Runoff plots and erosion phenomena on tropical steeplands

T. C. SHENG
Colorado State University, Fort Collins, Colorado 80521, USA

ABSTRACT Runoff plots are used in many developing countries for erosion studies. In the past, reports of plot studies concentrated mostly on presenting figures and statistics and less on explaining the background and the applicability of the results. This paper takes a different angle and emphasizes on discussion of plot design and logic, management needs, and particularly erosion phenomena and their implications for erosion control work. Its contents are based mainly on the experience obtained from the runoff plots in the steeplands of Jamaica, El Salvador, and Thailand from the early Seventies to the mid Eighties. The paper finally recommends the need for international societies' efforts to support, coordinate and synthesize such experiments.

FOREWORD

Runoff plots are extensively used in developing countries for erosion studies. Plot design, instrumentation, and data collection procedures vary greatly from place to place, so as their results even under similar climatic and physical conditions. People may sometimes wonder whether these results reflected the real situations or were due to design and management differences.

In the past, reports of erosion studies concentrated greatly on presenting figures and statistics (i.e. tons per hectare per year), but not very much on design criteria, logic, management experience, data usefulness and their applications.

This paper will briefly review the experience of establishing and maintaining the runoff plots in the steeplands of Jamaica, El Salvador, and Thailand from 1970 to 1984. Particularly, design criteria, management needs, erosion phenomena, and data usefulness and applications will be discussed. No attempt is made to present detailed figures of these plots since their results have already been published or reported (Sheng & Michaelsen, 1973; Michaelsen & Heymans, 1976; Sheng et al, 1981; Kraayenhagen et al., 1981).

DESIGN, INSTALLATION AND MANAGEMENT

Design and installation

Selection of crops and soils for plot study is usually not difficult. Government policy, research objectives and major soils...
and crops in the area usually dictate such needs. Design problems have always been the selection of slopes, sites, sizes, replications, and appropriate installations.

**Slope and site** Slope of plots depends on the terrain of the area, the major slope under which the test crops are grown, and the availability of the sites for such studies. In steep countries, it is not necessary to limit to 9% slope or follow the Universal Soil Loss Equation (USLE) standard. For instance, the plots in Jamaica, El Salvador and Thailand were all established on 30 percent slopes (17°) which is quite representative of the hill cultivation conditions of these countries. The site selected should be convenient for daily work and supervision. This is primarily important, otherwise, plot maintenance could be hampered.

**Size and replications** Plot length, width, and total area are usually constrained by the available sites. A proper size, however, should not only be chosen for economic maintenance but also for producing good results. On dissected hilly areas, it may be difficult to find a constant slope of 22.1 m (72.6 feet) as required by USLE type of study. A minimum length of 9-10 m (Mutchler et al., 1988) should be sufficient. The appropriate width of a plot depends upon crop needs. Too narrow a plot will have border effects. Many tree plots of 2 m wide in some countries may result in data inaccuracy. The total size of a plot should be manageable in terms of instrument capabilities and manpower to measure and clean the runoff and sediments. An integral fraction of a hectare or an acre would be convenient for future analysis i.e. 1/100 ha.

The sizes of a single plot in these three countries are:
(a) Jamaica: 6 m by 16.6 m (1/100 ha) for yellow yams (*Discorea cavennensis*) and subsequently for bananas.
(b) El Salvador: 5 m by 20 m (1/100 ha) for maize.
(c) Thailand: 5 m by 20 m (1/100 ha) for upland rice.

Replications may be needed for this kind of study. In Jamaica, two replications (two sets) were used, but many times the same treatment gave quite different results. Therefore, in both El Salvador and Thailand, three replications (three sets) were used for better statistical analysis.

**Instruments and installations** In developing countries, automatic devices such as various types of H-flumes with water level recorders and sediment samplers should only be used where repair and maintenance service is readily available. Otherwise, these instruments, once broken down, need to be sent elsewhere for repairs, causing a loss of data. Yet, heavy sediments due to cultivation from these kind of plots and high moisture in the tropics can cause these instruments to easily malfunction. Considering these problems, manual collection of data with simple devices and tanks were used in these three sets of plots. For instance, Jamaica and El Salvador had installed Parshall flume type of simple device which can be easily maintained. In Thailand, a slot type of device was used. At each plot, two tanks were installed, one for collecting mainly sediments and the other for
additional runoff. The flumes and slots are actually runoff divisors which connect two tanks and allow only a portion of the runoff to go to the second tank. Design criterion for the tanks depends on local climate. For instance, the Jamaican tanks were designed for holding the runoff from 178 mm (7 inches) of maximum daily rainfall, an equivalent of a 10 year return period. Over the last 20 years, the tanks overflowed only a few times. This is an important design because if tanks overflow often, the measurements and records will suffer.

Partitions of the plots in the three countries were built by bricks and placed deep enough to prevent any foreign flows from outside or between the plots. The tanks were built by bricks with mortar or by pre-casted concrete. This was deemed necessary for two reasons: First, that the plots can be used for many years to come and secondly, that the installation cost was only a fraction in comparison with long term maintenance cost.

**Treatments**  Treatment needs vary from research objectives. In all the cases, a control (or check) plot is needed for a unit set of treatments. However, whether the control plot should be representative of the farmers' cultural methods is a subject of debate. During Jamaica's first yam experimentation (1969-1973), the control plots were given the same amount of organic and chemical fertilizers as the treated plots resulting in a better first year production of yams of the control than the treated plots. The farmers in the region used no fertilizers at all. Although from the second year onwards, the yam production of the control plots was declined due to more erosion than the treated plots, but the yields were still higher than the surrounding farmers'. The result may give a false impression to the farmers that for increasing production, soil conservation is not at all necessary. The argument then was that if everything being held equal (i.e. slope, soil, size, fertilizers, etc.) the differences in soil erosion and yam production among the plots would be attributable to the single factor of conservation treatment.

One important consideration for all plots on steep lands under tropical conditions is drainage. It is unrealistic under the humid tropics that a plot be designed to hold all the rainfall. Without drainage systems, a plot will yield unusually low runoff and sediments, but the crops will be damaged. On the other hand, the land used for installing a waterway in a plot should be appropriate (i.e. not over 5 percent). Otherwise, runoff will be unusually high because waterways are normally protected with structures or sod which will seldom take in rainfall, especially on steep lands.

**Management**

**Personnel needs**  In the tropics and sub-tropics, heavy rains may fall every day during the three to four peak months of rainy season. Collection of runoff and sediment data becomes a tedious task. Therefore, ample manpower and good management should be provided. The personnel needs, according to the past experience, was as follows: One overall supervisor, two field assistants stationed nearby, and two to four labourers for about one dozen
plots. The necessity of two field assistants is because rains may fall on holidays and weekends. With two of them, they can alternatively cover the necessary work year round.

Measurement and data collection It is essential to measure and collect data from plots after every runoff-producing rain. This means that such chores will be needed almost every day during the rain seasons. For instance, the number of runoff-producing rains in Jamaica amounted to 75-95 a year. Usually the torrential rain falls in the afternoon, and all the necessary work needs to be completed by the following morning to make way for the next storm. The work includes measuring and recording rainfall and runoff, weighing and sampling sediment for each plot and clearing all the tanks, etc. The overall task usually requires two to three hours to complete. If the measurements are carried out after several storms, as many other countries did, not only will the results of individual storms be unidentifiable, but also the tanks will easily overflow, affecting data accuracy.

Data analysis Runoff, sediment, and crop productions may constitute the major items for analysis. Under runoff, the total amount and percentage of runoff in relation to rainfall are probably two of the most important items. Runoff timing and peak flows cannot be measured without automatic recorders. For sediment measurements, the sludge of the tanks, mainly heavy sediments, can be weighed, sampled, and oven dried for determining their dry weight contents. Whether suspended loads need to be measured is a subject for further study. The work could be time consuming, and the quantity obtained may be quite negligible according to our experience. Therefore, for all three sets of runoff plots, no suspended load measurements were needed. Also, nutrient loss was not measured for these sets of plots. Crop productions of the plots was analyzed in Jamaica for yams and bananas but there were no complete reports on production for the other two sets of plots. Too busy on erosion measurements and neglecting crop management was the major reason.

EROSION PHENOMENA

This paper does not intend to give a detailed analysis of erosion results of the three sets of runoff plots. Instead, some important findings and interesting phenomena are brought up for discussion:

Important findings

From the results of these plots and other reports (JCRR, 1977; Liao, 1981; Sheng, 1982; Veloz & Logan; 1988), it can be summarized that under the humid tropics, cultivated slopes of 30% and the like could lose soils at 100-200 t ha⁻¹ year⁻¹ without practising proper conservation measures. The actual rates vary according to crops, tillage, soils, and local rainfall patterns and intensities. To reduce soil erosion to an acceptable level, therefore, is a much greater challenge to the conservationists under this kind of
environment than others. According to our experience, both conservation structures and agronomic conservation measures are needed to control soil detachment and transportation, as well as to safeguard runoff which is inevitable in humid tropics. The right combination of structures and agronomic measures are dependent on local research. For instance, based on the runoff plots in Jamaica and Thailand, hillside ditches (the improved type) combined with agronomic measures could reduce erosion by 80%, yet their cost was about 1/5 the cost of bench terraces which may reduce additional 10% of erosion.

Interesting phenomena

Some interesting phenomena found from these plots are explained as follows:

(a) Bench terraces were most effective in reducing erosion, but not for runoff especially for new terraces. The main reasons except for intense and frequent rains are: 1) In a plot, the risers of bench terraces and a waterway occupy considerable area. The risers are protected by grasses, and the waterway by grasses or structure. These areas can take in very little rain, if any. 2) Subsoils exposed at the cut portion of the terraces need several years of continuous tillage to improve its infiltration. 3) The type of terraces designed in the tropics are for safe drainage of runoff so that the water has less chance to infiltrate. According to an experiment conducted in Taiwan, the runoff reducing function of bench terraces was greatly improved after several years of cultivation (Liao, 1981). An earlier study in Taiwan found that the benches generally conserved more moisture than the check plots on slopelands (Chiang, 1965). This subject may need more studies.

(b) The majority of soil losses were due to a dozen or so heavy storms in a year. For instance, on 1 June 1972, a storm of 103 mm at the Jamaican site produced 30 t ha$^{-1}$ of sediment (in terms of dry soils) from the check plots (Sheng & Michaelsen, 1973). The amount was almost 1/4 of the average annual soil loss per hectare from the checks. The 1979 results of the Thailand plots showed that 88% of the soil loss from the control was caused by six storms (Sheng et al. 1981). In 1981, 33 t ha$^{-1}$ were lost from the control during two storms fell on 2-4 September (Kraayenhagen et al, 1981). Therefore, data collection during heavy storms should be carefully exercised and no overflow of tanks should be allowed.

(c) Runoff percentage can be as high as 95% according to Jamaica experience (Sheng & Michaelsen, 1973). This may be because of heavy soils, but more probably because of frequent, torrential rains and steep slopes. During the rainy season, soils are saturated or nearly saturated so that any additional rains will run off quickly. Runoff percentage is an important factor used for designing flood and erosion control structures.

(d) Soil loss figures obtained from this kind of runoff plots are usually less than actual erosion occurring in the field, mainly because the length of a plot is confined by walls and no foreign runoff is allowed to flow in. This may not be the case in the field. Longer slopes and added runoff usually cause more erosion. Another reason is that the plot length of 10-15 m may fit in the
designed space between two structures (hillside ditches or other types of discontinuous terrace) under the field conditions. In other words, the walls at the two ends protect the plot, just as conservation structures protect the field. With this kind of protection, agronomic conservation measures such as grass barriers and residue management seem quite effective in erosion control, as some results indicated in El Salvador. However, this may not be true when they are applied alone on long slopes in the field without structures to take care of the runoff. The effectiveness of agronomic conservation measures on tropical steeplands merits further studies.

(e) Minimum tillage seems quite helpful for erosion reduction. In the upland rice plots of Thailand, "Dibbling method" (Using a wooden stick to open a hole) was used for seeding rice and leaving the remaining area untilled. The average soil loss of the control plots for three years was 48 t ha⁻¹ year⁻¹. This amount might be doubled without practicing minimum tillage. Soil erosion rates could reach 100 t ha⁻¹ year⁻¹ or more under traditional cultivation in the region of Northern Thailand (Wichaidit & Bourreau, 1977; Marston et al, 1985; Harper, 1987). Proper minimum tillage systems for tropical steeplands occupied by subsistence type of farmers is a subject for further study. Small farm sizes, root crops, and extra inputs of pesticides and fertilizers, etc. are some of the obstacles for developing and adopting such systems. However, any practical system found through additional studies should be helpful and useful to the farmers.

(f) From past records, it can be said that erosion is a more erratic phenomenon than most of us thought it was. In theory, under similar storms, intensities, soil moisture and cover conditions, the erosion rate of a plot should be similar. In reality, however, the results can be quite different. Depressions created by cultivation need to be filled up before sediment enters the tank; sediments may pile up in plots during heavy storms and to be washed out by lighter rains; structures may suddenly slipped off during storms; and weeds may provide better cover in only a few days. All these and others contribute to different erosion rates. Unless the real parameters influencing erosion are completely understood on the site, actual prediction is almost impossible. Predictions can generally be made for average conditions and for long terms.

THE USE OF PLOT DATA

For verifying soil loss equations

A part of the banana plot data from Jamaica has been used for verifying the USLE, MUSLE (Modified USLE) and the Simplified Process (SP) model developed recently by D. M. Hartley, USDA-ARS. The findings were that the USLE and MUSLE generally overestimated several times more soil loss while the SP model, though somewhat overestimating the soil loss, was much close to actual measured results. The high LS (Length & slope steepness) and C (Cropping) factors of the USLE and MUSLE are probably the main cause of their overestimation on steep slopes. The SP model
performed extremely well in predicting runoff (Hartley et al, 1986; Hartley, 1987).

Another independent study using yam plot data of Jamaica to verify MUSLE and the Morgan and Finney model, was done very recently by Miller (Miller, 1989). His main findings were that the MUSLE grossly over-predicted soil loss in comparison with measured values because the LS values were too high. The Morgan and Finney model produced results generally closer to the measured ones, though it underestimated soil loss of the control plots and the runoff of all the plots.

For conservation planning

The plot data, together with the results from a demonstration area in Jamaica, have provided a basis for planning several soil conservation and watershed projects in terms of estimating erosion rates, effectiveness of conservation measures, and crop production potentials on treated lands. This has been very helpful in developing countries like Jamaica where basic data are usually lacking.

CONCLUSIONS AND RECOMMENDATIONS

Runoff plots are popular for erosion studies in many developing countries because of their relatively simple in installation and briefness in obtaining results. However, to secure useful results, the plots need first to be carefully designed and maintained, and followed with meaningful analysis and interpretation. Merely collecting or presenting erosion figures and statistics without sufficient discussion of their limitations and usefulness is a job incomplete. People can consequently learn more from interpretations and discussions than from cold statistics. This paper is written based on this belief and is meant only for stimulating purpose.

Runoff plot studies have been carried out on the tropical steeplands in many countries and probably over many decades. Yet, their results are still sketchy. It is recommended that international soil conservation societies, research institutions, or other agricultural or environmental bodies should make efforts to investigate their installations, collect, collate, and coordinate their findings, and help synthesize and publish the results. Standardization of plot design and management practices should also be considered in order to avoid mistakes of the past as well as to make comparisons more meaningful.

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