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Determination of yield and erosion damage functions using subjectively elicited data: application to smallholder tea in Sri Lanka

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Tea has been Sri Lanka's major export earner for several decades. However, soil erosion on tea-producing land has had considerable on-site and off-site effects. This study quantifies soil erosion impacts for smallholder tea farms in Sri Lanka by estimating a yield damage function and an erosion damage function using a subjective elicitation technique. The Mitscherlich-Spillman type of function was found to yield acceptable results. The study indicates that high rates of soil erosion require earlier adoption of soil conservation measures than do low rates of erosion. Sensitivity analysis shows the optimum year to change to a conservation practice is very sensitive to the discount rate but less sensitive to the cost of production and price of tea.

1. Introduction

Soil erosion is a widespread problem in many countries of the world and policy-makers are deeply conscious that soil erosion needs immediate attention. Some argue that agricultural support policies have encouraged over-intensive use of the soil resource (Grepperud 1995). Clarke (1992) posits that investment in soil conservation measures will increase when product prices are favourable and economically viable conservation technologies are available. LaFrance (1992) concludes that where both the cultivation intensity and the level of conservation activity respond to market forces, policies that subsidise crop prices or the prices of inputs, such as irrigation water, may contribute to land degradation. Coxhead and Jayasuriya (1995) have shown that trade policy reforms reduce environmental degradation under plausible parameter values. In the developing countries, poverty is a major cause of soil degradation when farmers are compelled to cultivate fragile soils to subsist (Lonergan 1993).

The costs of soil erosion are difficult to determine but existing studies indicate them to be high. The annual total costs of soil erosion in Java have been estimated at US$340–406 million, around 0.5 per cent of total GDP

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(Magrath and Arens 1989). In Sri Lanka, losses due to soil erosion in the Nuwara Eliya district were assessed at Rs. 814 million per year (Abeygunawardena and Samarakoon 1993). Land degradation has been estimated to cost Australia over A$2 billion in lost agricultural production per year (Chisholm 1992).

To formulate effective erosion control policies, the bio-physical causes and the economic effects need to be examined critically. Research should broaden its scope to unravel the complex relationships that exist between soil erosion, crop yields and economic loss (Thampapillai and Anderson 1994). To date, most research on the impact of erosion on crop yields has been largely confined to the United States, Canada and Australia (Miranowski 1984; van Kooten *et al.* 1989). Most studies use data from field plot trials, artificial desurfacing or published time series data to assess economic and social losses. These approaches are time-consuming and expensive, especially for developing countries. This article examines soil erosion among tea smallholders in Sri Lanka using a subjective elicitation procedure.

The specific objectives of this article are to:

(a) develop a yield and an erosion damage function using subjective data;
(b) evaluate the effects of soil erosion on yield using the above function;
(c) evaluate the optimal time to switch to non-erosive practices; and
(d) evaluate the impact of selected erosion control policy variables.

2. Yield and soil erosion damage functions

Yield and erosion damage functions provide critical information for evaluating the impact of soil erosion. The development of these functions is severely constrained by a number of factors, especially the availability of relevant data. The estimation of these functions is discussed in the following sections.

2.1 Yield damage functions

A yield damage function shows the relationship between crop yield and some parameter of soil erosion. Most yield damage functions have used yield as the dependent and topsoil depth as the independent variable. Smith and Shaykewich (1990), using plot experiment data, found that the relationship is linear at the initial topsoil depth levels, and as the thickness of the topsoil declines, the relationship takes a non-linear form. Lal (1987) developed an exponential function for maize and cowpea in Nigeria, using five years' data on run-off plots with cumulative soil loss as the independent variable.

Various functional forms have been used to fit yield functions. The Mitscherlich-Spillman (M-S) function has found favour in a number of applications to describe the soil loss–yield relationship. Pawson *et al.* (1961)

used the modified M-S function to describe the relationship for wheat and pea in the Palouse area of the United States, incorporating both soil depth and organic matter content as explanatory variables. Segarra and Taylor (1987) analysed soil erosion using subjectively elicited data in the Piedmont area of Virginia for tobacco, barley, wheat and corn and applying equation (1):

$$Y_t = a + b(1 - R^{Dt}) \tag{1}$$

where, Y_t is crop yield in time t, a is the per acre crop yield (theoretical) when topsoil depth is zero; $a + b$ is the asymptotic value of crop yield when $\lim D_t \to \alpha$; R is the constant ratio of marginal product of the topsoil depth in time $t + 1$, D_{t+1} to marginal product of the topsoil depth in time t, D_t. They demonstrated that the subjective elicitation procedure produced similar results to the plot-regression analysis approach for soybeans. Gunatilake and Abeygunawardena (1993) examined the crop yield–soil loss relationship for tobacco, capsicum and carrot in Hanguranketha, Sri Lanka, using subjectively elicited soil depth information.

The choice of functional form for this study was influenced by data availability. Erosion data based on direct physical measurement generally do not exist for smallholder farms. The M-S function which has only modest data requirements was hence preferred. Subjective approaches can be further justified since farmers make important decisions on the basis of their perceptions. Saliba (1985) points out that while erosion-productivity research is relevant to economists investigating farmers' conservation incentives, it is not state-of-the-art models that influence actual conservation decisions but the farmers' perceptions of crop yield reduction resulting from varying rates of soil loss.

2.2 Erosion damage function

An erosion damage function incorporates the economic consequences of soil erosion to the farmer through a yield damage function. Walker (1982) defined the damage function as the difference between the present value of net revenue streams of erosive farming practice, π_e, and a non-erosive (conservation) practice, π_c, as given in equation (2):

$$\delta_t = \pi_e - \pi_c \tag{2}$$

where δ_t is the value of the damage function in year t. The private profitability of choosing the erosive (conventional) practice for the current year and postponing adoption of the conservation practice for another year, π_e, is given in equation (3):

$$\pi_e = P \cdot Y_e(t, D_{t-1}) - C_e(t, D_{t-1}) + \sum_{i=1}^{T-1} \frac{P \cdot Y_c(t+i, D_t) - C_c(t+i, D_t)}{(1+r)^i} \tag{3}$$

where P is price of the product; Y_e, crop yield with erosive practice as a function of topsoil depth and time; Y_c, projected crop yield with conservation practice; D_t, topsoil depth at the end of year t; C_e, variable cost of production with erosive practice; C_c variable cost of production with conservation practice; T, time horizon; and r is the real private discount rate. Time and topsoil depth are explicit arguments in the yield and cost functions. The private profitability of the erosive practice in the decision year is equal to the present value of the net revenue stream from conventional tillage again in the current year, and in each succeeding year over the time horizon. Equation (4) expresses the present value of the net revenue stream from using the conservation practice in the current year, and in each succeeding year:

$$\pi_c = P \cdot Y_c(t, D_{t-1}) - C_c(t, D_{t-1}) + \sum_{i=1}^{T-1} \frac{P \cdot Y_c(t+i, D_{t-1}) - C_c(t+i, D_{t-1})}{(1+r)^i} \qquad (4)$$

The present value of the net revenue stream in equation (3) is compared with the present value of the net revenue stream for switching to the conservation practice in the current year, given in equation (4). The difference in the summation term in equation (4) compared to equation (3) is that topsoil is deeper, due to the erosion which is avoided by adopting the conservation practice in the current year.

The damage function takes into account the private costs and benefits of choosing the erosive practice, thus linking soil erosion, yield loss and economic loss. Part one of equation (4) subtracted from part one of equation (3), shows the yield differential between the erosive practice and the conservation practice. If the erosive practice is higher yielding, this component will be positive and if not, it is negative. The cost components for both practices are shown in the second parts of equations (3) and (4). The differentials between the yield components in equations (3) and (4) and between the cost components, provide a measure of the influence of tillage choice on current income. The longer-term economic effects on income are captured by the third parts of equations (3) and (4).

If $\delta_t > 0$, the farmer will gain from employing the erosive practice in year t. In other words, the private economic incentive encourages 'soil mining'. If $\delta_t < 0$, the farmer would incur a net economic loss from selecting the erosive practice rather than the conservation practice in year t. That is to say, there is an economic incentive for conserving the soil. When the damage function assumes a negative value, it would be economical for the farmer to adopt soil conservation practices. Walker (1982) estimated the damage function using an exponential yield function with objective data. The difference between Walker's model and our approach is that we use subjectively elicited data to estimate the yield function which is then integrated with Walker's (1982) model.

3. The tea industry in Sri Lanka

The tea sector occupies an important position in Sri Lanka's economy. Tea is grown as a rainfed crop on an area of about 189 000 ha in Sri Lanka. Approximately 45 per cent of this area is under seedling tea while the balance is under high-yielding vegetatively propagated tea. Sri Lanka's annual tea production is now in the range of 255 million kg. Around 97 per cent of this tea was exported in 1998, and tea is the highest net foreign exchange earner for Sri Lanka.

Tea is classified as 'low-country', 'mid-country' and 'up-country' on the basis of elevation. The up-country holdings are located above 1200 metres. The mid-country and the low-country holdings are located at between 600–1200 metres and below 600 metres respectively. The teas produced in these three regions are referred to as high-grown, mid-grown and low-grown tea. In this study, three districts, namely Galle, Kandy and Badulla, are selected to represent the low-grown, mid-grown and high-grown tea.

Tea statistics for 1992 reveal that the large plantation sector and the smallholder sector had around 104 602 ha and 87 922 ha respectively. Most plantations have their own tea factories for processing tea. The green leaf is withered, ground and then fermented in the tea factory until an appropriate fermentation level and colour have occurred. This becomes made-tea which is packaged for export. One kilogram of made-tea requires 4.5 kg of green leaf. These large-scale plantations co-exist with thousands of smallholdings. Until 1975, all tea holdings below 4 ha were classified as smallholdings. After 1975, all holdings below 20 ha were defined as smallholdings. The tea smallholder area has increased by 16 per cent during the period 1982–92, while the plantation area has declined. Tea smallholders are scattered in all three districts. The Kandy, Galle and Badulla districts accounted for 25.3 per cent, 22.8 per cent and 8.3 per cent of smallholder tea respectively. The average farm sizes are small, being 0.5 ha, 0.4 ha and 0.5 ha in the Kandy, Galle and Badulla districts respectively. The smallholders use mainly family labour while the plantations have a resident labour force. The smallholders sell the green leaf to the plantations which then process it along with their own tea.

Tea is a perennial crop which is pruned periodically. Soil under tea is exposed to varying degrees of erosion depending on the planting density, type of planting, method of pruning, and the extent of manual weeding using scrapers. The average rainfall levels in Galle, Kandy and Badulla, are 2275 mm, 2200 mm and 1825 mm respectively. Intense rainfall on steep slopes with varying degrees of soil exposure has exacerbated the erosion of fertile topsoil. A total of around 20 000 ha of tea land in the mid-country of Sri Lanka has gone out of production due to soil erosion. Continued soil erosion threatens the long-term sustainability of the industry. Only a few estimates of soil erosion rates for tea land in Sri Lanka are available. Stocking (1992) estimated soil loss for tea plantations in Sri Lanka to be around 100–200 m/ha/yr. Quantification of erosion-induced productivity losses is vital to understand the nature and magnitude of the soil erosion problem.

4. The yield–soil loss function for tea

The empirical estimation of the yield–soil loss function for tea is discussed below. The discussion highlights various problems involved in estimation and the ways in which some of these problems have been overcome.

4.1 Data collection

The data required for this study were collected from the Badulla, Kandy and the Galle districts representing the high-grown, mid-grown and the low-grown teas respectively (Ananda 1997). Seventy-seven farmers (22, 35 and 20 from the low-grown, mid-grown and high-grown regions respectively) were selected using a two-stage random-sampling procedure. Given the time and resource constraints of the study, a survey of a larger sample was not feasible. Further, given the absence of farm-specific data for the smallholdings population on the major variables relevant for the soil erosion problem, a more sophisticated sampling procedure was not an option. Data were collected on tea yields, prices and costs of production and the various socio-economic characteristics of the sample of farmers selected (Ananda 1997).

For the estimation of the yield damage function using the subjective elicitation method, two yield values (minimum and maximum) and a ratio of marginal products of two successive soil depths from each farm are required. To determine the two yields (denoted as '*a*' and '*b*' in equation (1)), the respondents were first asked to estimate the potential yield if the tea land were extremely eroded. Next, the respondents were asked for the yield that could be obtained with very deep topsoil so that topsoil depth would not limit crop yield. These elicited yields and the averages of the low yield and the high yield for all three regions are given in Ananda (1997).

To derive an estimate for the ratio of the marginal products (R), the respondents were asked to comment on the increase in tea yield (as a percentage) generated by each successive unit increase in topsoil depth. However, farmers' responses were not satisfactory for this particular question. Hence, a figure of 0.85 for R, used by Gunatilake and Abeygunawardena (1993) for cash crop cultivation in the Hanguranketha area in Sri Lanka, was used. The

Table 1 Estimated yield damage functions

Region	Yield damage function
High-grown	$Y_{hg} = 3497 + 9040\ (1 - 0.85^{Dt})$
Mid-grown	$Y_{mg} = 1551 + 4166\ (1 - 0.85^{Dt})$
Low-grown	$Y_{lg} = 3919 + 10015\ (1 - 0.85^{Dt})$

Note: Y_{hg}, Y_{mg} and Y_{lg} = Green leaf yield (kg/ha/yr) for high-, mid- and low-grown areas respectively.

Hanguranketha area is situated at the border between up-country and mid-country, and has similar topographical features to the tea-growing areas studied. Thus, the use of this figure was considered to be appropriate. Sensitivity analyses were conducted with different R values (0.5, 0.6, 0.75, 0.85 and 0.90). The differences in results were found to be statistically insignificant (Ananda 1997). The survey average low and high yields for each region and the assumed R value (0.85) were used in formulating the yield damage functions given in table 1. In addition, the subjective estimate of the soil depth of each farm was elicited from farmers. Other data collected were the average yield of tea (green leaf), and average cost of production and prices.

4.2 Shape of the yield–soil loss function

The estimated yield equations can be used to determine the tea yield for each farm by substituting the farm-specific subjectively elicited topsoil depth. The estimated yield functions in figure 1 show that the relationship between yield

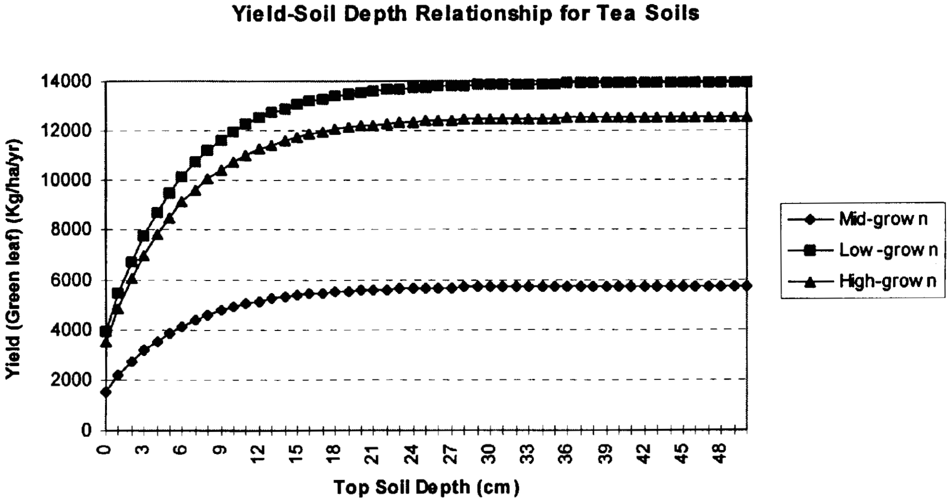

Figure 1 Yield–soil depth relationships for tea soils

and topsoil depth is non-linear. With deep topsoil, yield reductions are negligible. As the topsoil depth declines, progressively higher yield reductions were observed. Figure 1 also shows that when the topsoil depth is above 20 cm, the impact of soil erosion on yield is very small in all three regions. This accords with Anandacumaraswamy *et al.* (1997), who found that for topsoil depths greater than 20 cm, the impact of erosion on yield is very small, confirming that subjectively elicited data can provide similar results to those obtained from objective data. Figure 1 shows a similar relationship between yield pattern and soil depth. This may be attributed to the M-S function which interpolates yield between two extreme values. It may also be that farmers use similar rules of thumb in their responses but what this rule is, is not clear.

4.3 Yield reduction over time

The yield–damage functions were used to study the effects on yield using soil erosion rates computed by El-Swaify *et al.* (1983) for Sri Lankan tea for the three regions (table 2). Soil erosion rates were converted to soil depths using the relationship that 13 tonnes of soil loss per hectare is equivalent to a loss of top soil depth of 1 millimetre. The average soil depths used were obtained during the field survey.

Using the data in table 2, the times required to reduce the yield by 10 per cent, 25 per cent, 50 per cent and 100 per cent at the specified erosion rates were computed. The results are given in table 3 which shows that

Table 2 Physical parameters of the three production regions

Region	Mean topsoil depth (mm)	Potential soil erosion rate (mt/ha/year)	Reduction in topsoil depth/yr (mm)
Low-grown	355	147	11.3
Mid-grown	335	105	8.1
High-grown	450	412	31.7

Source: El-Swaify *et al.* (1983).

Table 3 Time taken to reduce yield by a specified percentage

	Time (years) taken to reduce yield by			
Region	10%	25%	50%	100%
Low-grown	20	27	31	35
Mid-grown	27	35	40	45
High-grown	8	13	15	16

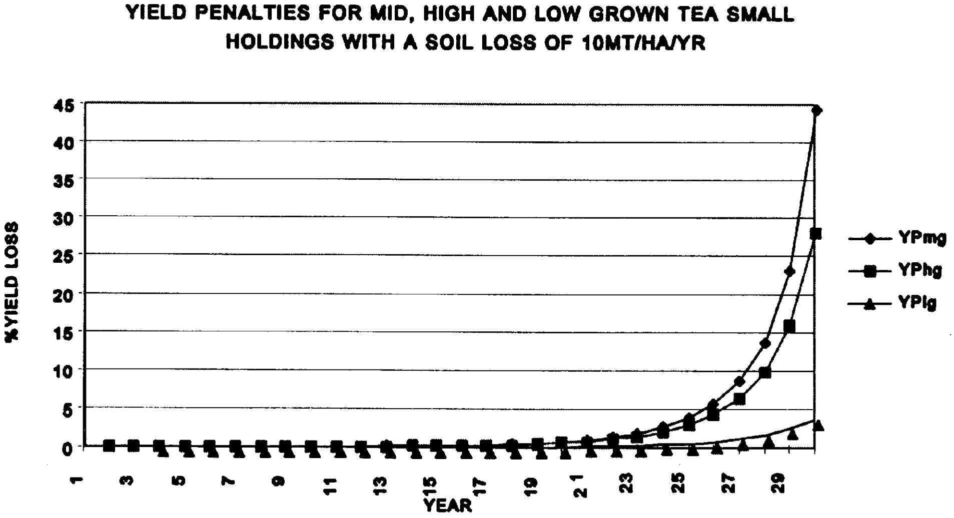

Figure 2 Yield losses with a soil loss of 10 mt/ha/yr

among the three regions, high-grown tea smallholdings took the shortest time to reach a given percentage reduction in yield. For example, the time required to lose 100 per cent of the yield and 10 per cent of the yield was 16 years and 8 years respectively for high-grown tea. Mid-grown and low-grown tea requires 45 and 35 years respectively for total loss of yield. These results show that the impact of soil erosion on yield is more acute for high-grown tea than in the other two regions. The reason is that the higher erosion rate for high-grown tea more than offsets the greater initial top soil depth.

Another scenario examined was the effect on yield over time when the same rate of soil erosion was assumed. An erosion rate of 10 mt/ha/yr was assumed. It is apparent that even at this low erosion rate, significant yield losses can be expected from the 20th year onwards. Mid-grown tea showed the highest yield damage, followed by high-grown and low-grown tea, as shown in figure 2. Mid-grown tea had the lowest soil depth and hence this result is not surprising.

4.4 Yield losses for different erosion rates within a 30-year time span

The yield damage equations were also used to estimate the average yield losses within a given time period attributable to different erosion rates. A time period of 30 years was chosen for this analysis. Six different soil erosion rates, namely, 10, 30, 50, 75, 100 and 150 mt/ha/yr, were used to examine the sensitivities. The analysis was carried out for the yields computed from

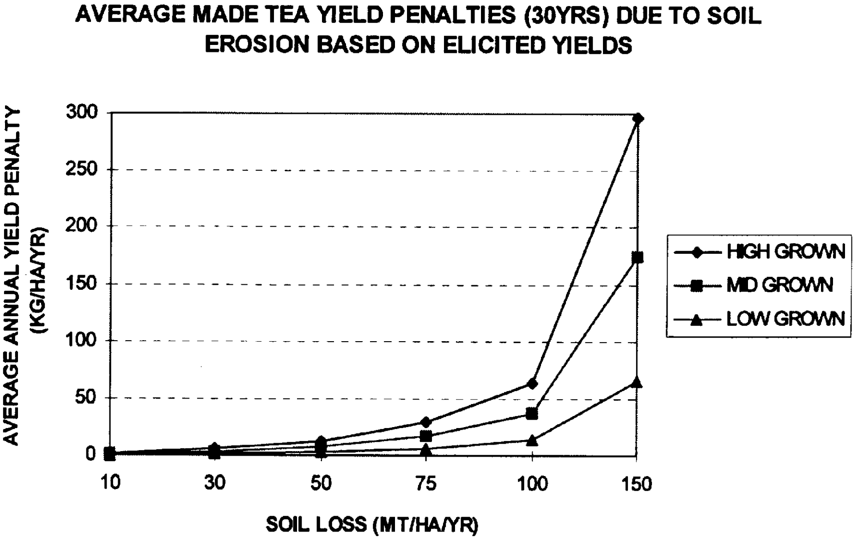

Figure 3 Yield penalties due to soil erosion

the yield equations as well as the actual average yields obtained from the field survey. The yield losses (made-tea) for different soil erosion rates, based on the estimated yields, are given in figure 3. The highest yield losses occur on high-grown tea smallholdings. The losses are 6.3 and 1336.6 kg of green tea leaf per hectare per year for soil losses of 10 mt/ha/yr and 150 mt/ha/yr respectively. These losses translate into 1.4 and 297.0 kg of made-tea. Mid-grown plantations lost 3.7 to 786.0 kg of green tea (0.82 and 174.7 kg of made-tea) per hectare per year for erosion rates of 10 and 150 mt/ha/yr respectively. Low-grown tea plantations showed the lowest yield losses, ranging from 1.4 to 291.5 kg/ha/yr (0.30 and 64.8 kg of made-tea) corresponding to 10 and 150 mt/ha/yr of soil loss.

The analysis carried out using actual yields showed that the yield (made-tea) penalties range from 1.0 kg to 207.1 kg for high-grown, 0.5 kg to 102.4 kg for mid-grown and 0.2 kg to 53.6 kg for low-grown tea. These results indicate that the yield penalties incurred when the yields estimated from the yield equations are used, are higher than those based upon actual yields. The regionwise yield decline patterns, however, remained unchanged.

5. Damage function analysis for soil erosion

The yield equations estimated in the previous section were used to estimate the damage function by incorporating prices and costs. The results are presented below.

5.1 Estimation of the damage function

The aim of determining the damage function in this manner is to determine the optimal year for a farmer to switch from an erosive practice to a less erosive practice. Tea plantations initially need to establish conservation measures such as lateral drains. However, most existing tea plantations are old and a re-establishment of conservation measures is necessary. The damage function analysis determines the year when re-establishment of the conservation measure should occur. The conservation practice examined is lateral drainage which is an important erosion control method for tea land. The changeover occurs when the value of the damage function is negative.

Several assumptions were used in estimating the damage function. The time span of the analysis was taken as 30 years. The additional expenditure incurred in establishing and maintaining the conservation practice was taken as the difference in production costs between the erosive and the conservation practice. It was assumed that the current yield remained constant during subsequent years when soil conservation measures were adopted. A discount rate of 10 per cent was used in the analysis. Soil erosion rates of 412, 105 and 130 mt/ha/yr for high-, mid- and low-grown teas respectively, were used. The initial soil depths considered were 45, 33.5 and 35.5 cm for high-, mid- and low-grown teas. The prices used were Rs. 11.77, Rs. 8.63 and Rs. 11.00 per kg of made-tea for high-grown, mid-grown and low-grown teas. The establishment costs of lateral drains for high-grown and low-grown tea are Rs. 7500 per hectare. The annual maintenance costs are Rs. 2500 and Rs. 2160 for low-grown and high-grown tea. For mid-grown tea, the establishment and maintenance costs are Rs. 6000 and Rs. 3315.

These data were analysed using equations (3) and (4) to obtain the value of the damage function. The results are given in table 4 and show that the times to changeover to the conservation practice in high-grown and low-grown teas were only 6 years and 14 years, respectively. For mid-grown tea smallholdings, which had the lowest rate of soil erosion, the switch to the conservation practice does not occur within the 30-year time horizon.

Table 4 Switchover year to the conservation practice

Region	Decision year	Soil depth (cm)
High-grown	6	29.2
Mid-grown	>30	–
Low-grown	14	22.5

5.2 Sensitivity analysis

Sensitivity analysis was conducted to examine changes in the switchover year to changes in various parameters. Sensitivity to changes in the erosion rate are given in table 5 which shows that for a soil loss of up to 100 mt/ha/yr, adopting the conservation practice is not economical for mid-grown tea within the first 30 years. At a soil loss of 125 mt/ha/yr, the farmers should change over to the conservation practice in year 22. The value of the damage function in this year is Rs. −23.15 and the topsoil depth is 13.3 cm.

Table 5 shows that for low-grown tea, for soil loss of up to 100 mt/ha/year, the farmer should not change over to the conservation practice during the 30-year period. When the soil loss is 125 mt/ha/year, the farmer should adopt the conservation practice in the 15th year. In this decision year, the damage function value is Rs. −65.61 and the topsoil depth is 22.0 cm. For high-grown tea, it is not economical for the farmer to switch over to the conservation practice when soil loss is 125 mt/ha/year or less. At a soil loss of 150 mt/ha/yr, the switchover should occur in the 22nd year and the value of the damage function is Rs. −47.19. It is apparent that as soil erosion rates increase, the switchover year is advanced. This is in agreement with the argument that for more erosive soils, investment in conservation pays off sooner.

The highest erosion impact can be seen in the low-grown tea smallholdings for which the time period to change to the conservation practice was shorter than for mid-grown and high-grown tea. This differs from the way yields varied with soil erosion. The difference can be attributed to the lower soil depths of low-grown tea compared to high-grown and mid-grown tea. This analysis also shows that in all three regions, it is not economical to adopt lateral drains for soil conservation if the soil erosion rate is below 125 mt/ha/year. These findings suggest that when the erosion rate is low, the farmer has no economic incentive to adopt conservation measures. If the damage function value is positive, there is an economic incentive to

Table 5 Sensitivity analysis for changes in soil erosion rate

Soil loss (mt/ha/yr)	Decision year (mg)*	Damage function value (Rs)	Decision year (lg)*	Damage function value (Rs)	Decision year (hg)*	Damage function value (Rs)
75	30	–	30	–	–	
100	30	–	30	–	–	
125	22	−23.15	15	−65.61	30	
150	16	−88.96	11	−67.40	22	−47.19
175	13	−206.48	9	−227.27	17	−83.89

Note: * mg, lg and hg represent mid-grown, low-grown and high-grown tea, respectively.

mine the soil by choosing the more erosive practice. However, in subsequent years, the immediate profit advantage declines, because of a decline in productivity with continued soil erosion. As soil erosion rates increase, farmers in all three regions should switch to the conservation practice sooner.

The changeover year can alter significantly with changes in the initial topsoil depths. For example, the adoption occurred in the 11th year with a 60 cm initial topsoil depth, but would be postponed to the 21st year when the initial topsoil depth was 90 cm. Conservation practices should be adopted sooner in shallower topsoils than in deep soils. This is because, in deep topsoils, yield reduction damage due to soil erosion is not substantial and the yield–soil loss function is relatively flat.

Changes in the discount rate influence the switchover year. For high-grown tea, the switchover year was 4 when the discount rate was 3 per cent. It increased to 6 with a 10 per cent discount rate. For mid-grown tea smallholdings, the switchover year was 30 with a 3 per cent rate of discount. The adoption year ranged from year 10 to year 14 with 3 and 10 per cent rates of discounts respectively for low-grown tea. The results show that the erosion damage function is sensitive to the rate of discount used. Higher discount rates give preference to earlier over later profits. The erosive practices generate higher profits initially, and hence they are preferred and conservation is postponed.

It is also observed that the switchover year changes with changes in production costs, product prices and length of the planning horizon. For an increase in cost of production up to 25 per cent, no change in the switchover time in high-grown tea occurred. However, higher production costs tended to postpone the switch to conservation. Product prices have a modest influence on the changeover year. For example, a 25 per cent increase in the green leaf price of high-grown tea resulted in the conservation adoption year changing from 6 to 5. A 25 per cent reduction in green leaf price did not change the adoption year, but significantly reduced the damage function value at the decision year.

6. Conclusion

The analysis shows that soil erosion influences tea yields significantly. There are also regional differences. The highest yield losses were observed for high-grown tea. But the highest economic losses were obtained for the mid-grown tea, followed by high-grown and low-grown tea. This may be attributable to price differences between the three regions. The analysis of the damage function shows that farmers will mine soil without adopting soil conservation measures as long as it is privately profitable. For all three regions, the adoption of soil conservation measures becomes profitable only when the erosion rate is 125 mt/ha/yr, assuming a 30-year planning horizon. The results are sensitive to the discount rate and soil erosion rate, but less sensitive to costs of production and tea prices. Sensitivity to discount rates is particularly important because if the subjective discount rates of farmers in developing countries are high, it will lead to rapid soil mining. The erosion damage function represents the private profitability of the conservation decision. The positive private returns for erosive farming practices are likely to be associated with high off-site costs. High off-site costs are inherent in a system which offers inadequate incentives to mitigate market failure and does not effectively penalise farmers who farm in ways that threaten long-term sustainability. *Ad hominem* criticisms of farmers are less convincing when we look beyond the farm gate for the driving forces behind soil erosion.

This analysis has its own limitations and caution should be exercised in extrapolating the results to the wider smallholding sector. The positive aspect of the study, however, is that low-cost and rapid collection of subjective data on soil depth permits easy duplication of the method on other farms. This is an especially important feature of the methodology for developing countries confronted with soil erosion problems. It opens up new possibilities for researchers and practitioners to assess soil erosion–yield relationships, facilitating wider incorporation of soil erosion impacts into economic analysis. It is, however, only through the cumulative results of further studies that the general applicability of the method can be established.

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