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Soil Conservation on Rainfed Bench Terraces in Upland West Java, Indonesia: Towards a New Paradigm

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Summary

Artificially bounded plots tend to underestimate runoff and sediment yield from backsloping bench terraces. An alternative approach is the so-called Natural Boundary Erosion Plot (NBEP) which comprises a single backsloping bed plus its adjacent upslope riser, with the measurements being made at the outflow point of the drain running at the foot of the riser.

Amounts of runoff and sediment from four NBEPs were determined on an event basis during two consecutive 5-month rainy seasons in rainfed upland terrain near Malangbong, West Java, Indonesia. Depending on original slope gradient, net sediment outputs ranged from 83-137 t/ha (10° slope) to 146-179 t/ha (20° slope). The erosion intensity on the terrace risers was very high (225-360 t/ha riser surface/5.5 months). Contributions from the risers made up 61-68% of the total soil loss from the two NBEPS on the gentler slope. Corresponding values for the steeper slope were all above 84%. It is probable, therefore, that the terrace risers (rather than the terrace beds) were the main producers of sediment. If stream sediment loads in the study area are to be reduced, conservation measures should aim primarily to reduce riser erosion. Proposed measures include (i) planting fodder grasses on the risers, (ii) leaving coarse harvesting residues (corn and cassava stalks) as mulch in the drainage gutter, possibly aided by (iii) the establishment of silt pits at the downstream end of the gutter.

Keywords: Bench terracing, Java, riser erosion, volcanic upland, watershed management

1 Introduction

In response to widely observed erosion and sedimentation problems, the Indonesian Government launched a major programme for the reforestation of State Forest land and the regreening of privately owned land (particularly on slopes above 50%) in 1976 (Pickering, 1979). As the programme developed, an increasingly large proportion of the budget was spent on the construction, rehabilitation and maintenance of check dams and bench terraces (Anonymous, 1989). The usefulness of the programme in reducing stream sediment loads has been questioned by some who consider that the role of geological erosion (e.g. landslides, bank erosion) has remained undervalued (e.g. Diemont et al., 1991). Similarly, attention has been drawn to the allegedly large volumes of sediment generated by rural roads and villages (Rijsdijk & Bruijnzeel, 1990, 1991). Partly as a result of such observations, watershed management in Java is currently undergoing considerable revision in terms of assumptions and approaches. However, there can be little doubt that, without quantifying the respective sediment sources in specific catchment areas, the debate will continue. Moreover, without such information it

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will also be impossible to evaluate the effectiveness of expensive soil conservation programmes (Bruijnzeel & Critchley, 1996).

A start was made in October 1994 to address some of these questions under the umbrella of a collaborative project of the Ministry of Forestry of the Republic of Indonesia and the Vrije Universiteit Amsterdam, in the 105-ha upland agricultural Cikumutuk catchment near Malangbong, West Java. The main objective of the research is to collect baseline data on catchment hydrological response, on-site erosion and sediment delivery for the prevailing land use and soil conservation setting (Edi Purwanto, 1996). This paper discusses results on runoff and sediment production on two bench terraced slopes of contrasting gradients during two five-month periods covering the bulk of the 1994/95 and 1995/96 rainy seasons, using an alternative technique known as the 'natural boundary erosion plot' (NBEP; Bruijnzeel & Critchley, 1996). The implications of the present findings for watershed management and soil conservation programmes in humid tropical volcanic upland terrain are discussed in detail.

2 Study area

The study catchment is situated at an elevation of 575-750 m in the headwater area of the Cimanuk River, close to the town of Malangbong, Garut District, some 55 km ESE of the city of Bandung. The area receives an average rainfall of ca. 2370 mm/yr (Malangbong, 1971-1987) distributed over about 125 rain days. Rainfall is generally <100 mm/month in June, July and August. Various types of oxisols (reddish brown latosols) have developed in the Holocene andesitic volcanic ashes and Plio/Pleistocene volcanic breccias underlying the area. Almost 80% of the catchment is covered by rainfed bench terraced fields (*tegal*) that are mostly used for the mixed cultivation of hill rice, maize and cassava (rainiest months: November-February), followed by groundnuts, maize and the remaining cassava (using residual moisture: March-June). Irrigated rice fields (*sawah*) occupy about 15%, mostly in the valley along the main stream while the remaining 6% are made up by residential areas (5%) and a single mulberry plantation (1%). Most of the homegardens and *sawah* are privately owned but for historical reasons the ownership status of the majority of the rainfed fields is unclear (Edi Purwanto 1996).

3 Plot instrumentation

Use was made of the 'natural boundary erosion plot' (NBEP) technique developed by Bruijnzeel & Critchley (1996) for the measurement of runoff and sediment yield from backsloping bench terraces. Basically, an NBEP comprises a single backsloping terrace bed plus its adjacent upslope riser, with the measurements being made at the outflow point of the toe drain running along the foot of the riser. Bruijnzeel & Critchley (1996) provide a detailed discussion of the pros and cons of the NBEP and of the traditional artificially bounded runoff plot.

Two complexes of backsloping bench terraces were selected for the construction of NBEPs in October/November 1994. Two NBEPs (nos. A and B) were built on a relatively gentle slope (original gradient 8-10°) and an additional two (nos. C and D) on a steeper slope (original gradient 20-28°). The basic characteristics of the NBEPs are listed in Table 1.

Terrace risers in the study area make up ca. 20-40% of the total area (depending on original slope gradient) on a projectional basis. Expressed as riser face area, these figures may increase to more than 60% on the steeper slopes (cf. Table 1). Adding the (projected) areas of the toe drains would raise the respective fractions by another 6-12%.

Terrace	Bed area (m^2)+	Riser area (m^2)#	Total plot area (m^2)	Fraction occupied by riser*
A	136	46 / 34	183	0.25/0.19
B	89	32 / 26	128	0.25/0.20
C	20	27 / 19	46	0.59/0.42
D	28	44 / 29	69	0.63/0.42

+excluding toe drain.
#expressed as riser face area and projectional area, respectively.
*expressed as the ratio of actual and projected riser surface area, respectively, to total projected plot area.

Table 1: Basic characteristics of four 'natural boundary erosion plots' in the Cikumutuk catchment, West Java.

Rainfall at the two terrace pairs was measured daily using a standard raingauge placed at 1.5 m to avoid rainshadow and surface splash effects. The four terrace units were equipped with a runoff and sediment collecting device situated at the lowest point of the drainage gutter on each terrace. The NBEPs drained via a concrete 90° V-shaped inlet into a 210-litre capacity stilling basin in which coarse material could settle. The basins had a divider system made of 102 mm diameter pipes, allowing one-fifth of the excess runoff to be drained into a first collecting drum of 180 litre capacity. The latter, in turn, was equipped with a divider system made of 38 mm diameter pipes which discharged one seventh of the excess runoff into a second collecting drum of 200 litre capacity. All collecting devices were covered against rainfall.

Measurements of *runoff* volumes were made in the morning after each event using a graduated yardstick and converting waterlevels to volumes by pre-determined conversion equations. Depth-integrated 0.5 litre or 1.5 litre samples were taken from the stilling basin and, where necessary, from the collection drum(s) for the determination of the *concentration of sediment in suspension*. The water in the drums (but not in the stilling basin) was stirred thoroughly before sampling. The volume of any *coarse material* that had settled in the stilling basin was determined separately after gradually draining off the supernatant water after which a 100 cm^3 core sample was taken for the volume to weight conversion. All collectors were cleaned after sampling was completed. Concentrations of sediment in suspension were measured by filtering through pre-weighed 'Melita' coffee filters, oven-drying the residues at 105 °C for 24 h and weighing to the nearest 0.01 g (0.001 g in 1995/ 96). A comparison of sediment concentrations in streamflow obtained with the paper filter method and 0.45 μm Millipore filters suggested an underestimation of 3-6%. The present data were adjusted accordingly. It is possible, however, that this represents an underestimate because of the presence of finer particles in the collected runoff compared to the streamwater.

Riser erosion was estimated using hundreds of 50 cm steel erosion pins of 5 mm diameter inserted horizontally into the riser. During the 1994/95 season, two pins were used per metre riser length, one in the topsoil section (fine sandy loam, slope 31-37°) and one in the subsoil section (fine sandy clay, slope 50-63°). All pins stuck out by 50 mm at the start of the observations (18 November). They were remeasured on 4 May 1995, i.e. after 167 days. Detailed measurements of riser dimensions (one cross section per metre riser length) were made as well on these two days, enabling the estimation of the volume of soil lost between the two dates. To improve the estimates, four erosion pins were used per metre of riser length during the 1995/96 season, which were read five times between 10 November 1995 and 24 April 1996. On three occasions, the dimensions of the risers were measured as well. In addition, a number of bench mark pins with a concrete base were installed vertically at the top of the risers, connected by horizontal wiring to facilitate the measurement of terrace dimensions. The lowermost pins stuck out 100 mm to improve the quantification of the deposition of loose material at the foot of the riser. Finally, the rate of gutter fill-up by eroded material was monitored separately in 1995/96: by means of three vertical pins per drain.

Because the precision with which the pins could be read was ±1 mm at best, this implies an uncertainty equivalent to 8-10 t/ha per reading for the prevailing bulk density of 0.8-1.0 g/cm^3.

3 Results

Runoff and sediment yield data for the four NBEPs have been processed for two consecutive five-month periods covering the main part (November-March) of the 1994/95 and 1995/96 rainy seasons. Seasonal rainfall, runoff and sediment yield totals are listed in Table 2. The amounts of rainfall recorded during the two seasons differed by about 10%, with the 1994/95 season being slightly wetter. Runoff response varied considerably between plots, even for one and the same terrace pair (A and B, with runoff coefficients of ca. 0.18 and ca. 0.27, respectively), although daily amounts of runoff were highly correlated for the two terrace pairs (values of R-squared typically around 0.80). Runoff coefficients for the two NBEPs situated on the steeper slope (C and D) were consistently higher (0.33-0.37 in 1994/95 and 0.31-0.33 in 1995/96) than for terraces A and B on the gentler slope.

Terrace	Rainfall (mm)	1994/95 Runoff (mm)	Erosion (kg/m^2)	Rainfall (mm)	1995/96 Runoff (mm)	Erosion (kg/m^2)
A	2196	415	8.3	2019	359	9.2
B	2196	539	13.7	2019	589	11.4
C	2213	807	14.6	1935	633	16.1
D	2213	686	17.9	1935	593	17.5

Table 2: Rainfall (mm), runoff (mm) and sediment yield (kg/m^2 projected area) totals for four 'natural boundary erosion plots' during two consecutive five-month (November - March) rainy seasons in the Cikumutuk catchment, West Java.

To examine to what extent such differences might be related to potential differences in runoff contributions by the riser and gutter areas of the respective terraces, the runoff totals were expressed as a fraction of the latter areas (on a projectional basis). If the resulting 'riser cum gutter runoff coefficient' (RGRC) would be less than unity, then this could be taken as evidence that all the runoff could be provided (at least in theory) by the riser cum gutter area. If, on the other hand, the value of the RGRC would exceed unity, then contributions from other parts would be required. On a seasonal basis, the RGRC remained below unity in all cases, except for terrace B in 1995/96, which lends some support to the contention that the majority of the runoff is indeed generated in the riser cum gutter area. Nevertheless, in about 20 and 10% of the rainfall events, runoff contributions from outside the riser cum gutter area (presumably the terrace bed) were inferred for storms larger than 40-60 mm on terraces A and B, and C and D, respectively (Edi Purwanto & Bruijnzeel, unpublished).

The sediment yield data in Table 2 illustrate the fact that surface erosion on backsloping bench terraces in humid tropical volcanic steeplands can still be unacceptably high. To obtain an idea of the source of the eroded material, a preliminary comparison has been made in Table 3 of the overall seasonal sediment losses from the respective NBEPs and the corresponding amounts of sediment generated on the risers. Although the periods of the respective observations do not match entirely (per season), such a comparison is still valid because the amounts and size distribution of rainfall during the weeks for which the NBEP output data have not yet been processed (April 1995 and 1996) were similar to those received during the 18 and 10 days in November 1994 and 1995, respectively, which were not included in the riser retreat observations.

	1994/95			1995/96		
Plot	Riser erosion (kg/m^2)	Input from riser (kg)	(%)*	Riser erosion (kg/m^2)	Input from riser (kg)	(%)*
A	22.6	1033	68	28.8	1148	67
B	32.6	1053	61	35.8	925	62
C	40.9#	1096#	165#	28.7	735	95
D	36.0	1584	128	32.1	1002	84

#believed to be overestimated
*computed as input from riser (kg) divided by sediment loss from plot (kg)

Table 3: Riser erosion intensity (kg/m^2 projected), gross sediment input from the riser in kg and as a percentage of the net overall sediment loss from four 'natural boundary erosion plots' during two consecutive rainy seasons (November-March) in the Cikumutuk catchment, West Java. Riser erosion data pertain to the periods 18 November 1994 - 4 May 1995 and 10 November 1995 - 24 April 1996.

The findings listed in Table 3 are of particular interest. Firstly, the erosion intensity on the unprotected terrace risers of the study plots was very high. Also, the total amounts of sediment produced by the risers of the two NBEPs on the steeper slope exceeded (1994/95) or approached (1995/96) overall sediment losses from the plots. Even on the gentler slope (where the risers constituted a smaller fraction of the total area (Table 1), did riser erosion still make up 61-68% of the overall sediment loss (Table 3). The quoted percentages become even more remarkable if the volumes of freshly eroded riser material that went into storage in the gutter (8-13% at A,B; 2-6% at C,D) are added (1995/96 only). Although the pin-based estimates of riser erosion are admittedly crude (±8-10 t/ha), they are nevertheless of the same order of magnitude between terraces and years (Table 3). Work is currently in progress to refine the above estimates using more sophisticated techniques to determine the volumes of runoff and sediment produced by the riser on an event basis (cf. Critchley & Bruijnzeel 1995).

5 Implications for soil conservation strategy

Although in the absence of actual observations of erosion on the terrace beds the data presented thus far cannot be taken as direct evidence that the terrace risers are the chief producers of sediment in the steeper parts of the study area and in similar rainfed bench-terraced volcanic steeplands, it is nevertheless highly probable (cf. Bruijnzeel & Critchley 1996). The implications for soil conservation strategies are potentially profound. For example, it has been stated that the costs of soil erosion in Java mainly manifest themselves as on-site losses of plant productivity (estimated by Doolette & Magrath (1990) at about 300 million US$/yr) rather than as off-site losses (such as reduced efficiency of irrigation systems and reservoirs due to siltation, estimated at 25-90 million US$/yr). At first sight, the large contrast in on-site and off-site costs associated with soil erosion would seem to justify the high investments involved in on-site mechanical conservation works like bench terracing. However, these frequently quoted cost figures may well need to be revised if the bulk of the eroded sediment derives from the terrace risers rather than the beds. After all, most terrace risers in Java are largely unproductive!

The consequence is that, if stream sediment loads in these volcanic uplands are to be reduced via soil conservation, practices should aim primarily at reducing riser erosion and trapping eroded material deposited at the foot of the riser. In view of the absence of readily available rock material to be used as riser support it is proposed here to apply a combination of (i) planting fodder grass on the risers, (ii) leaving coarse harvesting residues (corn and cassava stalks) as mulch in the drainage gutter (called *'vertical' mulching* in the Javanese literature; Edi Purwanto 1996), possibly aided by (iii) the establishment of silt pits at the end of the gutter.

Technically speaking, the *planting of grass* is probably the best way to protect the vulnerable risers of the study area against erosion. Also, there would be other benefits such as increased plant productivity per terrace unit and additional income. However, the farmers in the Cikumutuk area are generally reluctant to plant fodder grass on their land. The most frequently cited reasons include: the promotion of pests and diseases, fear of theft, fear of shortage of fodder during the dry season forcing the selling of livestock, and the general feeling that grassed risers are 'untidy' (Edi Purwanto 1996). Clearly, some major incentives are needed if the planting of fodder grasses is to become widely accepted as a standard conservation practice in the area.

Similarly, whilst the use of *surface mulch* has been demonstrated to reduce surface erosion as well as boost plant productivity in many tropical areas (Young, 1989; Hudson, 1995), the use of crop residues as a mulch on terrace beds is hardly practised in the study area. This is mainly because most of the leafy crop residues are already used as fodder or composting materials while in addition a thick layer of mulch presents problems during the planting and sowing of the mixed crops (Edi Purwanto 1996). However, coarse crop residues such as corn and cassava stalks (i.e. the ones not used for the next rotation of cassava) often remain on-site, usually in stacks along field boundaries. When such coarse crop residues were arranged along the contour (at a rate of 3 t/ha and at 11 m intervals) on a 15% slope in the lowlands of West Java, plot-based sediment losses were reduced considerably, even more so than in the case of ridge terracing at equally large intervals (Kamir, 1995).

The concept of 'vertical mulching'

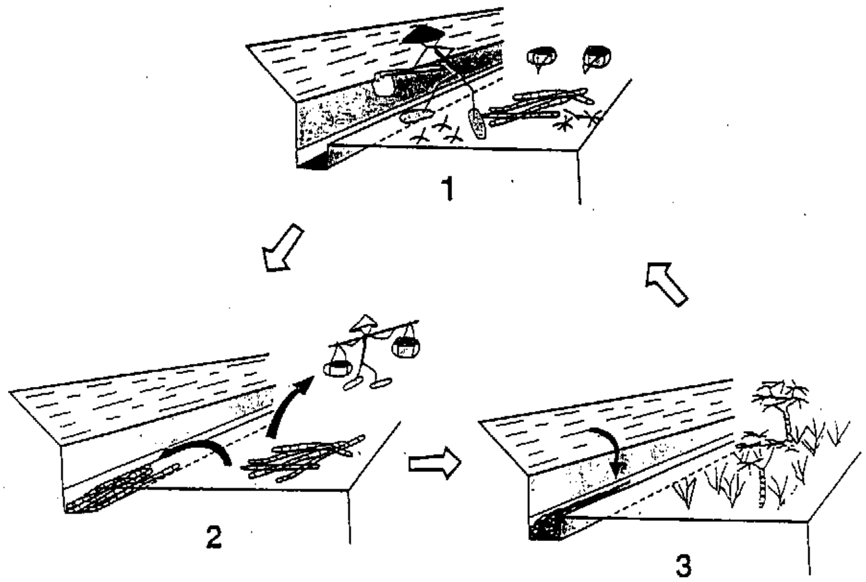

Figure 1: The 'vertical mulching' technique on backsloping bench terraces (modified from Edi Purwanto 1996). Stage 1: Crop harvest and deepening of the drain; Stage 2: Distributing the dug up soil over the terrace bed while maintaining the reverse slope; filling the gutter with coarse harvesting residues; Stage 3: Decomposition of harvesting residues while new crops are growing.

A variant of the 'vertical' mulching technique of Kamir (1995) for use on backsloping bench terraces has been proposed by Edi Purwanto (1996) and is illustrated in Figure 1. The method is both simple and cheap. In addition, levels of organic matter on the terrace beds are maintained while at the same time runoff and sediment coming from both the terrace riser and bed are trapped. However, if the 'vertical' mulching technique is to be effective, the corn stalks and other coarse material harvested during the second half of the rainy season should especially be used to trap material during the more critical initial part of the rainy season. Finally, the *traditional silt pits at the outlet of the drainage gutters* (typically ca. 0.5 m deep with a surface area of about 1 m^2) could be added to the above two measures as an extra precaution. Again, the technique is simple and only requires the regular cleaning of the pits. Although the majority of the local farmers appreciated the function of the pits, only 20% of the people had actually constructed them on their lands (Edi Purwanto 1996).

Now that baseline conditions of hillslope runoff and erosion in the Cikumutuk area have been determined with sufficient accuracy, a sound basis is available for the evaluation of the effects of specific soil conservation methods on on-site erosion or, depending on the scale at which such measures would be applied, off-site sediment yield. An experiment involving the planting of *Paspalum conjugatum* on two NBEPs was initiated at the start of the 1996/97 rainy season.

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