Analysis of Rainfall–Runoff Relationship on Sloping Uplands

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Abstract

The long-term data accumulated by the ASIALAND Management of Sloping Uplands Network were used to study the relationship between rainfall and runoff. An attempt was made to determine any relationship between these parameters and soil infiltration capacity. Data for seven years from Vietnam were used. In general, higher rainfall produced higher runoff. It was also shown that the runoff from the different soil conservation treatment plots (which could represent different land use) varied. The bare plot (T5) produced the highest runoff, followed by the farmer's practice (T1). The alley crops of corn + black bean with tea as the hedgerow (T2) and corn + black bean with Tephrosia candida *and tea as the hedgerow (T3) were equally effective in reducing runoff. Alley crops of corn + black beans with* Tephrosia candida *as the hedgerow (T4) produced the lowest runoff. This analysis supports the findings of the network which showed varying soil loss from different plots under different rainfall conditions. Relating the critical rainfall (rainfall at which runoff starts to occur) further showed that higher runoff occurred in treatments with lower values of critical rainfall. Further relating this to soil infiltration capacity, shows that T2, T3, and T4 are more efficient in promoting infiltration compared to bare soil and the traditional farming system. In terms of relationship between the infiltration and runoff coefficient, there was a trend of higher infiltration with lower runoff coefficient as shown in T1, T2, and T5. This trend was not observed in T3 and T4. This may need consideration of other parameters like rainfall intensity and duration and antecedent soil moisture content in the analysis.*

Introduction

Rainfall, runoff, and infiltration are three related parameters (Figure 1). When the rain falls on the ground, the water moves into the soil primarily through the forces of capillary action and gravity. As rainfall continues, water continues to infiltrate into the soil until the rainfall intensity exceeds infiltration capacity and runoff is generated. Rainfall at this point is called "critical rainfall" when runoff starts to occur. As shown in Figure 1, it is the rainfall at point 4. The surface runoff will be generated first before the soil has become fully saturated (Horton, 1933 as cited in Boutorabi, 2001). The generation of runoff will continue as long as the rainfall intensity exceeds the actual infiltration capacity of the soil. It will stop when the rate of rainfall becomes lower than the actual infiltration rate. Dune and Black (1975) as cited by Boutorabi (2001) present a second mechanism of runoff development brought by the volume of water exceeding the storage capacity of the soil. It occurs particularly in soils where the groundwater is close to the surface and rainfall of low intensity and volume can still saturate the soil.

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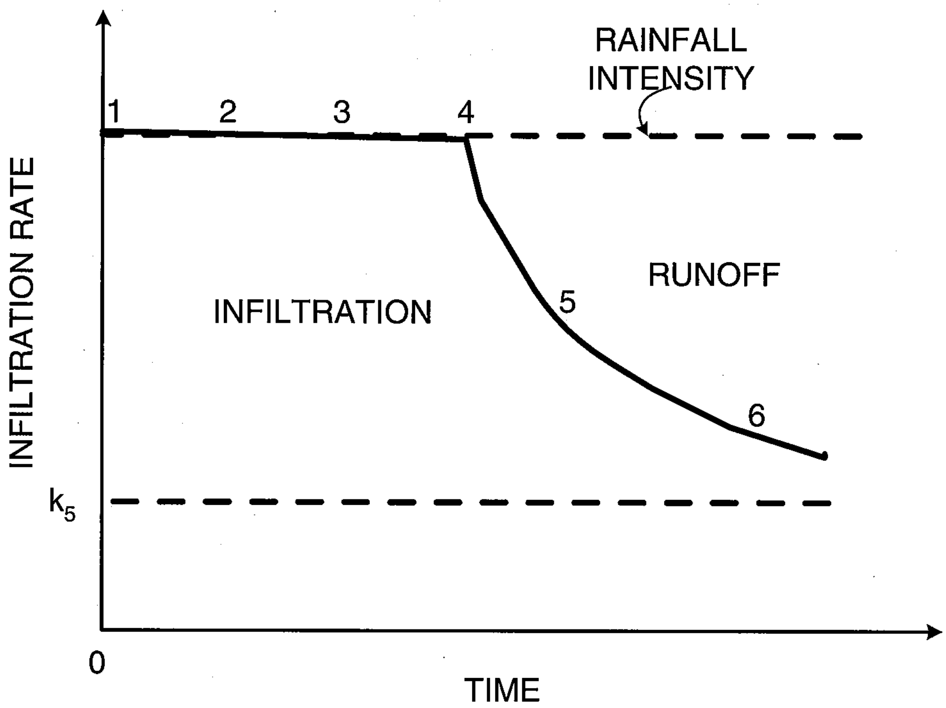

Figure 1. Infiltration rate as a function of time (after Mein and Larson, 1971a as cited in Singh, 1989)

Infiltration is the process of entry of water into the soil through the soil surface (Singh, 1989). The infiltration rate is the rate at which water enters into the soil surface. It is expressed as volume per unit area per unit time and has the dimension of length per unit of time. The infiltration capacity of the soil depends on many factors such as soil characteristics, surface characteristics, precipitation characteristics, antecedent condition, and fluid characteristics (Boutorabi, 2001; Paige, 2000; Critchley, 1991; Singh, 1989)

While there are many factors that may have a direct bearing on the occurrence and amount of runoff (Dijk, 2002; Byer, 2002; Boutorabi, 2001; Paige, 2000; Gatot *et al.*, 1999; Critchley, 1991; Singh, 1989; Sharma, 1986), there is a dearth of knowledge on the infiltration capacity measurements on steep slopes. This paper presents an analysis of the relationships between rainfall and runoff and evaluates derived values of soil infiltration capacity. Further evaluation of these parameters could then be related to soil loss and erosion.

Methodology

The analysis made use of the long-term data of the ASIALAND Management of Sloping Uplands network collected for seven years from the Vietnam site. The network has collected data from five other countries: China, Laos, Malaysia, Philippines, and Thailand. The data have been entered in a database termed "SALAD".

Data of rainfall and runoff collected from 1993 to 1999 were used. A simple histogram was created for the annual rainfall and runoff from the daily data. Linear regression analysis was done to relate rainfall and runoff using the equation, Y = aX + b, where Y is runoff (mm), X is rainfall (mm), and a and b are linear regression coefficients.

Using the same equation, the critical rainfall was determined by obtaining the value of X at Y = 0. The runoff coefficient was calculated by getting the ratio of the total runoff and the total rainfall. The difference between rainfall and runoff was considered as the infiltration. Regression analysis was also done to determine the relationship between runoff coefficient and infiltration.

Further analysis of the relationships was done considering the different treatment plots of the experiment. The site in Vietnam had five different treatment plots:

Treatment 1 (T1) = Farmer's practice using corn and black bean, no hedgerow.
Treatment 2 (T2) = Corn and black beans and tea as the hedgerow.
Treatment 3 (T3) = Corn and black beans with *Tephrosia candida* and tea as the hedgerow.
Treatment 4 (T4) = Corn and black beans with *Tephrosia candida* as the hedgerow.
Treatment 5 (T5) = Bare plot.

Results and Discussion

Relationship between Rainfall and Runoff

Figure 2 shows the yearly rainfall and runoff values of the different treatment plots from 1993 to 1999. The general trend indicates higher runoff at higher rainfall. In all years, the bare plot (T5) always produced the highest runoff, followed by the farmer's practice (T1). The alley crops of corn and black beans with tea as the hedgerow (T2) and corn and black beans with *Tephrosia candida* and tea as the hedgerow (T3) were equally effective in reducing runoff. Alley crops of corn and black beans with *Tephrosia candida* as the hedgerow (T4) produced the lowest runoff. The results clearly show the positive effect of the hedgerow treatments in reducing runoff.

The positive relationship between rainfall and runoff is further illustrated in Figure 3. There were however different degrees of relationship, with T3 and T4 showing higher correlation values between rainfall and runoff. This result is somewhat misleading as one expects an increased soil infiltration rate in the treatment plots.

It was also observed that the runoff from T2 was almost the same in 1994 and 1995 although the rainfall in 1994 was twice the amount in 1995 (2,000 as compared to 1,000 mm). This was also observed in T5. This can possibly be explained by factors like the intensity of rainfall, which unfortunately was not measured. A rough explanation is provided by Figure 4 which shows a higher runoff on a per rainy day basis in 1995 in both treatments.

Relationship between Critical Rainfall and Runoff

Figure 5 shows the comparison between critical rainfall and runoff. Relatively higher runoff was observed at lower critical rainfall. This implies that a larger proportion of rainfall may have infiltrated into the soil which caused further delay in the occurrence of runoff. Thus the alley cropping treatments could have enhanced the infiltration capacity which could be a reason for reduced runoff. Using actual field measurements, Beloy and Paningbatan (2002) showed that land use/land cover types largely influence the infiltration rate of the soil.

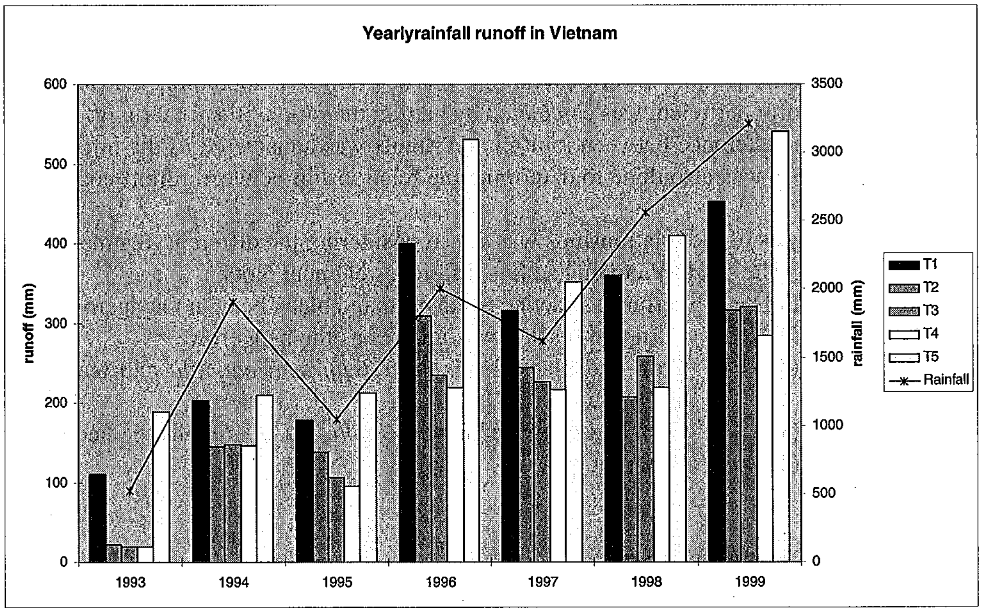

Figure 2. Yearly rainfall and runoff values of different treatments from 1993 to 1999

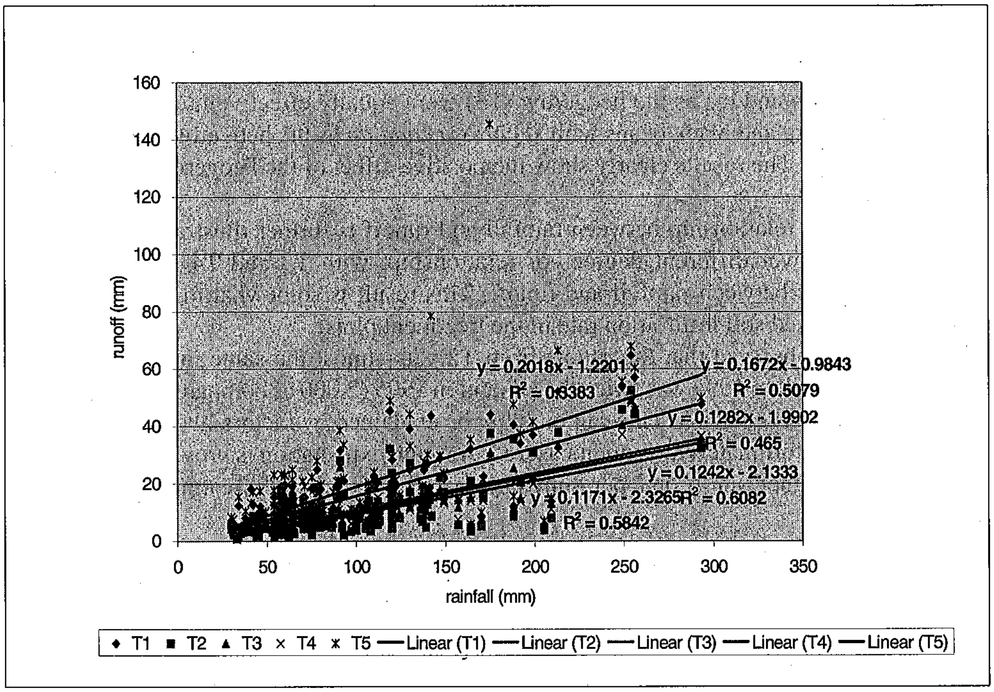

Figure 3. Relationship between rainfall and runoff under different treatments

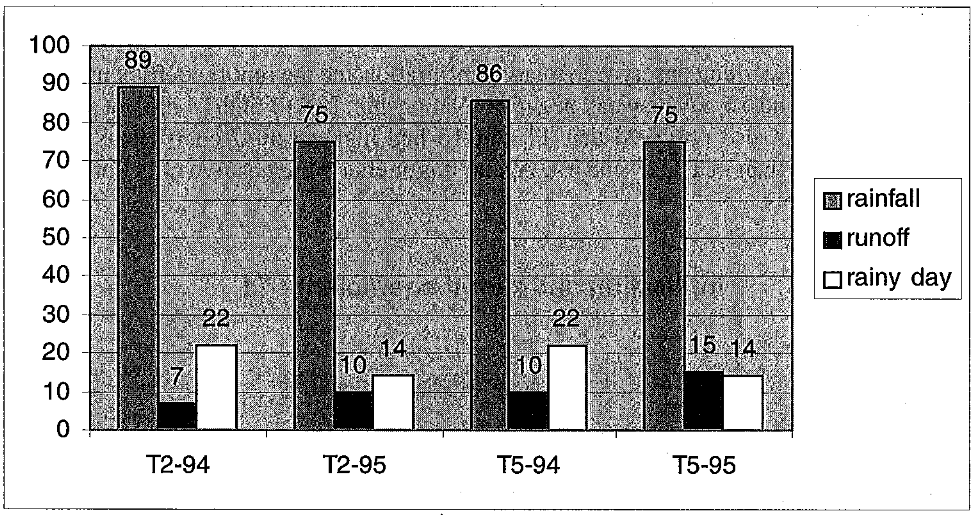

Figure 4. Rainfall and runoff per day and the number of rainy days in 1994 and1995

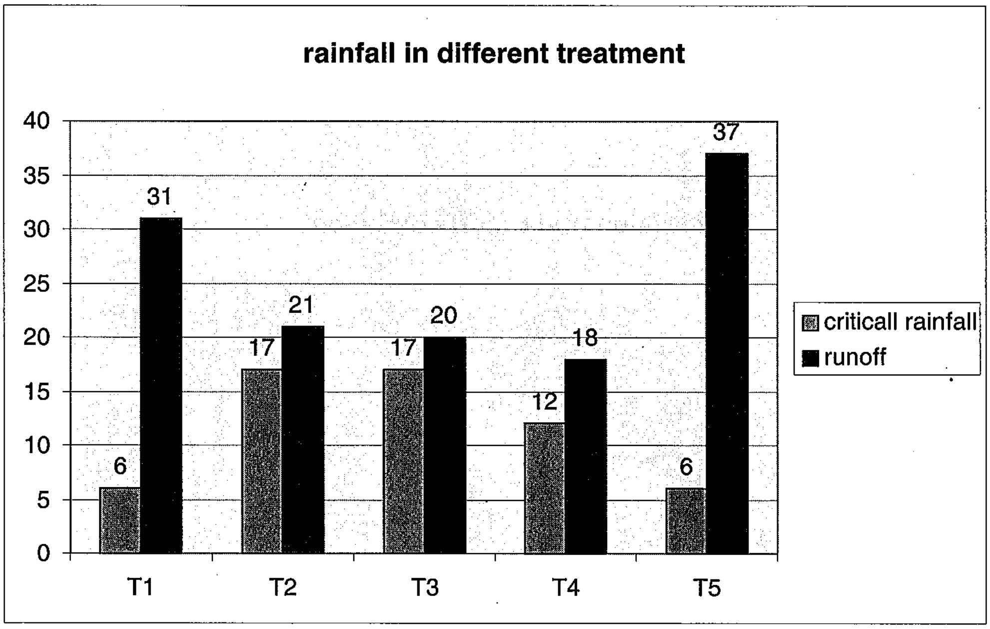

Figure 5. Relationship between critical rainfall and runoff in each treatment

Relationship between Infiltration and Runoff Coefficient

There was no general trend observed in relating infiltration and the runoff coefficient (Figures 6 to 10). T1, T2, and T5 gave a weak negative relationship, but T3 and T4 did not show any trend at all. It was also observed that T1 and T5 had higher runoff coefficients at lower infiltration values than in T2, T3 and T4. Again, this supports the positive effect of the alley cropping treatments.

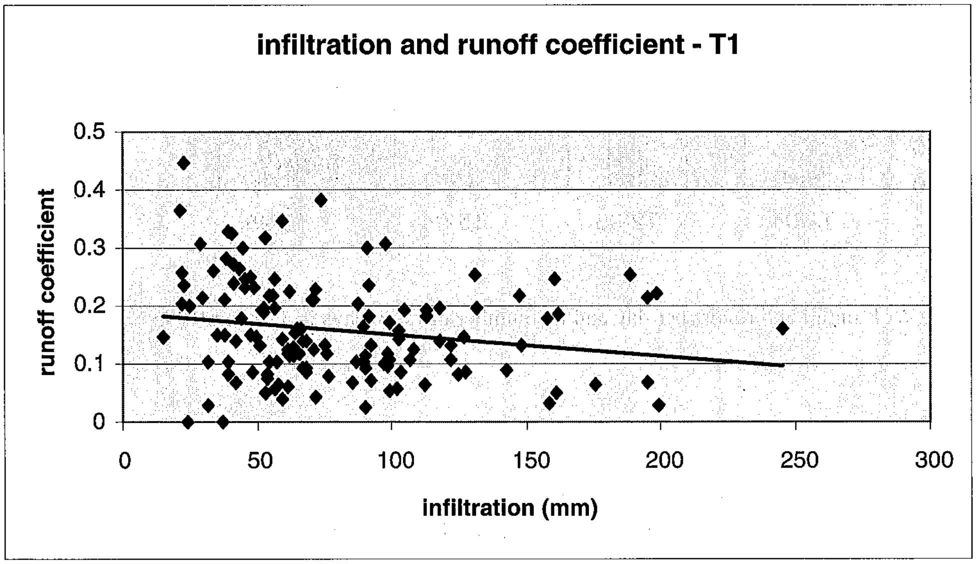

Figure 6. Relationship between infiltration and runoff coefficient in T1

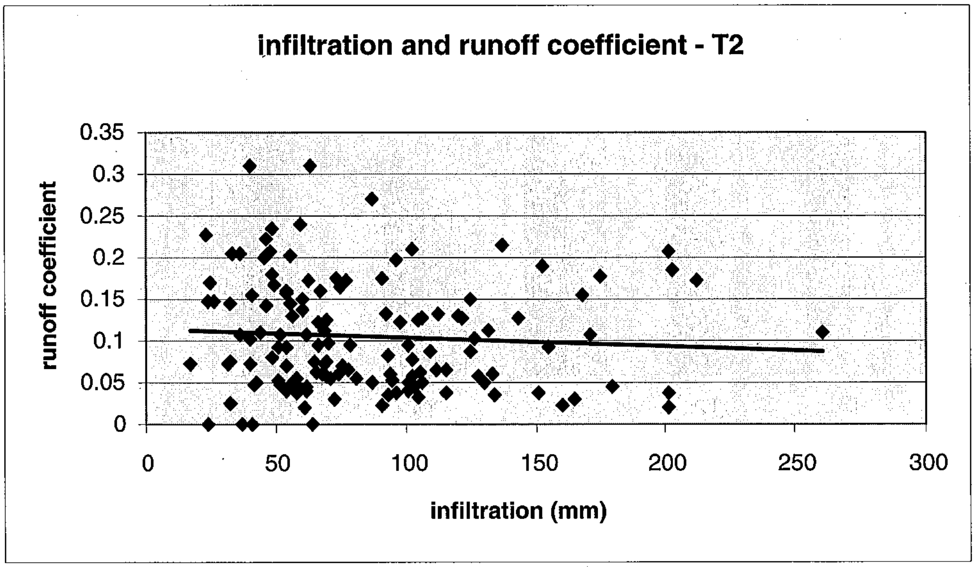

Figure 7. Relationship between infiltration and runoff coefficient in T2

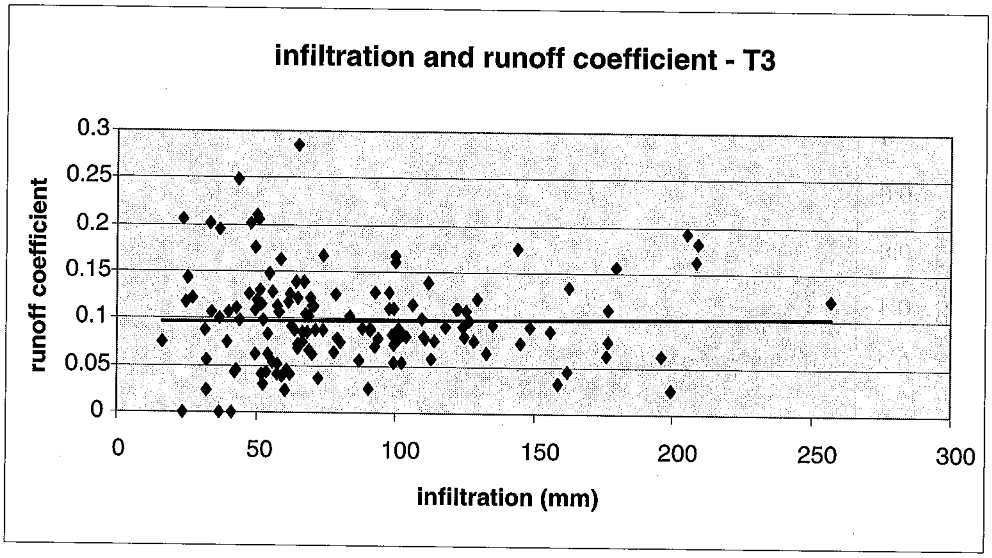

Figure 8. Relationship between infiltration volume and runoff coefficient in T3

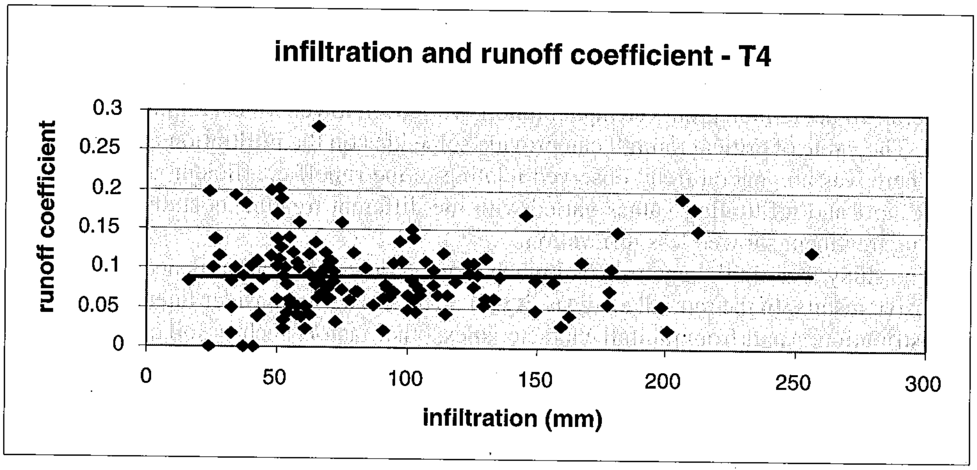

Figure 9. Relationship between infiltration volume and runoff coefficient in T4

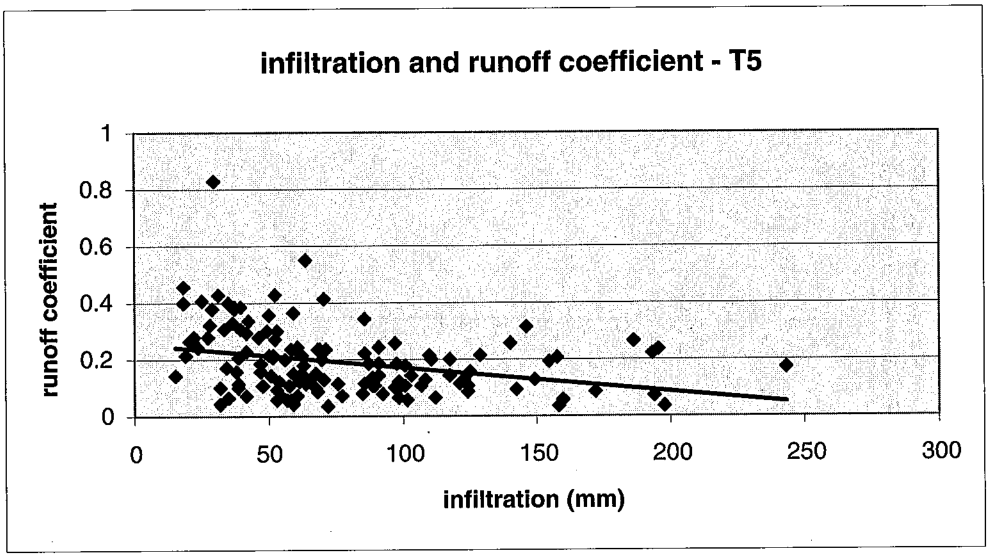

Figure10. Relationship between infiltration and runoff coefficient in T5

Summary and Conclusion

The seven year data on rainfall and runoff from the ASIALAND network site in Vietnam were used in the analysis and evaluation of the relationship between rainfall, runoff, and infiltration. In general, higher rainfall produced higher runoff. Moreover, lower critical rainfall gave higher runoff. The value of critical rainfall can provide some idea on the infiltration capacity of the soil. There was no general trend observed relating to the runoff coefficient and infiltration rate. Runoff and infiltration values varied with the different treatments studied. The alley cropping treatment showed less infiltration.

The study is an initial analysis and much more detailed evaluation is needed for more conclusive results. In the rainfall analysis, it will be necessary to consider intensity, duration and distribution. Apart from rainfall characteristics, other factors such as soil characteristics, antecedent soil moisture, and slope must be considered.

Acknowledgement

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