A Matter of Relativity — Design for Low-Cost Soil Erosion Monitoring under Differing Land-use Regimes

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Colleagues who are subscribers to the electronic mail network, SE-LIST (Soil Erosion List), will be aware of the continuing debate concerning the use of absolute and relative measures in soil erosion studies. To some degree the debate is artificial in the sense that both kinds of measures have their place, and the latter, particularly, in studies directed towards elucidating the relationships between land-use systems and erosion. The use of rather crude relative measures, which may provide no more than order-of-magnitude estimates, is justified for several reasons, mainly economic, for they may be substantially cheaper than attempting to make more precise and absolute measures.

First, it is necessary to be aware of several problems of research design. The two major sources of materials moving on slopes (and delivered ultimately into streams), surface wash and slope failure, are not equally susceptible to measurement. Slope failure and sudden mass movement are difficult to measure for several reasons. In open terrain, where aerial photography is possible, it is a fairly simple matter to measure the scars of landslides and their runout paths. Using stereoscopy, such measurements can be further refined to estimate the volume of material that has moved. But, on well-vegetated terrain, whether covered with forests, woodlands, or tree crops, only large landslides which open up the canopy can be observed stereoscopically. Consequently, it is difficult under natural conditions to establish the necessary baseline against which a possible increase in incidence of landslides under various land-use systems may be compared. Very broadly, the incidence increases in the period roughly two to 12 years after deforestation, following which slopes tend to re-equilibrate themselves to the new conditions. However, there has been little study of this in tropical regions. A further consideration is that slope failure is frequently episodic and therefore difficult to research in short funding periods of two to three years.

The classical answer to such problems is one that dates back to Blackwelder, a half-century ago, when a small catchment study was conducted. In this, all the eroded materials, both suspended and in solution, which leave the soil, were measured. Such measurements are normally continued for five to ten years. In the conditions of tropical Asia, the difficulties of designing such studies are manifold, quite apart from the financial considerations. Except in forest reserves and on tree-crop plantations, the spatial scale of land use tends to be small, making it difficult to find small catchments with a single, stable land-use pattern, let alone similar soils, slopes, orientation, and other variables which may influence the amount and kinds of materials leaving them. Finding an unused control site to match with used catchments is not only difficult but the control may be vulnerable to fire or destruction by change of use.

These considerations have led to a substantial reliance on plot studies, despite the inherent difficulty in scaling these up to larger areas. One major difficulty is that sediments moving along slopes by surface wash are only one component, and not necessarily the largest, of the total quantity of material delivered into streams. That total also includes delivery in solution, substantial in limestone regions; delivery by soil creep; and, as indicated earlier, delivery by mass movement resulting from slope failure. The study of water movement is likewise difficult since runoff is only one component, groundwater being the other. In soils where soil pipes develop, some heavy clays for example, these may deliver significant quantities of materials in both solution and suspension into the streams. If the catchment is taken as the system, it needs to be recalled that as much as 70 per cent of the sediments moving on slopes may, for varying periods, be stored within the system as flood-terraces, point-bars, and so on — a basic fact that must be borne in mind during the implementation of soil erosion control measures.

Plot studies, because they are relatively simple to implement, though not cheap, are thus likely to continue to be carried out in many regions. Despite other disadvantages, their major advantage is that, at least in tropical and subtropical regions, they probably more nearly capture the reality of soil loss than a model such as the Universal Soil Loss Equation would, which is in actual fact designed for temperate conditions and for application on the global or large-region scale though it has been applied with varying success to specific sites. One basic problem of the Equation is that it is multiplicative rather than additive, so that shortcomings in any parameter weigh rather heavily (Rijsdijk and Bruijnzeel 1990).

But the standard approach, using a large trough at the foot of each plot to capture water and sediment or diverting such materials through one or more splitters, is relatively expensive to set up, especially if plots are walled in. The trough approach also has the inherent problem of satisfactorily sampling the materials caught, for, where the material is coarse, no amount of agitation will give a uniform dispersion of material in suspension, as a result larger materials tend to be under-represented. Splitters may have similar problems.

These considerations lead to the question: Is it essential that absolute measures be used? If relative measures suffice and are cheaper, especially if farmers themselves can apply the procedures for measuring erosion, are these measures not to be preferred? Given that within a single land-use regime, even on similar slopes, there are likely to be substantial site-to-site variations in surface erosion, is not a design strategy that allows a good number of replications, using relative not absolute, 'catch-everything' measures, to be preferred?

The designs which follow have been tried out in Hong Kong over the last three years and have proved to be cheap and satisfactory, showing very clearly differing orders-of-magnitude of erosion on grass/fernland (control), annually-cut grass/fernland, burnt grass/fernland, and land deliberately kept bare in order to establish the upper limits of erosion. The mean slope angles are about 15° and about 26°, and the soil is sandy clay loam (sand 62%, silt 12%, clay 26%).

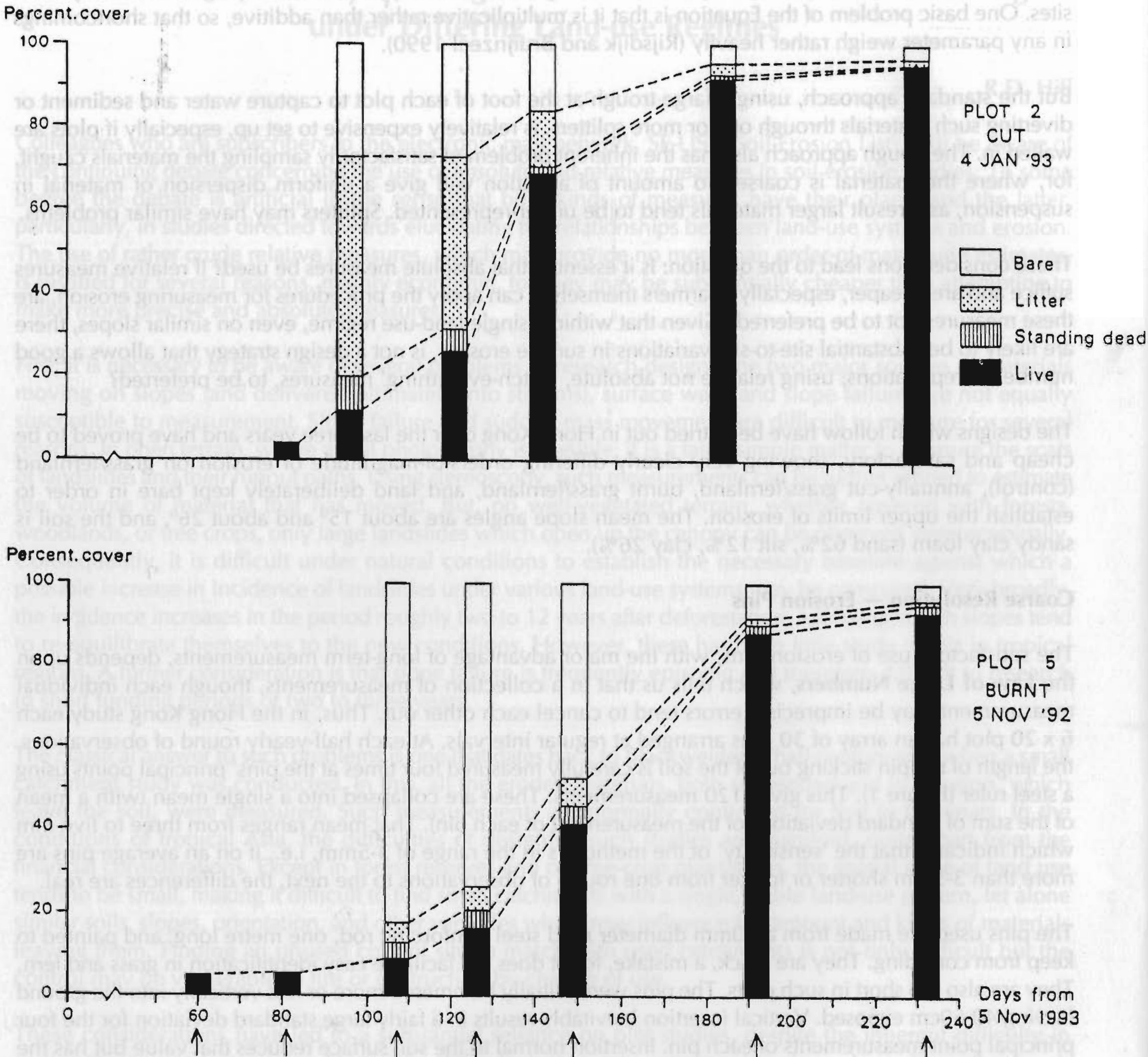
Coarse Resolution — Erosion Pins

The satisfactory use of erosion pins, with the major advantage of long-term measurements, depends upon the **Law of Large Numbers**, which tells us that in a collection of measurements, though each individual measurement may be imprecise, errors tend to cancel each other out. Thus, in the Hong Kong study each 6 x 20 plot has an array of 30 pins arranged at regular intervals. At each half-yearly round of observations, the length of the pin sticking out of the soil is carefully measured four times at the pins' principal points using a steel ruler (Figure 1). This gives 120 measurements. These are collapsed into a single mean (with a mean of the sum of standard deviations of the measurement of each pin). That mean ranges from three to five mm which indicates that the 'sensitivity' of the method is in the range of 3-5mm, i.e., if on an average pins are more than 3-5mm shorter or longer from one round of observations to the next, the differences are real.

The pins used are made from a 10mm diameter mild steel reinforcing rod, one metre long, and painted to keep from corroding. They are black, a mistake, for, it does not facilitate easy identification in grass and fern. They are also too short in such plots. The pins were initially hammered more or less vertically into the ground leaving 40-50cm exposed. Vertical insertion inevitably results in a fairly large standard deviation for the four principal point measurements of each pin. Insertion normal to the soil surface reduces that value but has the disadvantage that, with time, soil creep is likely to rotate the pins' downslope, thus resulting in increasing standard deviations. Obviously, at the expense of more labour, more than four measurements of each pin can be made, thus improving accuracy.

The pins thus readily detect erosion and sedimentation in the centimetre range. If used where the soil is cultivated a further, and possibly a large, source of error is introduced. Cultivation artificially bulks up the soil while also disturbing the pins. It is obviously not possible to insert pins immediately after cultivation and to expect valid measurements, for substantial compaction of clods and other aggregates may occur after cultivation and the soil surface is, in any case, highly irregular. The problem of surface irregularity at the base of each pin can be partly remedied by sliding a plastic disk over the pin just prior to each set of measurements and measuring to it rather than to the soil surface, an approach used in the study of sand movement on beaches where scouring around the base of pins occurs.

Figure 1: Regeneration Diagram, 1993



Fine Resolution — Measuring Splashed Materials

Under monsoonal conditions which produce a number of high intensity rainfall events every rainy season, the impact of drops upon the soil, resulting in the detachment of particles and their downslope movement, is probably highly significant, though the relative importance of this process, compared to overland flow, is not well established. (On light sandy soils and on soils with deep litter and a good granular structure in the A horizon, overland flow is probably fairly rare.) While it is true, as suggested earlier, that by no means all the mobile materials generated on slopes quickly find their way into streams, a measure of mobilisation is useful in that it reflects erosivity and the degree of slope protection offered by plants (and litter).

Since no standard method exists, a simple catcher (splash pan) was designed. This comprised of a plastic lunch box, square, with an area of 160sq.cm. and 7cm high. This was modified by cutting a hole in the side and glueing in a plastic filter-funnel into which a standard Whatman No 42, ashless filter paper was fitted, using double-sided cellulose tape to secure it in place (Figure 2). The purpose of this was to evacuate water and to retain materials splashed over the sides of the trap. (A rain-chamber test showed that the filter-funnel could cope with rainfall of 800mm/hr without the catcher overtopping.) The catchers were pegged to the soil surface, five on each 120sq.m. plot. These were replaced at 400°C, the last as a rough measure of the amount of organic matter present. In addition, each plot carried two catchers at a height of 60cm above the ground, the objective being to catch air-borne material so that the values for the ground-level catch could be deflated by the amount caught at 60cm, since air-borne material could also find its way into the ground-level catchers. (In this case, catches at the 60cm level were very small and highly variable, though there is a possibility that these were underestimated since strong winds could remove already enmeshed materials once these were dry — a probability also at ground level.)

In this experiment, substantial differences in the catch of mineral soil in the splash pans between closed grass/fernland and cut-over plots were found. For example, in 1992, pooled data (from 10 pans) in the 32 days following cutting of two plots showed a total catch of 27.5g of mineral soil from the cut plots compared to only 1.7g from the uncut ones. (Subsequently, as the live plant cover on the cut plots regenerated, the values for the two treatments converged).

Order-of-magnitude differences are thus so large and so obvious that greater sophistication (and expense) of design is not justified, though there is some scope for this. A clear weakness is the fact that dry, already-captured material may readily be evacuated by wind, especially on open sites. Coating the bottom of the pan with an easily soluble but non-drying substance, in order to keep the catch in the pan, may be a solution. Another problem is to avoid catching leaves shed by the vegetation as they senesce. This is basically insoluble since any kind of protector, e.g., a fine mesh set above the splash-pan, would inevitably change the characteristics of the falling raindrops. It is thus impossible to distinguish between organic matter falling directly into the catcher from that splashed up into it. In retrospect, it would also have been cheaper to have fabricated metal catchers, because the plastics become brittle and fragile with exposure — presumably to ultra-violet rays.

Fine Resolution — Measuring Downslope Material

Since the order-of-magnitude data for different treatments were required, a simple device to intercept some of the materials moving downslope sufficed. Traps, to a design shown in Figure 3, were made simply by cutting and bending the top of an oil tin to form an opening and a flap and by punching holes into the cap fitted with a standard glass-fibre filter (Whatman GFD, 4cm diam.), thus trapping sediment, but draining water. (Tins were painted inside out for preservation and required replacement only after three years.) Four such sediment-traps were dug into holes in the soil shaped to receive them, the surplus soil removed, and the soil between the sides of the holes and the traps being firmly tamped down to avoid artificial contribution to the supply of material on the slope. The flap was pressed firmly into the soil and sealed as flush pans. These catchers remain *in situ* to minimise soil disturbance, and their contents are later evacuated by scoop and brush into beakers for drying and analysing. Over these traps is placed a standard sized shelter to keep off direct rain and to minimise rain splash near the trap opening. We used sheet aluminum on painted steel rods (Figure 4A) with a simple attachment (detail in Figure 4B). This design is cheap, easy to make, and has successfully withstood three typhoon seasons.

A sample of results for the rainy season of 1993 (130 days) shows that the traps were indeed successful in establishing order-of-magnitude differences amongst treatments. On 25-27° slopes the total catches of mineral soil were for control (uncut), cut, and burnt plots respectively, 28g, 1,436g, and 7,700g. In no case had the traps been overtopped, though those on the burnt plot came close to it.

Figure 2: Mean Total Catch (Dry Weight) Per Trap and Rainfall (Cumulative)
July 1992 - Jan 1993

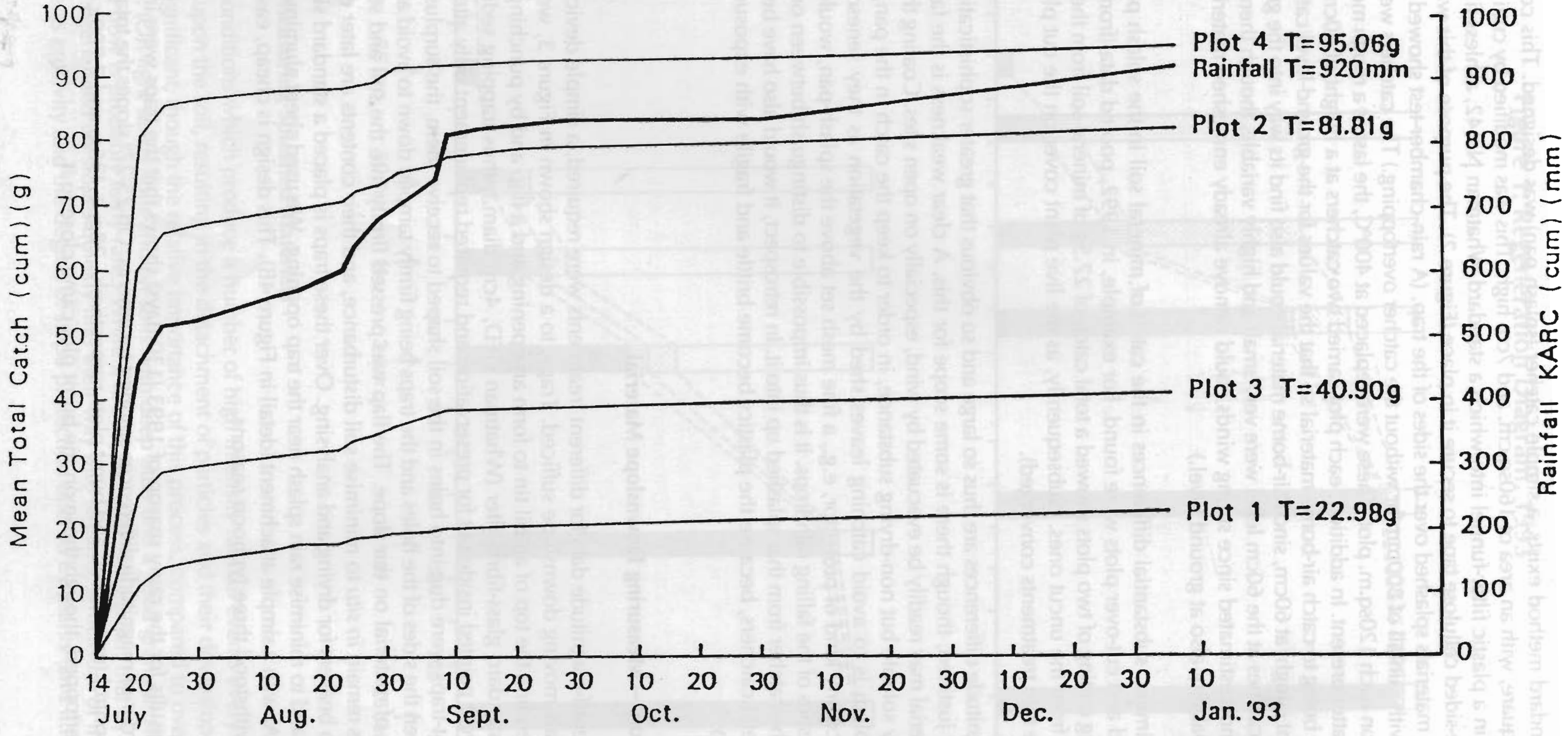


Figure 3: Total Dry Matter Catch and Rainfall, 1993

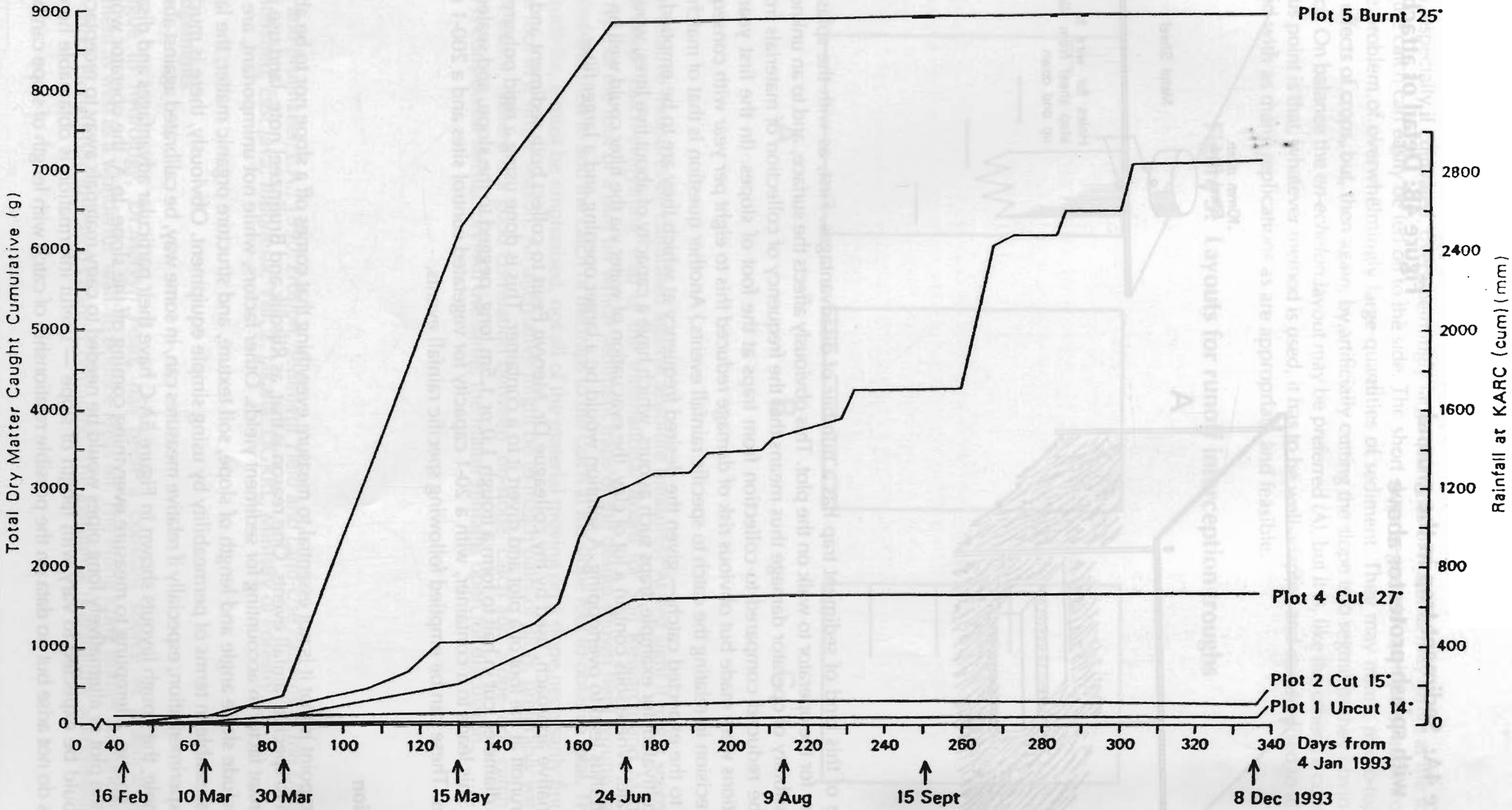


Figure 4A: Sediment trap in the ground with splash-protector above

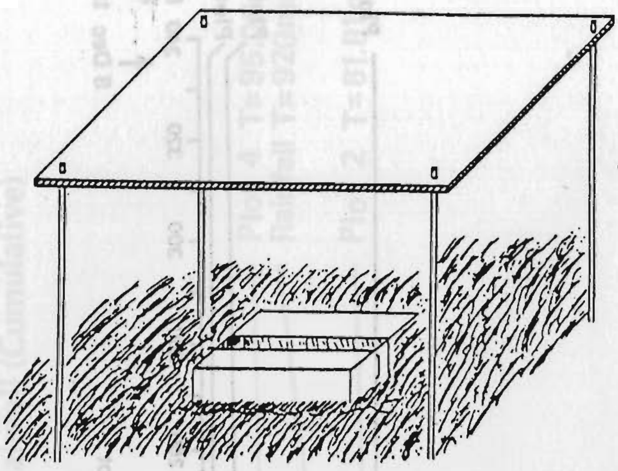
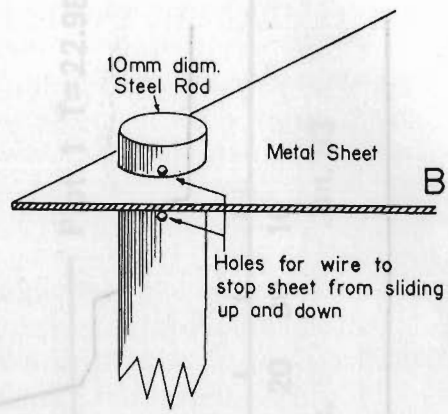


Figure 4B: Detail of attachment



The use of this kind of sediment trap has a number of disadvantages. First, as with the splash-pans, it is necessary for the operator to walk on the plot. This obviously affects the surface, and to an unknown degree. The possibility of operator damage thus means that the frequency of collection of materials from the traps has to be reduced compared to collection from traps at the foot of slopes. (In the first year, 18 sets of observations were made but obvious risk of damage reduced this to eight per year with consequent loss of some precision in relating the catch to specific rainfall events.) Another question is that of matching the size of traps to the expected catch — given the desired frequency at which they are to be emptied. Where the land is cultivated, for example, traps such as ours, which have a capacity of about five litres, would be totally inadequate. Where soils contain a lot of clay, the evacuation of water via the filter could well be excessively slow and thus lead to overtopping. A solution would be a larger opening and a larger filter.

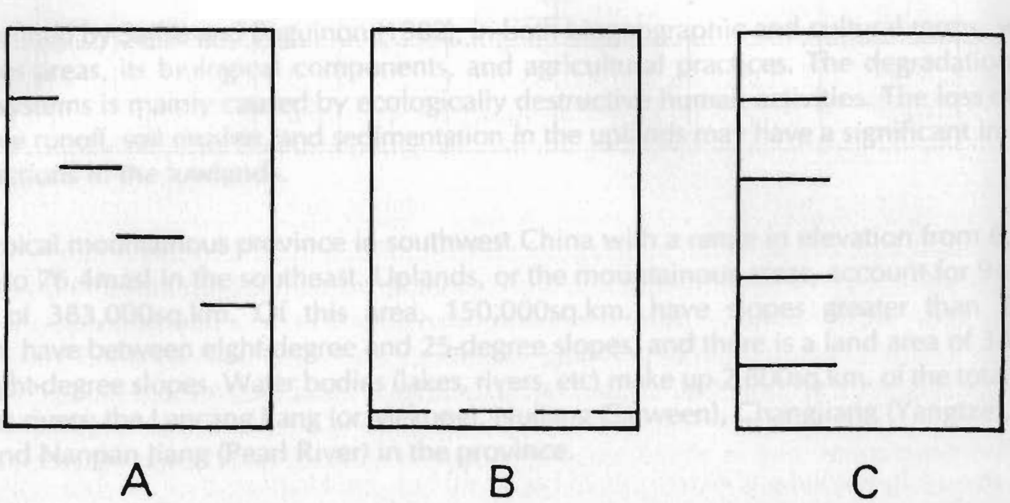
An alternative approach, used by my colleague Dr. Mervyn Peart to collect both sediment and water, is to capture runoff at the foot of a plot and divert it to a container. This is done using a rigid polyurethane pipe, 10cm in diameter, cut in half to form a trough 1.0 or 1.5m long, pegged to the slope, and sealed to the soil surface. This leads to a container, with a 20-1 capacity for vegetated control sites and a 200-1 capacity for bare sites. These can be emptied following specific rainfall events.

Conclusion

The basic point is that it is not essential to measure everything that comes off a slope nor to be able to relate the catch to specific rainfall events. One reason is that, as Rijsdijk and Bruijnzeel note, land use is by far the predominant factor in accounting for sediment yields. Other factors, while not unimportant, are secondary. These include slope angle and length of slope, soil texture, and structure organic matter; the last three are readily assessable in terms of permeability by using simple equipment. Obviously, there is much scope for further experimentation, especially if relative measures can, in some way, be calibrated against absolute ones. For example, the trough layouts shown in Figure 5A-C have their particular advantages and disadvantages, none, of course, attempting to measure everything coming off the slope. In A, the operator would have to walk on the plot or alternatively long pipes would be needed to carry materials away to receptacles. But the catch would be expected to vary with length of slope — useful information is obtainable here. In B, the problems do not arise but no data on the possible relationship of catch with length of slope can be obtained.

In addition, especially if cultivated, overwhelmingly large quantities of material may arrive at the foot of the plot. In C, the catch can easily be led off to the side. The short slope segments' upslope of each trough may reduce the problem of overwhelmingly large quantities of sediment. They may mimic micro-topography and/or the effects of crops, but, then again, by artificially cutting the slope into segments they obviously alter its dynamics. On balance the *en-echelon* layout may be preferred (A), but it is, like the others, a compromise. The obvious point is that, whatever method is used, it has to be well-adapted and standardised to all the sites investigated with as many replications as are appropriate and feasible.

Figure 5: Layouts for runoff interception troughs



How might relative measures be calibrated against absolute measures? At first sight it might seem possible to install a deep 'catch-everything' trap of the International Board for Soil Research and Management (IBSRAM) type at the foot of a plot on which sediment traps of the design shown here (young traps) have been installed and then to add the catch of the traps to the catch at the slope foot to obtain a total. This would be rather crude for, it must be emphasised, not all of the material moving on a slope necessarily finds its way to the slope foot in a single season. An alternative might be to match pairs of plots, preferably with several replicates. Clearly, if there is a good correlation between 'on-slope' catch and 'slope-foot' catch then the calibration is considered satisfactory. All the same, the matter remains open for discussion.

Reference

Rijsdijk, A. and Bruijnzeel, L.A., 1990. *Erosion, Sediment Yield and Land-Use Patterns in the Upper Konto Watershed, East Java, Indonesia,* Vol. 2. Jakarta: DGRRL, Ministry of Forestry.

Acknowledgements

My colleague in hydrology, Dr.Mervyn Peart, has been a constant source of practical help and encouragement as well as a wonderful 'wall' to bounce ideas off. The Hong Kong studies are funded through the University of Hong Kong Research Grants Committee. The assistance is gratefully acknowledged.

Footnote

Colleagues who are on-line may wish to join SE-LIST. The address is SE-LIST@ UNI-TRIER.DE. The list manager is Bodo Bernsdorf, University of Trier, Applied Physical Geography, D-54286, Trier, Germany. E-mail BB@UNI-TRIER.DE.