Evaluation of interrill erosion under forest canopy

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Abstract:

Soil loss plots on open and under canopy sites were installed to study the effect of the canopy on interrill erosion. The erosion rate under the canopy was smaller than that on an open site, and it was highly correlated with the maximum rainfall intensity for 3 hour and total rainfall, independent of the slope angle. The throughfall rate showed a relatively continuous value under high rainfall intensity conditions, although varied with rainfall intensity. When the throughfall rate was initiated at a relatively continuous value, the rainfall intensity was very similar to the threshold of rainfall intensity for erosion under a canopy. These results imply that the canopy storage had been changed due to the rainfall intensity, and this change affected the interrill erosion under the canopy. These results will contribute to the development of an erosion prediction model under a forest canopy.

KEYWORDS interrill erosion, canopy effect, rainfall intensity, canopy storage, slope angle

INTRODUCTION

Rainfall intensity has been considered as a critical factor for interrill erosion. The relationship between rainfall and interrill erosion is expressed directly by an exponential formula with rainfall intensity (Meyer, 1981) or the relationship to rainfall Kinetic Energy (KE; Morgan et al., 1998; Nanko et al., 2008). KE correlates with rainfall intensity via two types, i.e. logarithmic model and exponential model (Forni et al., 2005).

The physical characteristics of rainfall on a surface are changed by the vegetation canopy in a forested area. First, the amount of rainfall through the canopy decreases due to canopy interception (Leyton, 1967; Aston, 1979; Gash, 1979; Gash et al., 1995). Second, the drop size distribution (DSD) and terminal velocity of throughfall are changed due to scattering, dripping and the height of lowest trunk. Although the amount of throughfall generally decreases, the KE of throughfall increases, resulting in greater interrill erosion under the canopy than on an open site (Mosley, 1982; Brandt, 1989; Kinnell, 1993; Morgan et al., 1998; Valmis et al., 2005), but few have studied the effect of the slope angle on interrill erosion under a canopy. According to Mizugaki et al. (accepted), the splash detachment under Hinoki, Japan showed a polynomial relationship to the slope angle. However, few studies are available on contemporary comparisons of interrill erosion rates between under a canopy and on an open site. Also, the relative importance of sheet flow erosion to rainsplash is still unknown. Therefore, the objective of this study was to characterize the effect of the canopy on interrill erosion, thereby contributing to the development of an erosion prediction model.

STUDY AREA & METHODS

Six plots were installed on an open site and under a canopy on a mountainous slope (127°6' 12.2'E, 37°5’ 50.5”N) at Anseong-si, in the central part of the Korean Peninsula (Fig. 1a). The annual mean temperature and rainfall of Ichoen-si, near Anseong-si, have been about 11.2°C and 1,329.2 mm, respectively, over the last 30 years (Korea Meteorological Administration, 2008). The topsoil around the erosion plots was SP classified by USCS, and contains approximately 4% silt/clay, 76% sand and 20% gravel, and has developed on banded gneiss.

Each soil loss plot was 0.45 m long and 0.4 m wide (0.18 m²). Three plots were located on the open site (Fig. 1b) and the others located under the canopy (the canopy site; Fig. 1c), and installed at different slope angles; 10, 20 and 30 degrees, respectively. A small rectangular tank for the collection of sediment was connected to the end of the fence. A moat, about 20 cm in width and 10 cm in depth, was dug around each plot to prevent surface runoff from flowing into the experimental area of the plot. To enable the effect of the canopy on interrill erosion to be studied, an area with no visual vegetation was selected, with the erosion plots installed. To maintain the vegetative cover of each plot close to 0%, the bare surface on the plot was controlled using herbicide, with the surface ground cover, including fallen leaves and litter, also removed during the study period.

The sediment eroded from each plot was used to evaluate the combined delivery by rainsplash and sheet erosion. Some trials were conducted during six periods (Fig. 2). Sediment eroded from each plot was collected at the end of each period, oven-dried at 105°C for 48 h, and weighed in the laboratory. The organic matter content was also analyzed by measuring the loss on ignition (LOI) after heating the samples at 450°C for 5 h. The Japanese conifer (Larix leptolepis), with a mean
height of 18 m and DBH (diameter at breast height) of 23.9 cm inhabited the canopy site. For each plot, the mean canopy openness (%) during the study period were about 28 (10° plot), 37 (20° plot) and 19 (30° plot), respectively, as assessed using a Gap Light Analyzer 2.0 (Frazer et al., 1999).

Tipping-bucket type rainfall gauges, connected to a data logger (HOBO Event; Onset Computer Corp., MA), were installed around the open site from March 2006, and at the canopy site from July 2007. Logging of the rainfall data was conducted six times, but data obtained during the second period were not used in this study because no rainfall data were taken during that period (Fig. 2).

RESULTS & DISCUSSION

Various rainfall indices and interrill erosion processes

Daily rainfall and soil erosion for each plot during the six study periods are shown in Fig. 2. The total rainfall during the study periods was 1,284 mm. The maximum rainfall event occurred on July 27, 2006 during the fifth period, with a total daily rainfall of 307.5 mm, and maximum rainfall intensities during 10 min, 30 min, 1 hr and 3 hr of 54, 42, 37.5 and 29.7 mm h\(^{-1}\), respectively. The total interrill erosion rate observed in each erosion plot over the entire period varied from 22 to 5,260 g m\(^{-2}\), with averages over each period ranging from 217 to 2,487 g m\(^{-2}\). The maximum erosion rate was observed in the fifth period. The erosion rate on the open site was higher than that under the canopy over all observation periods except for the fifth period. The average and standard deviation of the erosion rate on the open site were 854.1 and 764.1 (g m\(^{-2}\)), and those under the canopy were 726.9 and 1,382.1 (g m\(^{-2}\)), respectively. The erosion rates with respect to the slope angle were highest for the 20 degree plots in both sites.

Many studies (Mosley, 1982; Brandt, 1990; Nanko et al., 2004, 2008) have reported that the KE (kinetic energy) of raindrops under a canopy was greater than that on an open site due to the increased rate of larger drops in the DSD (drop size distribution). The results for the erosion plots in this study; however, showed the opposite trend, i.e. the erosion rate on the open site was higher than that under the canopy, implying the erosion rate under the canopy was a reflection of the interception loss of throughfall for rainfall events with relatively low intensity. Because interception, like storage capacity, has an increasing tendency under lower rainfall intensity (Calder, 1996; Robin, 2003), the interception loss during each low intensity rainfall event reflected on these lower erosion rates under the canopy. Another possibility is that the erosion rate under the canopy was underestimated. The eroded sediment in the plots was mainly transferred by sheet flow. Although sediment eroded from the plots by the combined delivery of rainsplash and sheet erosion was collected, the dominant process under the canopy is rainsplash (Miura et al., 2002; Nanko et al., 2008).

We conducted linear regression analysis for each plot between the erosion rate and rainfall indices of various time intervals; maximum rainfall intensities for 10 min, 30 min 1 hour, 3 hour and rainfall duration and maximum rainfall, mean rainfall and total rainfall during each period. Figure 3a shows the results of linear regression analyses for three erosion rate classes based on slope angle and maximum rainfall intensities for 10 min and 3 hour and total rainfall on the open site.
The coefficient of determination ($r^2$) for 10 min maximum rainfall intensity was highest (0.95) for the 10° slope angle. For the 20° slope angle, $r^2$ was highest (0.96) for 3 hour maximum rainfall intensity. For the 30° slope angle, $r^2$ was highest (0.52) for total rainfall (Fig. 3a). On the open site, the correlation between the erosion rate and the rainfall indices may vary with the slope angle. The relationship between the erosion rate and rainfall indices under the canopy shows a positive trend (Fig. 3b). For total rainfall, $r^2$ at the slope angle of 10°, 20° and 30° was highest (0.98, 0.97 and 0.98, respectively) and for 10 min maximum rainfall intensity, $r^2$ at the slope angle of 10°, 20° and 30° was lowest (0.55, 0.56 and 0.58, respectively). Under the canopy, the $r^2$ for each rainfall indices was similar to each other regardless of the slope angle.

Many experiments dealing with the relationship between the interrill erosion and slope angle have shown increases in interrill erosion with increasing slope angle (Kinnel, 1993; Morgan et al., 1998; Nearing et al., 1989; Valmis et al., 2005). However, Mizugaki et al. (accepted), who studied the rainsplash under a Japanese cypress plantation in southern Japan, documented that the correlation between the slope angle and splash detachment was not a consistent relationship, but that the relationship between rainsplash and rainfall intensity varied with the slope angle. Mizugaki et al. (accepted) indicated that a ponding depth which is affected by the degree of soil surface crusting results in a complex relationship between on splash detachment and slope angle. Their study supports the result of this study on open site. In contrast, the obtained result under the canopy showed the difference with the result in terms of the effect of slope angle presented by Mizugaki et al. (accepted). The erosion rate under the canopy was highly correlated with 3 hour maximum rainfall intensity and total rainfall regardless of the slope angle (Fig. 3b). It might be reflected that a rainfall index of longer period is required for sheet flow to entrain the detached sediment because the eroded sediment in the plots was mainly entrained by sheet flow in this study. To better explain the relationship between the interrill erosion and slope angle, an experiment separating the splash detachment and sheet erosion will be required.

**Relationship between throughfall rate and interrill erosion under canopy**

Figure 3c shows the relationship between the rainfall intensity and throughfall rate using the throughfall data from July 29 to September 4, 2007. The throughfall rate varied under relatively low rainfall intensity conditions, but gradually increased and showed rates over 60% with increasing rainfall intensity. The rainfall intensities when the throughfall rate was continuously over 60% were about 25 mm h$^{-1}$ for 10 minute rainfall intensities and 5 mm h$^{-1}$ for 3 hour rainfall intensities. However, the relationship between the throughfall rate and total rainfall showed that the throughfall rate sharply increased up to 20 mm of total rainfall, but
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above this point slowly increased, suggesting a similar trend to an asymptotic curve.

The interceptions of X-axis in the regression curves between the rainfall intensities and erosion rates define, for each case, the threshold value of the rainfall intensity for erosion, with mean values of about 29.3, 6.6 and 49.5 mm h⁻¹ for rainfall intensities of 10 minute, 3 hour and total rainfall, respectively. These interceptions of rainfall intensities for 10 minute and 3 hour were similar to the values of the rainfall intensities when the throughfall rates continuously exceeded 60%.

In the WEPP (Nearing et al., 1989; Alberts et al., 1993; Flanagan et al., 1995; Foster et al., 1995) and RUSLE2 (Foster et al., 2008) models, the interrill erosion under a canopy is considered to be proportional to the product of the rainfall intensity and interrill runoff rate, with the constant of proportionality being the interrill erodibility parameter, which is adjusted for various temporally changing factors. However, EUROSEM (Morgan et al., 1998) and LISEM (Jetten, 2002) deal with the effect of the canopy on soil erosion, not as an erodibility parameter, but as an erosivity parameter. To estimate the interception store, the equations of Merriam (1973) and Aston (1979) are adopted in EUROSEM and LISEM, respectively. Thereafter, the KE (J m⁻² mm⁻¹) of direct throughfall is calculated using the formula of Brandt (1989) and the KE of leaf drainage is estimated using the formula of Brandt (1990). Both values of KE are summed and finally used to estimate the detachment induced by rainsplash under the canopy. The dominant factors for soil erosion under the canopy, accordingly, are cumulative rainfall and the maximum depth of the interception store in EUROSEM, and cumulative rainfall, canopy storage and average leaf area in LISEM. Therefore, those factors were calculated via the regular canopy storage value. Although the interception rate varies with rainfall intensity, those models do not consider this variation in the interception rate. Therefore, the problem could occur that events with the same total rainfalls, but with different intensities, would give the same interception rate.

The original Gash (1979) model and sparse Gash et al. (1995) model have mainly been used to study interception models, as the Rutter model employed to predict the quantity of interception assumes that the canopy storage (capacity; Leyton et al., 1967) has a specific value. The storage capacity; however, varies with each rainfall event (Robin, 2003) and has an upward tendency under rainfall conditions of smaller drops and a lower rainfall rate (Calder, 1996). Similarly, the result of this study showed that the throughfall rate increased with rainfall intensity, towards a relatively constant value; an asymptotic curve. The interrill erosion in this study area began at a relatively constant throughfall rate. Therefore, the relationship between the erosion rate and rainfall intensity can be expressed as a linear function. Consequently, these results imply that it is possible to predict the initiation and quantity of interrill erosion under a canopy using the rainfall records. Further studies will be required to develop an erosion prediction model for under a canopy.

CONCLUSIONS

To study the effect of a canopy on interrill erosion, soil loss plots were installed on open and under canopy sites at Anseong-si, in the central part of the Korean Peninsula. The experiment was carried out to evaluate the combined delivery by rainsplash and sheet erosion between March 30 and October 12, 2006. The erosion rate under the canopy was smaller than that on an open site, and it was highly correlated with the maximum rainfall intensity for 3 hour and total rainfall, independent of the slope angle. On the open site, however, the correlation between the erosion rate and the rainfall indices may vary with the slope angle. The throughfall rates varied with rainfall intensity, but were relatively continuous under high rainfall intensity, like an asymptotic curve. The rainfall intensity of the inflection point was very similar to the threshold rainfall intensity for erosion under the canopy. Consequently, these results may imply that canopy storage has been changed due to the rainfall intensity, and that this change has an effect on the interrill erosion under the canopy. These results on the initiation and quantity of interrill erosion under a canopy will contribute to the development of an erosion prediction model under a canopy by considering the rainfall intensity.

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SUPPLEMENTS

S1. Characteristics of individual storms during the study period
S2. The R-square values of the linear regression analysis between soil loss and various rainfall indices

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