition, we assessed the effectiveness of charcoal and crop rooting depth in reducing runoff, in which we compared the effect of lupine (a deep-rooted crop) to that of barley. Daily rainfall, surface runoff, and root zone moisture content were measured during the monsoon seasons of 2012 and 2013 (with all plots being tilled in 2012, but only barley plots in 2013). In addition, long-term surface runoff (from four plots) and outlet discharge data from the research site (1989–1993) was analyzed and compared with our observations. Results showed that the degree of soil degradation and soil disturbance (tillage) were significant factors affecting plot runoff responses. As expected runoff was greater from more degraded soils, while tilled plots had greater soil storage and thus less runoff. Overall, barley plots produced significantly less runoff than lupine plots. Specifically, considerable difference was observed for smaller rainfall events (ca. < 20 mm) in 2013, when lupine plots (non-tilled) resulted in greater runoff than barley plots (tilled). This suggests that plot rainfall–runoff relationships are greatly affected by root-zone storage, which is directly affected by soil degradation and tillage practices.

1 Introduction

Soil and water conservation practices are ubiquitous in the Ethiopian highlands, and necessary to counteract the loss of the top fertile soil from farmlands. However, surprisingly, most non-traditional soil and water conservation practices are ineffective because their placement is often not sufficiently aligned with where the runoff occurs.

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Planning effective soil and water management measures require knowledge of where runoff hotspots are located in a landscape. While most areas in the Ethiopian highlands receive a high amount of annual precipitation, its distribution is variable both spatially and temporally (Biazin et al., 2011; Bitew et al., 2009; McHugh et al., 2007). Location of the hotspots depends on whether runoff is generated by infiltration or saturation excess. There is no agreement on the causes of runoff and erosion in the Ethiopian Highlands. Previous studies highlight land use and topography as the critical factors in governing runoff processes (Bayabil et al., 2010; Bewket and Sterk, 2005; Taddese, 2001; Tilahun et al., 2013), mainly based on analysis of changes in the hydrograph at the outlet. Land use is important because it controls stream flow volumes. For example, several studies reported land use change from natural vegetation to agricultural lands to increase discharge during the rainy monsoon phase and reduce base flows during the dry phase (Bewket and Sterk, 2005; Feoli et al., 2002; Taddese, 2001; Zeleke, 2000).

Topography is important because of its control on water routing and thus where the runoff goes after it has been generated. A field study by Bayabil et al. (2010) found that in the Maybar watershed, with highly conductive soils, topography was the most important factor for runoff initiation by channeling water though the hillsides as interflow and saturating the lower lying fields that became hotspot areas for runoff. Likewise, in Debra Mawi watershed in the northern Ethiopian highlands, both degraded hillslope soils and the saturated lower lying fields contributed most of the surface runoff (Tilahun et al., 2013).

Many of previous watershed studies did not consider the role of hardpans on runoff. A hardpan is a restrictive layer that impedes downward flow of water and growth of plant roots (Biazin et al., 2011; Tebebu et al., 2013; Temesgen et al., 2009). Hardpans are ubiquitous in the Ethiopian Highlands and have in many cases formed after deforestation of the primary forests. Once the trees are removed, the soil loses its organic matter and becomes more acidic. As discussed by Bayabil et al. (2015), clay particles in these acidic soils can disperse easily and therefore be picked up in the infiltrating water

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and cause plugging of the original macropores. Tebebu et al. (2013) found that hardpan formation in the Anjeni watershed was greater on intensively cultivated agricultural fields compared with forest land. Temesgen et al. (2009) observed peak penetration resistance of soils at 20 cm depth. In other countries as well, soil degradation after cutting down the forests resulted in decreased infiltration rates (Hanson et al., 2004; Mendoza and Steenhuis, 2002; Nyberg et al., 2012; Shougrakpam et al., 2010). Installation of physical soil and water conservation measures (e.g. *fanya juu* terraces in the Anjeni watershed) on fields with hardpan will cause waterlogged conditions and runoff will not be reduced unless soil infiltration is improved (Bayabil et al., 2010; Temesgen et al., 2012). This can be done by restoring the macropore network through the hardpan (either physically or biologically), and by improving soil organic matter contents to limit further clay dispersion. As traditional tillage practices using oxen pulled plow only loosen the top 10–15 cm of the soil (Biazin et al., 2011; Temesgen et al., 2012), these methods are inadequate for disrupting the more deeply located hardpans.

A solution may be planting deep-rooted crops that penetrate the hardpan and thereby increase hardpan conductivity (Angers and Caron, 1998; Cresswell and Kirkegaard, 1995; Lesturgez et al., 2004; Meek et al., 1992). Another solution, improving soil acidity and organic carbon pool through the addition of biochar or charcoal, which 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). Although biochar and charcoal amendments can both be effective in improving soil water relationships, 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.

Since effective soil and water management requires accurate understanding of runoff generating mechanisms, the objective of this study was, therefore, to assess the drivers of runoff generation in the Ethiopian Highlands. We characterized effects of soil degradation status and landscape position, and investigated the effects crop rooting depth

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(barley with and without charcoal, and deep-rooted lupine crop) on spatial and temporal rainfall–runoff relationships. Understanding rainfall–runoff processes and identifying runoff source areas in the landscape will aid future efforts towards planning effective soil and water management practices that allow improved use of green (rain) water to boost smallholder farm productivities.

2 Materials and methods

2.1 Study site

This study was carried out in the Anjeni watershed, situated in the northwestern part of Ethiopia (Fig. 1). Among other reasons, this watershed was selected because of the availability of historic discharge records at the outlet and from runoff plots inside the watershed. The watershed has a drainage area of 113 ha and is one of the experimental watersheds established under the Soil Conservation and Research Program (SCRP) of the Ministry of Agriculture of Ethiopia in collaboration with the Swiss Agency for Development and Cooperation (SDC) (Hurni et al., 2005). Its gauging station is located at 10°40′ N, 37°31′ E.

The watershed has a unimodal rainy season that lasts from mid-May to mid-October, with a mean annual rainfall of 1690 mm yr^{-1}. The topography of Anjeni is typical of Tertiary volcanic landscapes; it has been deeply incised by streams, resulting in the current diversity of landforms (SCRP, 2000) with elevation between 2407 and 2507 m (Herweg and Ludi, 1999). The soils of Anjeni have been developed from the basaltic Trapp series of Tertiary volcanic eruptions and is similar to most parts of central Ethiopia with major soils Alisols (41.5 ha), Nitisols (23.8 ha), Cambisols (18.9 ha), and Regosols (10 ha) covering more than 80 % of the watershed (Fig. A1 in Supplement A) (SCRP, 2000; Zeleke, 2000). The deep Alisols cover the bottom part of the watershed; moderately deep Nitisols cover the mid-transitional, gently sloping parts of the watershed, while the shallow Regosols and Leptosols cover the high, steepest part of the watershed

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(Zeleke, 2000). Fields are intensively cultivated for crop production and large proportion of the watershed is degraded (SCRP, 2000). In 1986, graded fanya-juu structures were installed resulting in terraces across the landscape (SCRP, 2000).

2.2 Experimental setup

Runoff generating mechanisms were studied using 24 runoff plots installed across the watershed, accounting for spatial variability in soil degradation status and slope position (Fig. 1). Effects of charcoal amendment and crop rooting depth were assessed for each transect location. The 24 plots were positioned in groups of three along three transects perpendicular to the slope (Fig. 2). Soil degradation varied between transects: Transects 1 and 2 are located in the southeast and southwest part of the watershed (Fig. 1b), and have deep soils while Transect 3, located between Transects 1 and 2, is characterized by shallow and degraded soils. Transects 1 and 3 are steep (with slopes ca. 14.5 and 15.6 %, respectively), while Transect 2 has moderate slope (ca. 11.8 %). Effects of landscape position were assessed by placing plots at different slope positions: at downslope, mid-slope, and upslope positions along Transects 1 and 2; and at the two upper positions along Transect 3 (Fig. 1c).

At the start of the 2012 growing season (June), all plots were plowed and two plots were seeded with barley. Effects of charcoal amendment were assessed by amending one of the barley plots with charcoal during plowing, the non-amended barley plot serving as a control treatment. Effects of crop rooting depth were assessed by seeding the third plot at each transect location with the deep-rooted lupine (*Lupineus albus* L.) crop, with again the non-amended barley plot serving as a control treatment. Barley and lupine crops were assigned randomly to plots; and the same crop was maintained on each plot for two years (2012 and 2013). These crops were chosen as they are widely grown throughout the Ethiopian highlands. Farmers grow lupine as intercrop with cereals (e.g. barley and wheat) or as sole crop on marginal lands without additional farm inputs.

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2.3 Agronomic practices on plots

Barley, one of the predominantly grown crops in the watershed (SCRP, 2000), was grown following local farmers' cultural practices and thus barley plots were tilled in both 2012 and 2013. 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^{-1} Di-Ammonium Phosphate (DAP; 46 % Nitrogen, 23 % Phosphorous, and 21 % Potassium) during seeding, and 100 kg ha^{-1} of Urea (100 % Nitrogen) one month after sowing. While lupine plots were not fertilized.

Moreover, on charcoal-amended barley plots, charcoal was applied at a fixed rate of 12 t ha^{-1} during tillage in 2012 and 2013. Charcoal (prepared from Eucalyptus camaladulensis biomass in a way similar to that described by Bayabil, 2015) was manually crushed to obtain relatively uniform particle size (ca. 2 mm diameter) and then manually incorporated on the top 20 cm of the soil.

2.4 Plot installation and data collection

While crop and charcoal treatments were applied to 9 m^2 (3 m wide, 3 m long) areas, runoff was only measured from inside 4.5 m^2 (1.5 m wide, 3 m long) area, to avoid trampling and disturbing of the soil inside the runoff plots while taking auxiliary measurements for instance soil moisture contents. For this, runoff plot boundaries were installed 0.75 m inside the seeded area from both sides. As illustrated in Fig. 2 above, all runoff plots were constructed at the level bottom ends of terraces. The plot boundaries consisted of 50 cm high metal sheets of which 25 cm was belowground and 25 cm was aboveground, and the lower plot boundaries were reinforced with concrete. A 2-inch PVC pipe carried surface runoff into a primary collection tanks (ca. 76 L volume).

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When the primary tanks were full, excess water flowed through divisor slots directing one-tenth (10 %) of the excess flow into secondary tanks (ca. 76 L volume). The tanks were made from barrels cut in half and were covered on the top to minimize evaporation and prevent rainfall entry.

All runoff plots were monitored manually for runoff volumes on a daily basis during the monsoon season (from 29 June to 4 October in 2012 and from 25 June to 8 October in 2013). When runoff occurred, the depth of water in the two tanks was measured and then the water was drained out through valves fitted at the bottom of the tanks. Daily rainfall totals were measured using a manual rain gauge installed at the weather station (see Fig. 1b "Weather station"). In addition, during the 2013 growing period, soil moisture content, θ ($g\,g^{-1}$), was measured gravimetrically by taking bulk soil samples from the top 20 cm depth at 10 day intervals. To prevent disturbance, samples were taken inside the seeded area but just outside each runoff plots.

2.5 Long-term plot runoff and river discharge data

In addition to runoff data from the 24 newly installed plots, we obtained long-term data from the Amhara Regional Agricultural Research Institute (ARARI). The data consists of runoff from four long-term 30 m^2-plots (2 m wide, 15 m long) (Fig. 1b, "Permanent plots") and discharge at the outlet of the watershed (Fig. 1b, "Gauging station"). To place our newly installed plot-scale runoff observations into a broader and longer-term context, we compared our data with historic plot-scale runoff data available in the watershed for the years 1989 through to 1993. These data were measured on 2 m wide by 15 m long plots with slopes of 12, 16, 22, and 28 %. The 16 % sloped plot was on grassland, while the other three plots were cultivated with food crops (e.g. barley and wheat) (SCRP, 2000). Discharge was measured continuously since 1984 (two years before the installation of the "*fanya juu*" conservation structures) as part of the ongoing hydrological and erosion monitoring activities (SCRP, 2000), and we used discharge data for the 2012 and 2013 monsoon seasons to compare our plot-scale observations

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with watershed-scale patterns. Rainfall data was available for the same period and was obtained from the watershed (Fig. 1b, "Weather station").

2.6 Data quality control and aggregation

We checked all daily data to make sure that peaks of daily rainfall and runoff coincided, both visually and by calculating the daily runoff coefficients (Rcoef; the quotient of the daily runoff depth and precipitation). Plot-scale rainfall–runoff data (Figs. B1–B3 in Supplement B) showed that there were 214 events (spread over 11 and 32 days in 2012 and 2013, respectively) out of 5232 events total (4.1 %) where daily runoff was greater than corresponding rainfall amount recorded on the same day (i.e. Rcoef > 1). In some cases, large rainfall events were visible that did not produce runoff on the same day, but for which peak runoff appeared on the following day (see for example the black arrows in Figs. B1–B3 in Supplement B). In other cases, there was more runoff than rainfall without delays (see spikes of blue, green, and red lines in Figs. B1–B3 in Supplement B). Runoff in excess of rainfall can be caused by rainfall and runoff measurement periods that do not coincide. Here, rainfall was measured at 8 o'clock every morning. The first of the 24 runoff plots was also measured at 08:00 LT but emptying the barrels and scooping out the sediment is time consuming, causing the last plot to be emptied around noon. Other potential causes for runoff exceeding rainfall are high spatial variation in rainfall not picked up by our single rain gauge, and interflow from outside the plot entering the plot during large rainstorms.

To reduce the impact of delayed peak runoff, we, therefore, decided to aggregate rainfall and runoff data over a 3 day period, resolving most of the high runoff coefficients. Yet 47 events (2.6 % of total) observed form the 24 plots and recorded from 11 observation days spread over the two-year study period were left with Rcoef > 1 (Fig. C1 in Supplement C). Further data aggregation, even on a weekly interval, did not solve these high runoff events. One of the options to deal with such outlier data points would be excluding observations from data analysis. However, to avoid bias between treatments and spatial locations, all observations from those 11 days need to

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be discarded for all (24) plots, which would result in discarding 264 observations. Losing this many observations (14.9 % from 1777 total observations) would considerably reduce the power of our analysis.

Thus, to achieve a balance between the number of runoff events remaining for analysis and the objective to analyze large runoff events, such high runoff events (Rcoef > 1), after data aggregation on 3 day intervals, were therefore assigned a maximum value that equals the 3 day rainfall amount – resulting in a runoff coefficient of 1. As such, adjusted and 3 day aggregate runoff data were used for all statistical data analyses in this paper.

2.7 Statistical analysis

Data analysis aimed for detecting spatial and temporal trends in rainfall–runoff relationships during the two-year study period. Statistical data analysis was performed using R (R Development Core Team, 2010). To determine the impact of charcoal amendment and deep-rooted lupine as well as spatial location with different soil degradation levels (transects) and slope position, a linear mixed effect model was fitted using the "nlme" package in R. In this model, crop type, slope position, and transect were used as fixed factors, and individual plots as random factors. For fixed factors with significant effects, post hoc mean comparison tests were performed using the "lsmeans" package in R to identify group pairs with significant difference.

3 Results and discussion

3.1 Plot-scale rainfall–runoff response and effect of charcoal amendment and deep-rooted lupine

The adjusted runoffs during the monsoon seasons of 2012 and 2013 for all eight groups of plots along three transects are shown in Fig. 3. In 2013, runoff response from lupine plots was considerably greater than barley plots; while in 2012, runoff tended to be

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more or less similar for all treatments. In addition, a summary of observed rainfall and original (non-adjusted) runoff data recorded from all 24 plots is presented in Table D1 in Supplement D. Average monthly rainfall in 2012 was similar to the 5 year average (based on 1989–1993 observations; Fig. E1 in Supplement E), while in 2013 it exceeded the 5 year average.

As discussed in the Methods section, runoff exceeding rainfall (i.e. Rcoef > 1), as shown in Figs. B1–B3 in Supplement B and Fig. C1 in Supplement C, is not expected and worrisome. We therefore checked historic long-term data (1989–1993) from four permanent plots measured by the well-trained technicians at the experimental station, and found the same "problem" that in many cases there was more runoff than rainfall (Fig. 4a). This indicates that our daily observations with Rcoef > 1 (Fig. 4b) are real and not caused by measurement errors. This phenomena of runoff exceeding rainfall has not been reported often for temperate climates, and it is therefore likely that rainfall in monsoon climates is more variable over short distances than rains in temperate climates. Studies found that rainfall in the Ethiopian highlands significantly varies in space (Bewket and Conway, 2007; Bitew et al., 2009). Bitew et al. (2009) observed up to 424 % coefficient of variation of daily rainfall between rain gauges. These authors further noted that in areas with complex topography (like the Anjeni watershed), extrapolation of point rainfall observations to larger scales could be less accurate.

3.2 Plot runoff and outlet discharge

All plots on degraded soils along Transect 3 produced greater 3 day runoff than plots along the other two transects with relatively deeper soils (Fig. 5). 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. Because of this, 2012 and 2013 runoff responses of barley (control and charcoal amended) and deep-rooted lupine were grouped by transect and then compared. Statistical test results showed that, for all transects, lupine plots produced significantly more than both the control and charcoal-amended barley plots. Charcoal amendment, on the other hand, caused no significant difference effects (Fig. 5). The cumulative runoff for the lupine plots followed the cumulative runoff for the outlet more than the barley plots, particularly in 2013 (Fig. 6).

Comparison of plot-scale cumulative runoff and cumulative river discharge 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 (ca. 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 after approximately 500 mm cumulative rainfall, watershed-scale discharge starts to exceed plot-scale runoff depths. The difference between plot runoff and outlet discharge at early season of the monsoon indicates greater 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) and 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.

A considerable difference in the runoff response of barley and lupine plots was observed in 2013 compared with 2012. In 2012, runoff tended to be more or less similar for all treatments, whereas in 2013 runoff from barley and lupine plots began to deviate after approximately 250 mm cumulative rainfall (Fig. 6). In agreement with this, a closer look at the plots (Fig. 3) clearly shows that for most of the high rainfall amounts, there is little difference in runoff response between the barley and lupine plots. Only for smaller rain events (ca. < 20 mm) and during the start of the 2013 rainy season (around 1 July), runoff from lupine plots exceeded that of barley plots. It is interesting that this is the case for all three transects in 2013, but does not occur in 2012. The only management difference between these two years is that lupine was tilled in 2012 but not in 2013. This implies that tillage resulted in relatively greater soil water storage for lupine plots in 2012 than in 2013, and that the difference in rainfall–runoff response between

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treatments in 2013 may be ascribed to the fact that barley plots were tilled and lupine plots were not. Soil water storage predicted using the SCS-CN equation (Steenhuis et al., 1995) confirmed smaller storage for lupine than for barley (Fig. 7). This would mean that there is very little infiltration in the lupine plots other than abstracted water to compensate evapotranspiration loss by the lupine.

Our findings indicated that both soil degradation status (here visible as differences in soil depth) and disturbance (tillage) were important factors affecting rainfall–runoff relationships in a landscape. In addition to tillage activities, inherent differences in plant root morphology (e.g. length and density) between the barley and lupine could likely be another factor. Most of the root masses of barley are located at shallow depths in the upper part of the soil profile (Lugg et al., 1988) and thereby take water from the top soil, whereas lupine roots grow deeper than barley and extracts water from deeper depths (French and Buirchell, 2005). These differences in root water uptake are somewhat visible in the slightly greater, albeit not significant, root depth moisture readings observed (measured from the top 20 cm) for lupine plots beginning in August in 2013 (not shown).

It is important to note that the fact that lupine did not decrease runoff during this study period does not imply it would not reduce runoff in the long-term. When the roots of lupine decompose, it is likely that biopores and channels would be created as reported by Meek et al. (1992) and Lesturgez et al. (2004) that have greater vertical and lateral continuity due to an improved network of macropores (Yunusa and Newton, 2003), which thereby would result in reduced surface runoff and associated erosion.

4 Conclusions and implications

Our findings have several important implications for future efforts towards modeling rainfall–runoff relationships and planning effective soil and water management practices that allow better use of green water (rainfall) for smallholder agriculture systems in the Ethiopian Highlands. First, results support previous findings that plot or hillslope

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scale rainfall–runoff relationships are mostly different from watershed outlets. This implies physical models that represent variable field conditions (e.g. soil and crop) into consideration are needed; analysis of hydrographs at the watershed outlet does not fully depict field conditions. Second, plot-scale rainfall–runoff relationships are greatly affected by root-zone soil storage capacity, which our data shows is directly affected by soil degradation status and tillage practices that in turn affect soil storage (Figs. 5 and 7). Finally, tillage practices (e.g. plowing) and root morphology (e.g. root length and density) of crops significantly affect storage of soils and therefore affect runoff responses.

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 biopores once its large taproot decomposes. 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.

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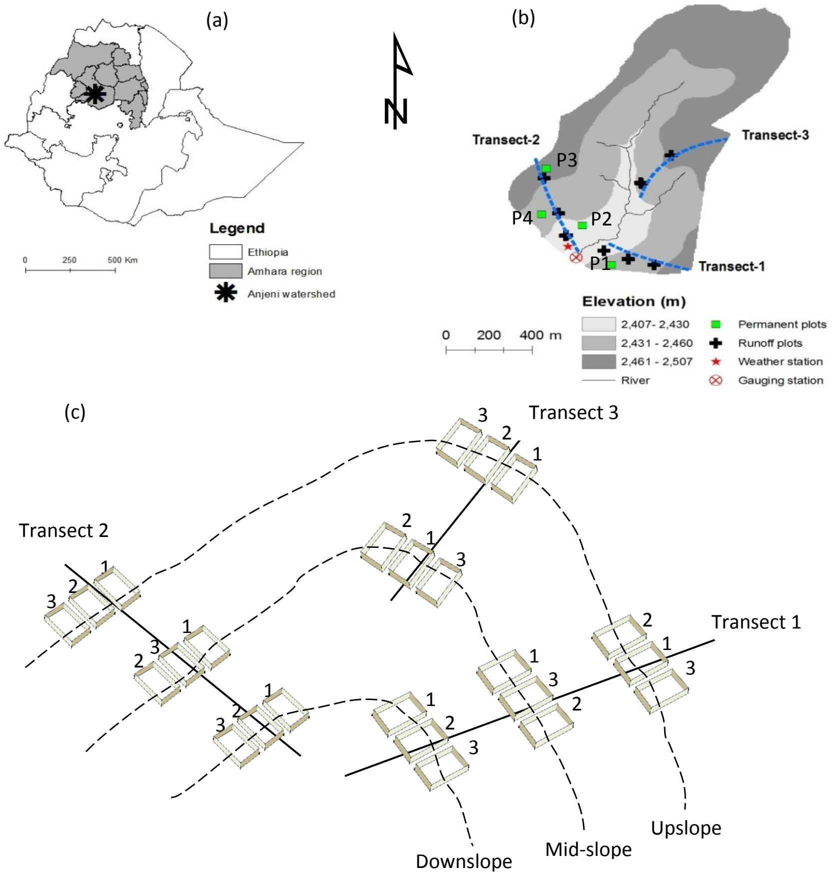

Figure 1. Location of the Anjeni watershed in the Amhara region in Ethiopia **(a)**, with the location of downslope transects and runoff plots indicated in (**b** and **c** – not to scale). Dashed lines in **(c)** are elevation contours. Plots labels represent treatment types: 1 = barley without amendment (Control), 2 = barley with charcoal, and 3 = Lupine.

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Figure 2. Groups of three runoff plots setup at downslope position along Transect 2. Water storage tanks are positioned below the plots, on the downslope side of the terrace edge. Dark brown lines above runoff plots are traditional conservation practices (drainage ditches) constructed by farmers to channel out excess water from fields.

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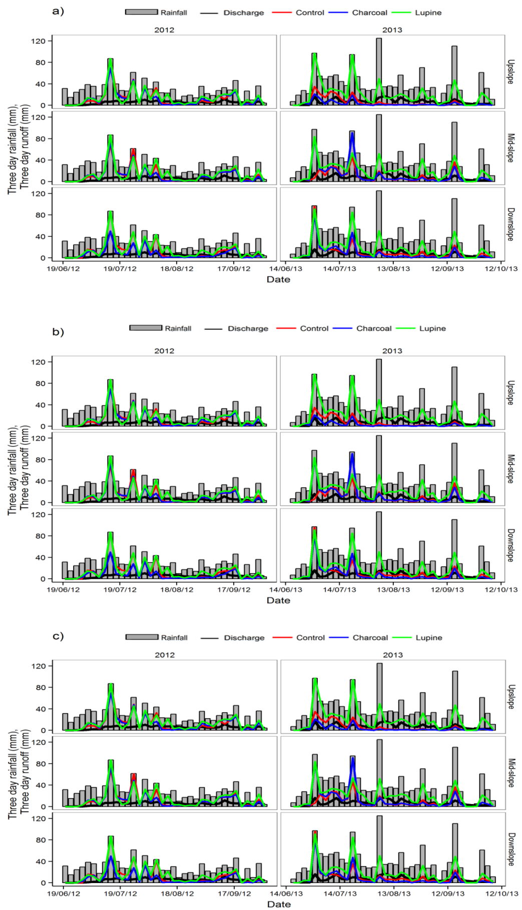

Figure 3. Three day rainfall and adjusted three day runoff depths (aggregated over 3 days) from individual plots at different slope positions along Transect 1 **(a)**, Transect 2 **(b)**, and Transect 3 **(c)**.

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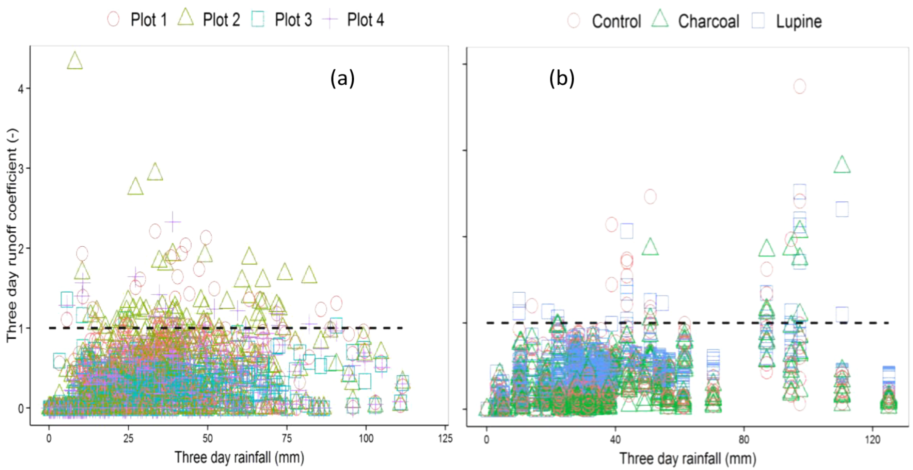

Figure 4. Runoff coefficients computed from observations from long-term monitoring plots **(a)** and plots in 2012 and 2013 **(b)**. Black dash horizontal line represents Rcoef = 1.

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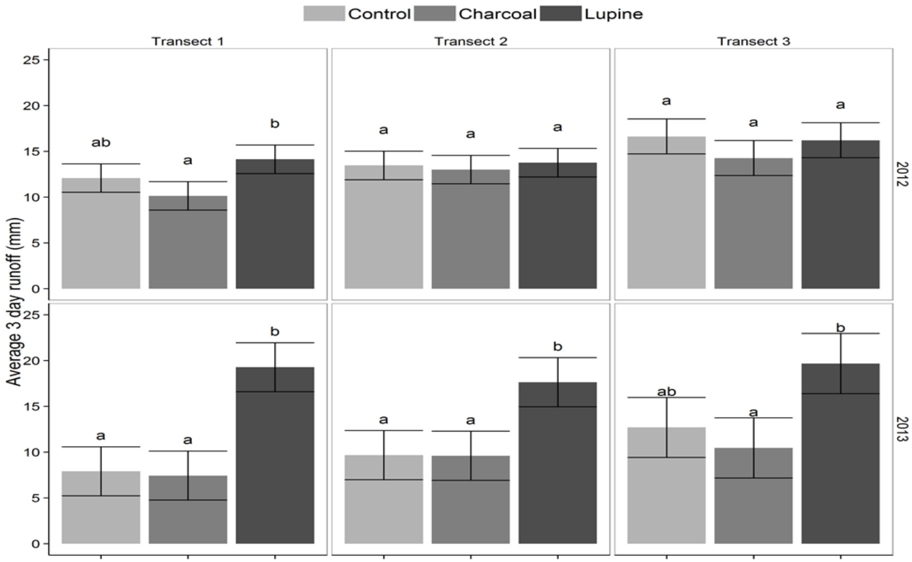

Figure 5. Effect of charcoal amendment and deep-rooted lupine crop on plot-scale runoff (3 day total) for each transect and year. Treatments not sharing the same letter within individual transects for a given year are significantly different at $p < 0.05$.

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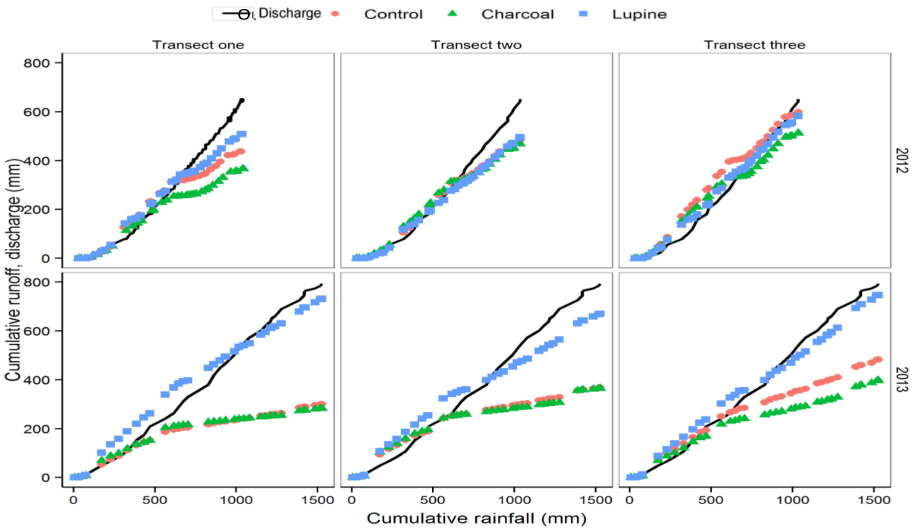

Figure 6. Cumulative rainfall vs. runoff from three transects and at the watershed outlet, for 2012 and 2013.

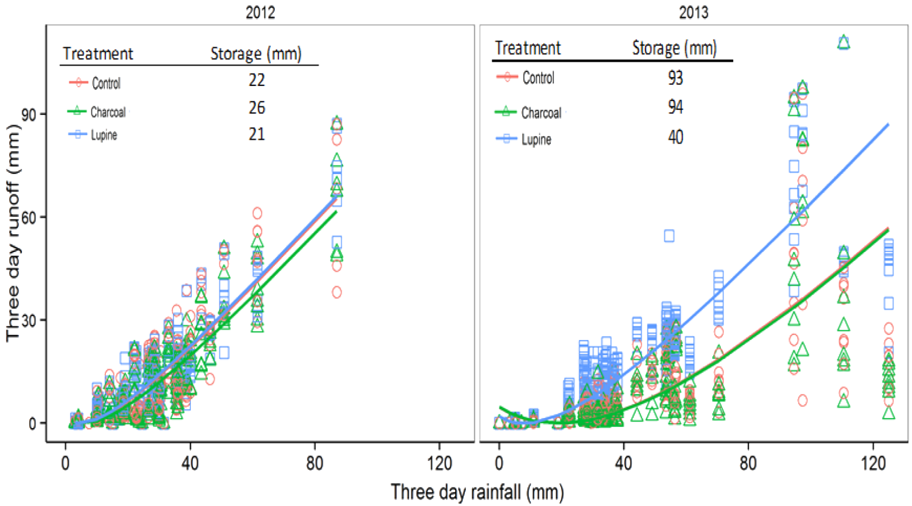

Figure 7. Effect of charcoal amendment and deep-rooted lupine on 3 day soil water storage: three day rainfall vs. three day runoff with SCS-CN fitted lines predicted using Steenhuis et al. (1995) SCS-CN equation.