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The establishment of experimental plots for studying runoff and soil loss in the rolling loess regions of China

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ABSTRACT The necessity of establishing experimental plots covering entire slope areas bordered by natural divides and extending over the entire slope length (i.e. from the hilltop to the foot of the gully slope) is dealt with in this paper. This is to comply with the particular features of water and sediment yield in the rolling loess regions. In addition, a brief account of the methods of evaluating the effect on sediment detention of different conservation measures is presented.

L'aménagement de parcelles expérimentales pour l'étude de l'écoulement et des pertes en sol dans la zone des collines de loess

RESUME Le présent article expose, à partir des caractéristiques des sols et de l'écoulement dans la zone des collines de loess, la nécessité d'établir la parcelle expérimentale sur la surface totale du versant délimité par ses limites naturelles, et de disposer cette parcelle sur la longueur totale du versant du sommet des collines jusqu'au pied de la rigole d'érosion. En plus, on apprécie simplement les effets de rétention des sédiments à l'aide des trois mesures de conservation de sol et d'eau.

INTRODUCTION

The loess plateau of the Yellow River basin is one of the places in China where the loss of soil and water is most severe. Since liberation, soil conservation experimental stations have been set up by the Yellow River Conservancy Commission at Tianshui, Xifeng and Suide and other places. In addition, a runoff experimental station has been established at Zizhou in order to investigate the processes of runoff and soil loss and to estimate the effect of various soil and water conservation measures. The purpose of these stations is to provide information as the basis for a soil and water conservation programme in the loess plateau. A large number of experimental plots have been established in order to monitor soil erosion from the slopes, and the results of the soil and water conservation measures have been evaluated.

ESTABLISHMENT OF PLOTS FOR EXPERIMENTS ON RUNOFF AND SOIL LOSS

Four different kinds of experimental plot have been established:

(a) Plots with different land uses to study the dynamics of soil and water losses and the benefits of soil conservation practices.

(b) Plots to study the effect of separate factors, including the influence of slope angle, length of slope, vegetative cover and cultivation method on the loss of soil and water.

(c) Observation stations for determining the effects of particular field works, including terraced fields, low banks of earth etc., on sediment detention.

(d) Large-scale experimental stations, to investigate the dynamics of soil erosion and loss of water from ridge slopes, gully slopes, and both combined (i.e. from plots extending over the entire length of a slope from the ridge to the gully); and to study the interaction between the different parts of a plot.

Equipment and methods of observation

The parameters observed include precipitation, quantity of soil eroded, runoff outflow, evaporation from the land surface, infiltration, soil moisture, soil fertility, and crop output.

The equipment and methods of measuring rainfall, runoff and sediment yield are as follows:

(a) Precipitation is measured by standard raingauges of 200 mm diameter and recording gauges. The total amount of precipitation and the time of the start and end of each rainfall event are recorded. The distribution of precipitation with respect to time is observed mainly by recording gauges, and in places without such equipment the time-dependency is obtained by taking manual readings at certain intervals.

(b) Runoff from small plots is collected in measuring tanks made of brick, slabstone or galvanized sheets, whereas triangular thin-plate weirs are used for large plots. The total runoff is determined from the water level in the tank after the rain, and the hydrograph is obtained by measuring the water level at regular intervals. The outflow during a certain period of time is then obtained from the stage-discharge relation (weir method) or the storage curve (tank method).

(c) Sediment measurements are carried out by one of two ways: (i) By reading off the top level of the sediment deposited and retained in the tank after rainfall. The total quantity of sediment is then determined from the storage curve of the tank. (ii) By thoroughly stirring the sediment-laden water in the measuring tank, which is subsequently sampled at different levels. The mean sediment content is then determined, which, multiplied by the total runoff, will give the total sediment yield. The hydrograph of sediment yield is obtained by sampling at regular intervals in order to determine the change of sediment concentration through time. The runoff hydrograph is then used for plotting the hydrograph of total sediment delivery.

Furthermore, in combination with the observations on runoff and sediment content, erosion of soil from the slopes, scour and fill, slumping and slipping etc. have also been investigated *in situ* after a rainfall. The extent and location of erosion in the form of rills and gullies is measured and photographs are taken to show changes in microrelief.

Size and shape of the plots

Small plots from 60 to 200 m^2 in area with a regular shape (generally 5 m wide and 12-40 m long, measured horizontally) were formerly used in the rolling loess regions. Subsequently, the size of the plots was gradually increased to 7.5-15 m by 15-60 m (length in the horizontal direction), to form rectangular tracts with areas of 150-900 m^2. Runoff plots were finally established to cover the entire slope, each extending from the top to the foot of the hillside and bordered by the natural divides of the catchment. In order to evaluate the effect of plot size on soil erosion, preliminary analyses have been undertaken on data collected from the experimental plots at Zizhou for the Tuanshangou (gully), a tributary of the Dali River in north Shaanxi. The location, layout and basic features of the plots are shown in Fig. 1 and Table 1. The relationships between total annual runoff and mean

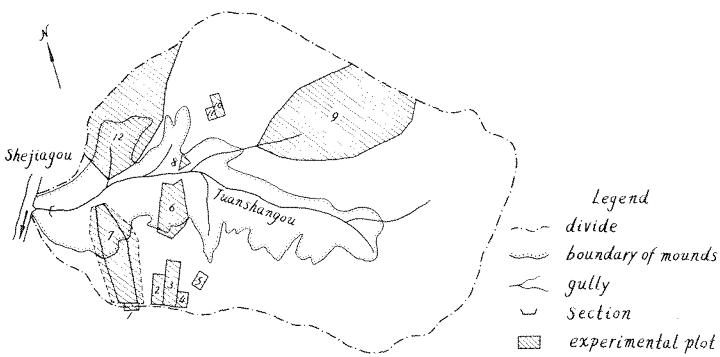

Fig. 1 Layout of experimental plots and gauging stations at Tuanshangou.

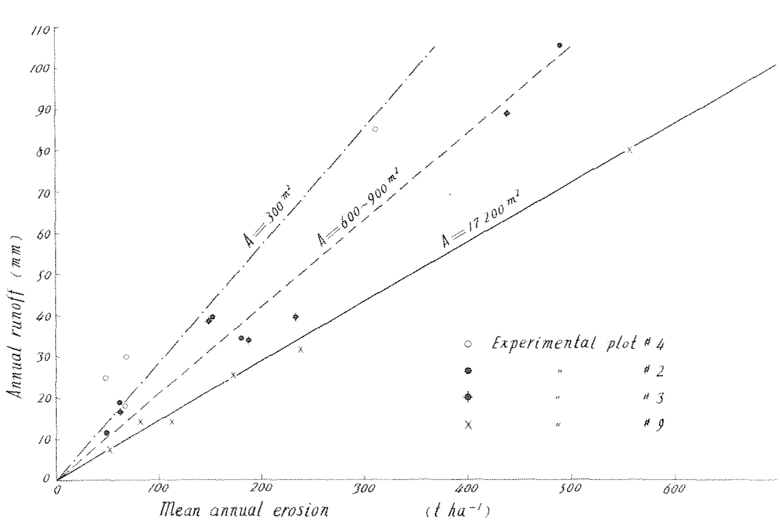

Fig. 2 Relationship between total annual runoff and mean annual erosion for experimental plots of different size.

Table 1 Basic data for the Tuanshangou experimental plots

Plot no.	Location	Soil	Land use	Exposure	Slope (°/oo)
1	Left ridge	Loess	Cropland	NW	158
2	Mound slope on the left	Loess	Cropland	NE	404
3	Mound slope on the left	Loess	Cropland	NE	404
4	Mound slope on the left	Loess	Cropland	NE	404
5	Mound slope on the left	Loess	Cropland	NE	601
6	Gully slope on the left	Loess	Steep, uncultivated	NE	827
7	Mound and gully slope on the left	Loess	Cropland and barren slope	NW	445 1730 344
8	Gully slope on the right	Red soil	Barren, scarp	SW	1280
9	Depression, right bank	Loess	Cropland	SW	differs
10	Mound slope on the right	Loess	Cropland	SE	625
11	Mound slope on the right	Loess	Cropland	SE	625
12	Mound and gully slope on the right	Red soil	Barren slope, scarp, cropland	SW	differs

Plot no.	Size			Measurement	Period of observation	Zone
	L(m)	B(m)	A(m^2)			
1	20	7.5	150	Tank	1963–1967	Sheet erosion
2	40	15	600	Triangular flume	1961–1967	Rill erosion
3	60	15	900	Triangular flume	1961–1969	Sheet, rill and shallow gully erosion
4	20	15	300	Triangular flume	1963–1967	Sheet and rill erosion
5	20	15	300	Triangular flume	1963–1967	Sheet and rill erosion
6			1 160	Tank	1961–1964	Hydraulic and gravitational erosion
7			4 080 5 740	Triangular flume	1961–1964 1965–1969	Hydraulic and gravitational erosion
8			564	Tank	1962–1966	Hydraulic and gravitational erosion
9			17 200	Triangular flume	1963–1969	Gully cutting
10	30	10	300	Triangular flume	1965–1967	Sheet and rill erosion
11	15	10	150	Triangular flume	1966–1967	Sheet and rill erosion
12			9 820	Triangular flume	1965–1969	Hydraulic and gravitational erosion

annual erosion for plots of different size (Fig. 2) indicate that, other conditions being similar, the erosion for a given annual runoff increases with the size of the plot. This can be explained as follows.

(a) Sediment yield is dominated by gully erosion. Erosion of soil resulting from rainstorms seldom takes the form of sheet erosion in the rolling loess regions in China. In general, gully erosion follows a sequence from rill development to shallow gullies, valley cutting, widening of gullies and headcut retreat. With an increase in slope length and consequently contributing area, small rills coalesce through cross-grading and capture, concentrating the flow and causing more pronounced gully erosion. This effect is shown by Table 2 which gives the results of field investigations of erosion patterns on different plots after a storm of 23 mm on 28 August 1963.

(b) The sediment content increases steadily along the path of flow. Because the soil in loess regions mostly comprises of relatively fine silt particles ($d_{50} \simeq 0.05$ mm) and the overland flow has a very high capacity for transporting sediment, scouring occurs along the path of flow. By comparing the data on flow and sediment concentration collected at adjacent plots no. 9 and no. 11, with areas of 17 200 and 150 m^2 respectively, it has been shown (Fig. 3) that under similar conditions of rainfall and runoff, the mean sediment content of flow from large plots may be 50-100% higher than that from small plots.

In addition the establishment of experimental plots covering entire slopes, i.e. complete natural catchments, also has the advantage of avoiding alteration of divides by human activity. This conforms with the objective of maintaining natural conditions with respect to the concentration of overland flow and the process of erosion due to runoff.

Therefore it seemed necessary to carry out observations and to make studies on a number of large-scale experimental plots covering entire slope areas bordered by natural watersheds, instead of merely establishing small plots of regular shape, as was done previously.

The necessity of establishing plots extending over entire slope lengths

In order to study the relation between sediment detention on a slope and the degree and extent of gully erosion, experimental plots extending over entire slope lengths (from the top of the ridge to the foot of the gully slopes) and plots covering entire gully slopes (from the break of slope to the foot of the gully slopes) were established at the Zizhou runoff experimental station. Parallel observations were made. The results obtained from the two types of plots (Fig. 4) indicate that the erosion rates are about the same for equal depths of runoff. In general the erosion rates on the overall slope are smaller than those of the gully (Gong Shiyang & Jiang Deqi, 1978). This indicates that the overland flow over the slopes not only carried solid matter as a result of slope erosion, but also scours the gully slopes, thus adding to the quantity of soil eroded in the gullies. Conservation measures on the slopes are effective not only in

Table 2 Gully erosion of slopes on some plots after a rainfall of 23 mm on 28 August 1963

Plot no.	Length of gully (m)	Width of gully (m)	Depth of gully (m)	Remarks
1	Gully erosion not pronounced			Rills appear only at walls enclosing both sides
2	39	0.2	0.25	
3	8	0.5	0.22	Numerous rills of different size (4-5 cm deep, 8-18 cm wide) over 20 m from collector
5	20	0.3-0.5	0.05	

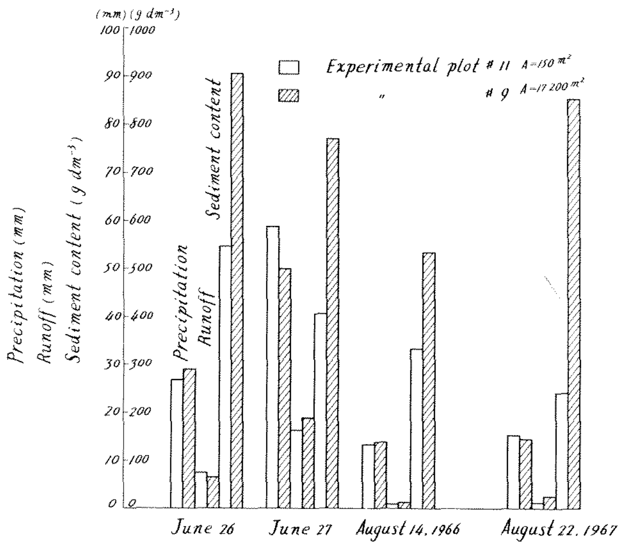

Fig. 3 Comparison of average sediment content produced by the same rainfall event on plots 11 and 9.

detaining the sediment but also in reducing gully erosion.

Hence, the addition of experimental plots extending over entire slope lengths and a comparison of the data collected from these with the data from plots covering entire slope areas and entire gullies will enable us to evaluate the overall effect of sediment detention resulting from soil and water conservation measures on the slopes.

As regards the size of the plots covering entire slope lengths, judgement should be made in accordance with local conditions. By no means should the size be the larger the better. Plots that are too large only bring about unnecessary increases in the demand for personnel, materials and equipment. Plot no. 7 established in 1961-1964 at the Zizhou runoff experimental station had an area of 4080 m^2 to cover the entire length of

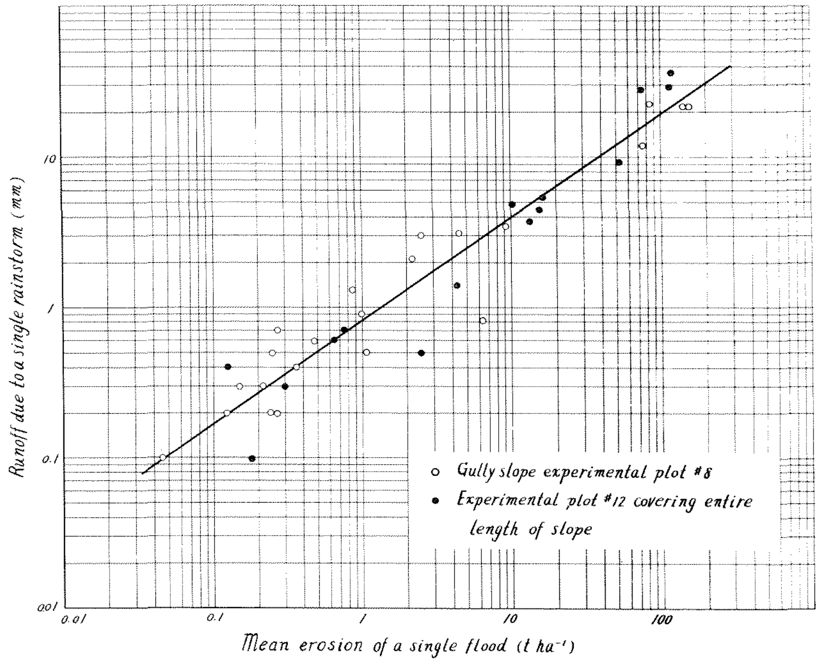

Fig. 4 Comparison of the relationship between runoff and sediment yield for the experimental plot covering the entire slope length and for the gully slope experimental plot.

slope. In 1965 an extension was made and the area was increased to 5740 m^2. The relationship between observed runoff and sediment yield remains the same for both plots (Fig. 5). This shows that the extension was unnecessary, but the problem requires further study.

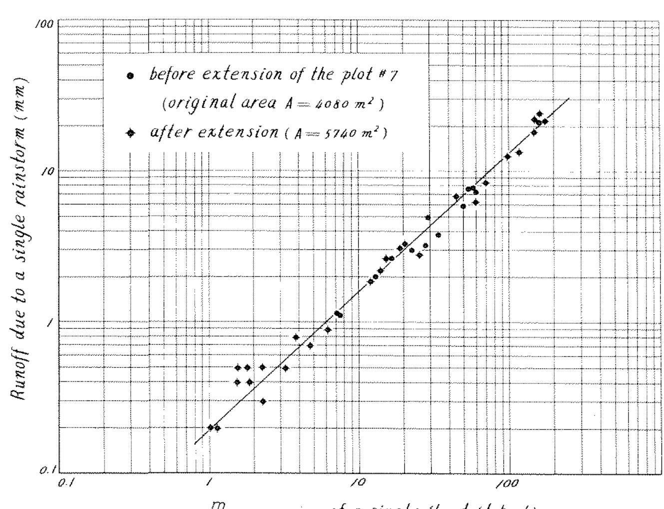

Fig. 5 The relationship between runoff and sediment yield before and after extension of plot 7, covering the entire slope length.

METHODS OF CALCULATING THE QUANTITY OF SEDIMENT DETAINED THROUGH CONSERVATION MEASURES

There are at present three ways to compute the quantity of sediment detention by conservation measures. All the methods are in general use in China.

The method of direct computation of the effect of individual measures of soil and water conservation (Mou Jinze & Xiong Guishu, 1980)
The method of superimposition is used here and the total quantity of sediment detained through various measures of conservation is taken as the sum of that detained through individual measures, or:

$$\Delta w_s = \Delta w_{sb} + \Delta w_{sg} = \Sigma M_{sb}\, a_i\, \eta_i + \Delta w_{sg}$$

where Δw_s = total quantity of sediment detained by various measures; Δw_{sb} = total quantity of sediment detained through measures taken on the slopes; Δw_{sg} = total quantity of sediment detained through measures taken in the gullies; M_{sb} = mean sediment yield from slopes; a_i = area of the slope on which a certain measure has been undertaken for slope improvement; η_i = index of sediment detention for the respective measure undertaken on the slope.

As the respective effects of individual measures for detaining sediment can be determined directly by using this method, it is accepted as the fundamental way of computing the quantity of sediment detained through conservation measures and is in general use in China today. However, the requirements of precision for practical purposes cannot be met unless the following problems have been properly solved.

(a) The amount of work required for conservation measures must be estimated. It includes the implementation of all types of control measures and information on the volume of work of the desired quality and the coordination and planning of various measures. These data are fundamental for applying the above method, but are rather hard to obtain, even for small basins of only several scores of square kilometres in area. The problem is more severe for large basins for which data collection and evaluation are extremely difficult to accomplish. This is the cause of large discrepancies in the results of computations.

(b) Another important problem lies in the accurate determination of the indices of sediment detention associated with various methods of controlling erosion on slopes, thus directly affecting the precision of the calculated results. At present, the indices are deduced from data collected from small experimental plots. With such small areas the distribution of rainfall is uniform, the landforms are homogeneous, the measures taken are intensive and the work carried out is of high quality. On the contrary, in the case of larger drainage basins the distribution of rainfall and of the measures employed will be uneven, the topography is complex, and the quality of the work is not so high. In addition, the detention effect of particular measures taken on small plots is quite different from that in larger basins.

Therefore, the precision of the computed results is questionable. Attempts have been made to introduce a certain reduction factor to improve the estimate, but as the problem is rather complicated, it is hard to make judgements appropriate to the actual conditions. The indices of sediment detention associated with gully stabilization are generally obtained by using data on the volume of deposits in reservoirs and silt-arresters. In practice, the base levels of erosion are raised through the construction of dams in the gullies, and consequently, erosion by hydraulic as well as by gravitational forces (such as slipping, slumping and earth flow) will be reduced. This is particularly so in regions where gully erosion predominates and will result in underestimation of the effect of conservation measures in the computation.

(c) The beneficial effects of soil and water conservation measures will vary depending on the intensity and duration of rainfall events. At present, however, observed data and statistics are lacking with respect to dam failure and other damage, so that the precision of the computed results is affected.

The correlation method of computation

The correlation of average rainfall over the drainage area with runoff and sediment content is established using hydrological data collected prior to the adoption of soil and water conservation measures. The transport of sediment resulting from a known rainfall can then be determined from the correlation analysis. The latter represents the sediment yield of a basin unaffected by conservation measures. This is compared with the sediment yield actually observed in order to show the effect of sediment detention through conservation measures.

As the correlation method is based on observed data, it gives results of acceptable precision and is often used to check out other computations. There are limitations, however:

(a) A long sequence of years of observation is required for the collection of hydrological and sediment data in a drainage area. This is hard to obtain for the numerous small and medium basins for which computations of sediment detention through conservation measures are to be carried out, because there are usually no gauging stations nearby.

(b) This method can only be applied to areas where a distinct correlation exists between rainfall and runoff and between discharge and sediment content. The relation between runoff and sediment content is relatively constant for the rolling loess regions in China, but the correlation between rainfall and runoff is weak. In general, soil and water conservation has not been practiced intensively in large and medium basins in China, with less than 20% of the sediment being detained in these basins. In such cases, the relative error will be much larger than 20% if the existing rainfall-runoff relations are used, so that it is difficult to tell whether the computed results are reliable.

(c) Only the overall effect of various conservation measures in the drainage area is determined and the influence of individual conservation measures remains unknown.

The method of comparison

A comparison is made between observed values of sediment yield for drainage areas already improved and those of adjacent basins of similar geomorphology but with no established control practices. The effect of sediment detention produced by measures applied in the basin is determined by estimation. However, this method also has its limitations:

(a) A similar basin with respect to climate, topography, soil properties etc. is needed for comparison. Furthermore, parallel hydrometric observations should be carried out in the two basins in question over a certain period of time before the measures are applied, so as to be sure that the two areas can be compared. In fact in most regions it is not easy to find two basins where conditions are similar in all respects.

(b) Only the overall effect of sediment detention through conservation measures over the entire area is determined.

A comparison of the results obtained by using the different methods

In order to study the applicability of each of the three methods described above, analysis and comparisons have been undertaken using data from the Jiuyuangou basin. Jiuyuangou is a first-order gully of the Wuding River in Shaanxi, in the gullied rolling loess region. The drainage area is 70.1 km^2. It is one of the focal points of basin improvement. Peijiamao is another similar gully adjacent to it, with a drainage area of 41.2 km^2. Before conservation measures were introduced the geomorphology of the two areas was alike. The effects of sediment detention produced by conservation measures applied to the Jiuyuangou basin, have been estimated using the three different methods (Table 3).

It can be seen that the difference in the computed results

Table 3 A comparison of results obtained by the three methods for computing the effect on sediment detention of conservation measures applied at Jiuyuangou

	Method	1962	1963	1964	Average
Sediment yield prior to control ($t\ km^{-2}$)	Method of individual measures	3047	11770	26830	13882
	Correlation method	3730	9870	32340	15313
	Method of comparison	3669	10300	33580	15850
Sediment yield observed after measures applied ($t\ km^{-2}$)		1296	6287	13900	7161
Reduction in sediment yield produced by sediment detention (%)	Method of individual measures	57.5	46.6	48.2	48.4
	Correlation method	65.3	36.3	57.0	53.2
	Method of comparison	64.7	39.0	58.6	54.8

is not large. This is the result of the long-term data available at Jiuyuangou and specialized personnel undertaking the scientific research and *in situ* investigations. For other basins this might not be the case. More work must be undertaken and the problem must be subject to further studies.

CONCLUDING REMARKS

(a) Small plots do not usually reflect the actual processes of soil erosion from a slope. A number of plots covering entire slope areas and with natural divides as boundaries are more representative than plots with artificial boundaries to provide an improved understanding of soil erosion and runoff processes.

(b) It is necessary to establish experimental plots extending over entire slope lengths in order to comply with the particular physical features of the gullied rolling loess regions in the Yellow River basin.

(c) The method of direct computation of the effect of individual measures of soil and water conservation is at present most often used in China for calculating the effect of conservation measures on sediment detention. Reliable statistical data concerning the volume of conservation work should be available, and the indices of sediment detention and the factor of dam failure and other damage should be determined correctly so as to achieve the desired degree of precision in the computed results.

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