Soil loss and crop productivity model in humid subtropical India

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The process of soil erosion leads to a huge amount of soil loss in humid subtropical India in both qualitative and quantitative terms and thus leads to low crop productivity. For the protection of land from soil erosion and to meet the increasing demand for food, it is imperative to locate and measure the type, degree and severity of soil erosion for proper planning to conserve or opt for alternative uses. The present work is a case study to describe the soil erosion and productivity model in one of the northeastern states of India, which represents humid subtropical climate. The model describes the relation between the topsoil loss due to erosion and the level of productivity. The study also allows the estimation of the tolerable soil loss, keeping in view the limit to permit crop productivity decline for a group of soils with specified depth range.

Keywords: Crop productivity, soil erosion, topsoil loss, tolerable soil loss.

EROSION by water has been considered as the most serious soil degradation problem in the humid tropical and subtropical India. Dhruvanarayana and Ram Babu[1] analysed the existing soil loss data of the entire country and indicated that soil erosion has been taking place at an average rate of 16.35 t ha^{-1} yr^{-1}, totalling an annual loss of 5334 million tonnes. Nearly 29% of the total eroded soil is permanently lost to the sea and nearly 10% is deposited in reservoirs, resulting in the reduction of their storage capacity by 1 or 2% annually. The remaining 61% of the eroded soil is transferred from one place to another. Rainfall erosivity, soil erodibility, topography, vegetative cover, management and conservation practices are the major factors affecting soil erosion. Erosion takes place in the form of sheet, rill and gullies. Sheet erosion takes place on slopes due to overland flow. Rills form in the areas where overland flow concentrates. Excess concentration of flow results in gully erosion. On decreasing slopes of overland flow, eroded materials get deposited. Total erosion in the form of sheet, rill and gullies is termed as gross erosion. Sheet and rill erosion from a unit area of a field at a specified slope is defined as soil loss. Singh *et al.*[2] reported the annual water erosion rate values from less than 5 t ha^{-1} yr^{-1} (for dense forests, snow-clad deserts, and arid regions of western Rajasthan) to more than 80 t ha^{-1} yr^{-1} in the Shiwalik hills. Ravines along the banks of the rivers Yamuna, Chambal, Mahi, Tapti and Krishna, and the shifting cultivation regions of Orissa and the northeastern states indicated a soil loss exceeding 40 t ha^{-1} yr^{-1}. The annual erosion rate in coastal regions of the Western Ghats representing humid tropical climate varied from 20 to 30 t ha^{-1} yr^{-1}. The soils, mainly supporting rainfed agriculture, are subject to severe sheet and rill erosion with an annual soil loss of 20–100 t/ha (ref. 1).

The northeastern states of India represent humid subtropical climate. These states have severe problem of soil-water erosion because of prevalent practices of shifting cultivation (jhumming). In the past, the practice of jhumming worked well because of long fallow cycle (20–30 years). But due to increasing population pressure, the cycle has been narrowed to 3–6 years and thus aggravated the degradation problems due to erosion. Forest tree-cutting, burning, clearing and dibbling of seeds cause nearly 4.1 t ha^{-1} of soil loss. Soil erosion from hill slopes (up to 60–70%) during the first, second and third years has been reported to be 146.6, 170.2, 30.2 t ha^{-1} yr^{-1} respectively[3].

The loss of soil due to erosion varies from different land uses in addition to quality of soil and intensity of climatic parameters, especially rainfall and temperature. Since soil erosion is the major reason for soil loss and consequent decline in soil productivity, it becomes imperative for the land-use managers and land-use planners to adopt appropriate soil conservation measures to check this. The type of soil conservation measure again depends on the degree of soil erosion. Thus, it becomes more important to know the amount of soil loss due to erosion. Erosion data have inherent limitations that should be recognized by both resource managers and researchers. Variability, often quite extreme, is characteristic of run-off and soil loss data, and thus sometimes leads to apparently conflicting results. A short-term local plot study does not explicitly evaluate the erosion hazard or treatment effects for an entire landscape. In a one-location study, the effects of rainfall, soil

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and slope characteristics can rarely be separated because these parameters usually occur at the same levels on all plots in the series or vary in unison. Also, many relevant secondary variables cannot be controlled under natural conditions. Some of these vary randomly over time. Some show seasonal or long-term trends, but fluctuate unpredictably for short time-periods. The positive and negative effects of random variables and their interrelation thus balance each other over long time-periods. These limitations were alleviated since grid observations (5 km × 5 km) of about 200 numbers in an area of approximately 100,000 ha in Tripura were considered to capture the actual scenario of soil erosion.

The present study explains the development of a regional-level methodology for estimation of actual soil loss in Tripura. It explains a soil loss and crop productivity model to estimate tolerable soil loss. It also demonstrates how topsoil loss can be converted into productivity loss to estimate soil conservation needs.

Materials and methods

Datasets in terms of physical and chemical properties of soils and the site characteristics for the 5 km × 5 km grid points for Tripura were used for the present work[4–6].

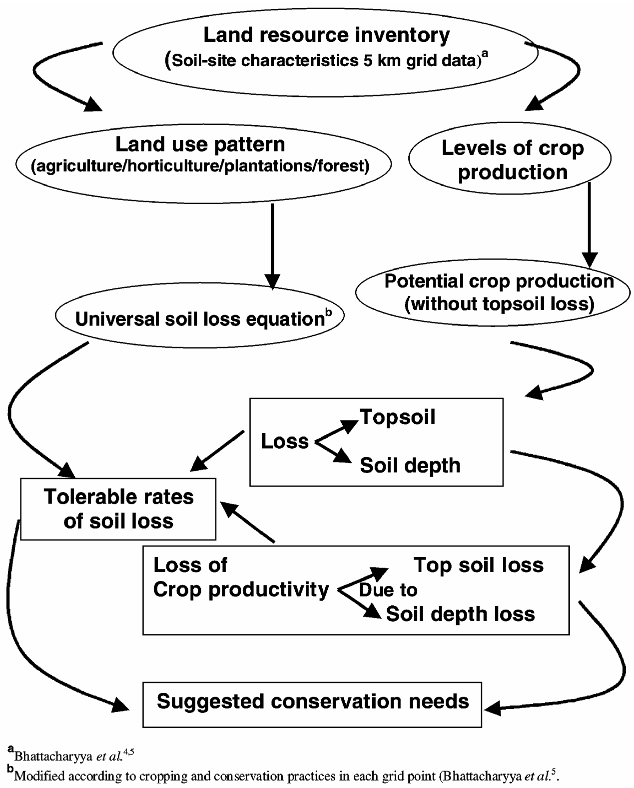

Figure 1. Soil loss and crop productivity model for suggested conservation needs in Tripura (adapted from Kassam *et al.*)[6].

The soil loss and crop productivity model methodology[7] has been modified for the study area (Figure 1). The method involves the following steps:

(a) Identification of land-use patterns and systematization 5 km × 5 km of grid points (200 grid points with nearly 2500 ha of each) in terms of soil-site characteristics. Most of the land in Tripura is under forest and agriculture. The other important land-use patterns include forests and plantations. Rubber is by far the most important plantation crop in Tripura. The other plantation crops include coffee and tea[4,5].

(b) Determination of various factors for universal soil loss equation (USLE) namely rainfall erosivity factor (R), soil erodibility factor (K), length and steepness of slope factor (LS), vegetation and crop cover factor (C) and soil conservation factor (P). To calculate soil loss, C and P have been specially looked into for each grid point. And thus the field observations for each grid point have been utilized for fixing the limits for C and P factors[5].

(c) Quantification of soil loss through erosion following USLE[8–10].

(d) Finding the relationship equation between loss of yield and loss of topsoil to group each grid point according to its susceptibility of loss of yield due to loss of soil by erosion.

(e) Application of the above relationship equation to estimate productivity loss in relation to productivity potential as quantified from the land-use productivity model.

(f) Estimate of productivity and tolerable soil loss.

In the model, the estimate is based on short-term losses in crop production due to loss of fertile topsoil, and long-term losses in land productivity due to reduction of overall depth of the soil profile. The model variables in the form of various land uses (Table 1) indicate permissible slopes under different levels of inputs[7]. The critical slope values in the slope–land use association indicate the upper slope limit to cultivation, and these limits are subject to modification depending on field conditions. The soil loss reduces the water-holding capacity, nutrient-holding capacity and finally the anchorage is affected, which decreases crop yield. In a specified number of years, viz. 25, 50 or 100, the acceptable rate of soil erosion is considered that does not result in a crop yield reduction of more than a specified amount due to loss of fertile topsoil; and does not result in more than a specified proportion of land being downgraded to a lower class of agricultural suitability due to soil depth reduction. Since the above two criteria are not interdependent, the acceptable rate of soil loss is taken as the lower of the two alternatives. The model, therefore, provides an opportunity to assess tolerable soil loss keeping in view its likely impact on crop yields and the future availability of cultivable land. The soil erosion and pro-

Table 1. Slope–land use association limits

Land use	Input levels (% slope)		
	Low	Intermediate	High
Wetland crops (with soil conservation)[a]	<30	<30	<30
Wetland crops (without soil conservation)	<5	<5	<5
Coffee, tea, rubber (with and without soil conservation measures)	<45	<45	<45

[a]Field bunding is commonly practised in Tripura for wetland crop, viz. paddy. For ~30% slope terracing is required for paddy cultivation.

ductivity model is linked to crop productivity, which provides assessments of land suitabilities and the associated yield potentials for the estimation of tolerable soil loss.

Results and discussion

Crop yield and loss of topsoil

The degree and extent of loss of crop yield vary from soil to soil since the loss of topsoil depends on various factors. Besides, since the soil properties in terms of their influence on crop performance vary, loss of topsoil will affect different degrees of loss of crop yield. It may be mentioned that loss of crop yield due to loss of topsoil may be compensated by the use of manures and fertilizers. At the same time, loss of topsoil by soil erosion is also compensated by the formation of new soil through pedogenesis. It is, therefore, interesting to observe that the processes of soil formation and soil erosion occur simultaneously in nature. To calculate loss of topsoil it is necessary to take into account the amount of soil regenerated, keeping in view the difference in the rate of soil formation under different types of climatic conditions.

The rate of soil formation has been reported to vary from <0.25 mm/yr^{-1} in dry and cold environments to >1.5 mm yr^{-1} in humid and warm environments[7]. Topsoil formation at the rate of 1 mm yr^{-1} is equivalent to an annual addition of 13.3 t ha^{-1}, taking into account the weight of a hectare-furrow slice (15 cm depth) soil as 2.2×10^6 kg. Since Tripura represents a humid climate, the limit of 2.0 mm soil formation should be equivalent to an annual addition of $(2.2 \times 10^3/150) \times 2.0 = 29$ t ha^{-1} soil. The rate of top-soil formation has been considered in assessing soils at various grid points in terms of their susceptibility and to develop six limits to assess the soil erosion status (Table 2).

On the basis of available data[4], the soils of each of the grid points have been classified in terms of their susceptibility to productivity loss of topsoil, and the presence of other unfavourable subsoil conditions. These rankings of susceptibility of the soils are related to actual yield losses, and by input levels which are as shown through a set of linear equations (Table 3)[7]. The reduced impact of topsoil loss under intermediate and high levels of input is due to the compensating effect of fertilizers, which is less on the more susceptible soils because of their more unfavourable subsoil condition.

Table 2. Soil loss of Tripura and its extent

Class	Soil loss (t ha^{-1} yr^{-1})	Area	
		Hectares	Percentage
Slight	<5	430,131	41
Moderate	5–10	216,115	21
Moderate–severe	10–20	147,923	14
Severe	20–40	68,192	6
Very severe	40–80	90,223	9
Extremely severe	>80	96,517	9

Table 3. Relationship between topsoil loss and yield loss

Soil susceptibility	Input level	Yield loss (*y*; %)
Least susceptible	Low	$y = 1.0x$
	Intermediate	$y = 0.6x$
	High	$y = 0.2x$
Intermediate susceptible	Low	$y = 2.0x$
	Intermediate	$y = 1.2x$
	High	$y = 0.4x$
Most susceptible	Low	$y = 7.0x$
	Intermediate	$y = 5.0x$
	High	$y = 3.0x$

x = topsoil depth (in cm). If x = 25 cm, then in least susceptible soils with low input, yield loss will be 25% as against 50 and 175% in case of intermediate and most susceptible soils with low inputs.

The tolerable loss rate for a given soil unit and specified amount and timescale of yield reduction was calculated in the model following the equation[7]:

$$TL = \frac{\{(Ra/Rm \times 100B \times Dt) + 3T\}}{T}, \quad (1)$$

where TL is the tolerable loss rate (t ha^{-1} yr^{-1}), Ra the acceptable yield reduction (%), Rm the yield reduction (%) at the given input level when the effective topsoil is lost, B the bulk density of soil (Mg m^{-3}), Dt the depth of effective topsoil (cm) and T the time (years) over which reduction is acceptable.

Crop yield as influenced by soil depth

It has been reported that the rate of soil formation by rock weathering is extremely slow, up to 0.025 mm/yr^{-1} on volcanic rocks in humid areas, and <0.01 mm/yr^{-1} on rock formations in the semi-arid and arid areas[11] characterized by an annual rainfall of <1000 mm. Even if a high degree of weathering is taken into account, it might take 4000 years to produce 10 cm of soil[11]. It is in view of this fact that the rate at which rocks weather to form soils, has not been considered as a factor in the model[7] in assessing tolerable soil losses in Tripura.

Estimation of the effect of soil-depth reduction is based on the assumption that there is no significant loss of productivity until the soil becomes so shallow that shortage of moisture becomes a limiting factor for crop growth. Critical depth is reached when the productivity loss is linear, since the soil becomes too shallow to produce any crop at all[12]. The yield potential could be equated with soil suitability (Table 4), where soil depth becomes a limiting factor, thus limiting the availability of soil water. In other words, the soil suitability classes, viz. HS, S, MS, mS and NS correspond to yield levels of >80, 60–80, 40–60, 20–40 and <20% of maximum attainable yield respectively (Table 4).

It is presumed that the end result of uniform soil erosion will make the soils non-productive or marginally productive, depending on the depth of the soils. It is, therefore, possible to find out the tolerable amount of soil loss when the depth of the soil is known. To calculate the tolerable soil losses, soil-depth reduction may be measured in terms of proportion of the soils in an area that will be shallower than a given depth due to erosion. The soil map of Tripura[4] indicates five depth classes, viz. shallow (<25 cm), moderately shallow (25–50 cm), moderately deep (50–100 cm), deep (100–150 cm) and very deep (>150 cm). The rate of soil loss is related to the proportion of land whose soil has become shallower than a specified depth by the following equation[7]:

$$P = \frac{SL \times T}{B \times Dr}, \quad (2)$$

where *P* is the proportion of land downgraded to at least the next depth class (%; for example, moderately deep (50–100 cm) to moderately shallow (25–50 cm), SL the soil loss (t ha^{-1} yr^{-1}), *T* the time (years), *B* the bulk density of the soil (Mg m^{-3}), *Dr* the depth range of the soil class (in cm; 25 cm for shallow and moderately shallow, and 50 cm for other soil classes). Setting a limit of $P = 10\%$, $T = 100$ years and $BD = 1.3$ in eq. (2), we find that $SL = 0.13 \times Dr$. Thus depending on the permissible limit of minimum 25 cm soil depth to allow crop production, the *Dr* values will vary with the different depth classes as 25 cm (50 – 25 = 25 cm) for shallow (<25 cm) and moderately shallow (25–50 cm), 75 cm (100–25 = 75 cm) for moderately deep (50–100 cm), 125 cm (150 – 25 = 125 cm) for deep (100 – 150 cm) and 150 cm (175 – 25 = 150 cm taking soil depth as minimum 175 cm) for very deep soils (> 150 cm) respectively. The *SL* values accordingly may be worked out as 0 (since the soil depth is <25 cm, these soils will not tolerate any topsoil loss for sustainable crop production) for shallow, 3.25 for moderately shallow, 9.75 for moderately deep, 16.25 for deep, and 19.50 t ha^{-1} yr^{-1} for very deep soils respectively.

Table 4. Soil suitability ratings and yield potential in Tripura

Soil suitability rating	Decrease in yield potential (%)
Highly suitable – suitable (HS–S)	20
Suitable – moderately suitable (S–MS)	40
Moderately suitable – marginally suitable (MS–mS)	60
Marginally suitable – not suitable (mS–NS)	80

Topsoil loss and soil depth reduction vis-à-vis tolerable soil loss

It, therefore, appears that estimation of tolerable soil loss could be done (i) through values of yield loss that can be tolerated, or (ii) the proportion of land (in %) that can be allowed to make the depth of soil shallower at least by one soil depth class over a specified time period. It has been found that these two ways to estimate soil loss do not produce the same values. As a matter of fact, the tolerable soil loss calculated through the second method (eq. 2) often produces a lower estimate. Following eq. (2), the proportions of land downgraded may be calculated. For example, from shallow (<25 cm) to bed rock (0 cm) soil depth class, at a moderate rate of erosion ($SL = 5$ t ha^{-1} yr^{-1}), with $T = 100$ years, $BD = 1.3$ mg m^{-3} and $Dr = 25$ cm, the proportion of land downgraded (*P*) is 15%. Again, at an accelerated rate of erosion ($SL = 50$ t ha^{-1} yr^{-1}), with similar values of *T*, *BD* and *Dr*, the proportion of land downgraded may be estimated as 154%. Since at 100% loss, no soil will exist, a *P* value of 100 will be accepted. It is thus observed that for shallow soils, at an erosion rate of 5 t ha^{-1} yr^{-1}, Tripura will lose 15% land over a 100-year period. It is obvious that a deep soil will lose less proportion of land at this rate of erosion. Thus, a very deep soil will be degraded to deep soil at an erosion rate of 2 t ha^{-1} yr^{-1} over 100 year period and will lose only 2% land (Table 5).

Estimation of tolerable soil loss

Combining the information gathered on topsoil loss (*SL*) and proportion of land degraded (*P*), the tolerable soil loss (*TL*) may be calculated. As has been mentioned earlier that the criteria for estimating tolerable soil loss (*TL*) have been decided keeping in view the tolerable yield

Table 5. Proportion of land downgraded from given depth classes due to soil loss in Tripura (over a 100 year period)

Soil depth class and change (cm)	Amount of land lost (% of class)[a] at erosion rates (t ha^{-1} yr^{-1})							
	5[b]	10	25	50	75	100	200	400
From shallow (<25 cm) to bedrock (0)	15	31	77	100				
From moderately shallow (25–50 cm) to shallow (<25 cm)	15	31	77	100				
From moderately deep (50–100 cm) to moderately shallow (25–50 cm)	5	10	26	51	77	100		
From deep (100–150 cm) to moderately deep (50–100 cm)	3	6	15	31	46	61	100	
From very deep (>150 cm) to deep (100–150 cm)	2	4	11	22	33	44	88	100

[a]*P* values in eq. (2); [b]SL values in eq. (2) as 5, 10, 25, 50, 75, 100, 200 and 400 t ha^{-1} yr^{-1}.

Table 6. Tolerable soil loss (t ha^{-1} yr^{-1}) equivalent to 10% *P* of the proportion of land downgraded and >50% reduction in crop yield at low input level[a] over 100 years (calculation assumes a minimum of 25 cm soil depth for crop production)

Soil susceptibility	Low *Rm* = 25%		Intermediate *Rm* = 50%		High *Rm* = 175%	
Soil depth class (depth, cm)						
Shallow[b] (<25)	0		0		0	
Moderately shallow (25–50)	3.25[c]	(68)[d]	3.25	(35.5)	3.25	(12.3)
Moderately deep (50–100)	9.75	(68)	9.75	(35.5)	9.75	(12.3)
Deep (100–150)	16.25	(68)	16.25	(35.5)	(16.25)	12.3
Very deep (>150)	19.50	(68)	19.50	(35.5)	(19.50)	12.3

[a]We have made estimates at low input level for Tripura (also see Table 3).
[b]Depth of shallow soils is <25 cm, which is the minimum requirement for crop production (according to this model). Therefore, soil loss will be nil.
[c]For moderately shallow depth soils (25–50 cm) and low soil susceptibility (25%, also see Table 3, with *P* = 10%, *Dr* = 25 cm, *T* = 100 yrs and *BD* = 1.3 mg m^{-3}, *SL* = soil loss is estimated as 3.25 t ha^{-1} yr^{-1} (also see eq. (2)).
[d]For moderately shallow depth soils (25–50 cm) and low soil susceptibility (25%, also see Table 3), with acceptable 50% crop yield reduction (*Rm*), 25 cm depth of effective topsoil (*Dt*) of 1.3 Mg m^{-3}, bulk density *B* for 100 yrs (*T*), tolerable soil loss (*TL*) is estimated as 68 t ha^{-1} yr^{-1} (also see eq. (1)).
Note: Since eq. (2), in general, gives the lower value of tolerable soil loss it is accepted. The corresponding values using eq. (1) for intermediate and high soil susceptibility classes are 35.5 and 12.3 t ha^{-1} yr^{-1} respectively, which are higher than the value (3.25 t ha^{-1} yr^{-1}) obtained using eq. (2). For deep and very deep soils, under high susceptibility soil class, the values obtained using eq. (1) are lower (12.3 t ha^{-1} yr^{-1}) and hence accepted. In general, parentheses values are higher and so not accepted as tolerable soil loss.

loss or in other words, the proportion of soil/land (*P* in eq. (2)) that can be permitted to become shallower than a specified depth over a specified time (*T* fixed as 100 years). Since the two bases for soil loss estimation do not produce the same result, the acceptable tolerable soil loss should be the lower estimate among the two. Taking into account 50% crop yield reduction and a soil depth reduction resulting in downgrading of 10% of each depth class, an estimate of tolerable soil loss has been made for different soil depth classes in Tripura over a period of 100 years (Table 6).

Table 7. Total annual soil loss in Tripura

Erosion class	Range (t ha^{-1} yr^{-1})	Soil loss (million tons) yr^{-1}
Slight	<5	–2.15
Moderate	5–10	–1.62
Moderately severe	10–20	–2.22
Severe	20–40	–2.04[a]
Very severe	40–80	–5.41[a]
Extremely severe	>80	–7.72[a]
Total		21.16
Effective soil loss	–	15.17

[a]Considered to estimate effective soil loss every year.

Total soil loss by erosion

Soil erosion is one of the major environmental concerns. The consequences of soil erosion have often led to debates generating two schools of thought[13]. The environmentalists believe that accelerated erosion is a cancer on precious natural resources like land, which declines soil productivity and causes environmental pollution. The amount of soil erosion has also been found to be alarming, therefore, seeking immediate attention for soil conservation. The second group is of the view that the soil erosion data are drastically exaggerated.

It should be mentioned that the estimates appear exaggerated when factual information is scarce. To make the generated information more factual, the huge datasets of Tripura have been utilized[4–6,14,15]. The realistic soil erosion datasets thus appear to be more useful for soil-conservation measures. In Tripura, totally seven classes of soil-erosion were identified. Taking the median values of the soil erosion range, the total soil lost under different erosion classes was estimated (Table 7). As mentioned earlier, there is an estimated annual addition of 29 tons soil in a hectare in Tripura. It is in view of this, the soil erosion class indicat-

Table 8. Estimation of conservation need through soil loss values (for moderately deep soils)

Year	Land use	Soil loss (t ha^{-1}) Annual	Total	Conservation need (*P* factor)
1–4	Fallow	4[a]	16	0.37
5	Crop – 1st year	12[a]	12	
6	Crop – 2nd year	18[a]	18	
7–10	Crop – 3rd to 6th year	25[a]	100	
Total soil loss over 10 years			146	
Tolerable rate of soil loss		9.75[b]	97.5	

[a]Adapted from Kassam *et al.*[7]. [b]For moderately deep soils in Tripura (see Table 6).

ing ≤ 29 t ha^{-1} yr^{-1} has not been considered while computing the effective soil loss. The annual loss of soil has thus been estimated as nearly 15 million tonnes every year (Table 7).

Application of soil erosion and productivity model

While applying the soil loss and crop productivity model (Figure 1), potential erosion losses for each desired land use may be evaluated assuming that no specific soil conservation measures are applied, which, in other words, indicates that the protection factor (*P*) is one. These results could be compared with what are considered as acceptable rates of soil loss under three levels of input (low, intermediate and high; Table 1), which are followed for estimation of the required conservation need and their associated costs.

The soil conservation need is estimated as the protection factor (*P*) when lands are not under any conservation programmes. The average rate of erosion covers both the cultivated and the uncultivated parts of the crop and fallow-period cycle. Estimation of conservation need shows that the required soil loss reduction is 48.5 t ha^{-1} (146–97.5 t ha^{-1}). In land under cultivation, the total soil loss over 6 years is 130 t ha^{-1} (12 + 18 + 100 t ha^{-1}). Therefore, the conservation need (*P* factor) required to achieve this is 48.5/130 = 0.37 (Table 8).

Conservation measures

Soil conservation helps achieve three types of benefit: (a) long-term reduction in checking the decline of agricultural production; (b) gradual increase in agricultural production, and (c) other nonagricultural benefits such as improved flow to river during summer, reduction in periodicity and severity of flooding, reduction in siltation of reservoirs, reduction in damage of various costly infrastructure, and low harmful impacts on farm lands.

In Tripura many areas in the higher and middle elevations are under forest (58% TGA)[4]. The tilla lands and the lower foothills are used for plantation of rubber and/or for agricultural and horticultural crops. These lands are highly susceptible to soil erosion, and therefore require soil conservation measures such as bench-terracing. Most of the areas showing nearly 15 million tons soil erosion every year (Table 7), occupy the degraded uplands and forest areas used for jhumming. In rainfed areas like Tripura, terraces may be constructed on slopes ranging from 6 to 33%. It has been reported that the value of supporting conservation practice (*P* factor) using bench terracing technique (0.5% longitudinal gradient, 2.5% inward gradient) is quite low (0.027) for very deep red soils in Ooty hills[16], with a slope of 25%. Judging by similar terrain conditions, such efforts could be recommended for Tripura. However, appropriate techniques could be evolved by the conservation experts.

Besides mechanical conservation measures, it may be mentioned that the tilla lands and part of the degraded lands with shrubs and bushes become exposed to erosion due to lack of vegetation. These areas need proper afforestation programmes. Earlier, part of these areas was recommended to be brought under rubber cultivation and other plantation and horticultural crops[4,15]. Such practice will be doubly beneficial since it will save the loss of the most valuable natural resource like soil and would also generate income source among the local people.

1. Dhruvanarayana, V. V. and Ram Babu, Estimation of soil erosion in India. *J. Irrig. Drain. Am. Soc. Civ. Eng*., 1983, **109**, 419–434.
2. Singh, G., Ram Babu, Bhushan, L. S. and Abrol, I. P., Soil erosion rates in India. *J. Soil Water Conserv*., 1992, **47**, 97–99.
3. Singh, A. and Singh, M. D., Effects of various stages of shifting cultivation on soil erosion from steep hill slopes. *Indian For*., 1978, **106**, 115–121.
4. Bhattacharyya, T., Sehgal, J. and Sarkar, D., Soils of Tripura for optimizing land use: Their kinds, distribution and suitability for major field crops and rubber. NBSS Publ. 65a and c (Soils of India series 6), NBSS&LUP, Nagpur, 1996, p. 154.
5. Bhattacharyya, T., Ram Babu, Sarkar, D., Mandal, C. and Nagar, A. P., Soil erosion of Tripura, a model for soil conservation and crop performance. NBSS Publ. No. 97, NBSS&LUP, Nagpur, 2002, p. 80 + 1 sheet of map (1 : 250,000 scale).
6. Bhattacharyya, T., Sarkar, D., Dubey, P. N., Ray, S. K., Baruah, U. and Sehgal, J., Soil Series of Tripura, NBSS Publ. No. 111, NBSS & LUP, Nagpur, 2004, p. 115.

7. Kassam, A. H., van Velthuizen, G. W., Fischer, G. W. and Shal, M. M., Agro-ecological land resources assessment for agricultural development planning. A case study of Kenya resources data base and land productivity. Land and Water Development Division, Food and Agriculture Organisation of the United Nations and International Institute for Applied Systems Analysis, Rome, 1992.
8. Musgrave, G. W., The quantitative evaluation of factors in water erosion, a first approximation. *J. Soil Water Conserv*., 1947, **2**, 133–138.
9. Wischmeir, W. H. and Smith, D. D., Predicting rainfall-erosion losses from cropland east of the Rocky Mountains – Guide for selection of particles for soil and water conservation. Agricultural Handbook No. 282, USDA, 1965.
10. Wischmeir, W. H. and Smith, D. D., Predicting rainfall-erosion losses – A guide to conservation. planning. Agricultural Handbook No. 537, USDA, 1978.
11. Dunne, T., Dietrich, W. E. and Brmengo, M. J., Recent and past rates of erosion in semi-arid Kenya. *Z. Geomorphol. Suppl*., 1978, **29**, 99–100.
12. Wiggins, S. L. and Palma, O. G., Cost-benefit analysis of soil conservation. Project Report 104, Land Resources Development Centre, England, 1980.
13. Lal, R. (ed.), *Soil Erosion Research Methods*, Soil and Water Conservation Society (Anxens, Iowa), International Society of Soil Science. Subcommission for Soil Conservation and Envionment, 1988, p. 244.
14. Bhattacharyya, T. *et al.*, Soils of Tripura – I. Their taxonomy and general characteristics. *Agropedology*, 1997, **8**, 47–54.
15. Bhattacharyya, T. *et al.*, Soils of Tripura – II. Suitability for rubber. *Agropedology*, 1997, **8**, 55–60.
16. Tejwani, K. G., Gupta, S. K. and Mathur, H. N., *Soil and Water Conservation Research*, *1956–71*, Indian Council of Agricultural Research, New Delhi, 1975.

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