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SUSTAINABILITY OF CURRENT AGRICULTURAL PRACTICES IN THE CAMERON HIGHLANDS, MALAYSIA

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Abstract. Cameron Highlands is a mountainous region with steep slopes. Gradients exceeding 20° are common. The climate is favourable to the cultivation of tea, sub-tropical vegetables and flowers (under rain-shelter). Crop production is sustained by high fertiliser and manure applications. However, agriculture in this environment is characterised by high levels of soil erosion and environmental pollution. A study on the sustainability of these agro-ecosystems was conducted. Results indicated that soil loss was in the range of 24–42 ton/ha/yr under vegetables and 1.3 ton under rain-shelter. Sediment load in the vegetable sub-catchment reached 3.5 g/L, 50 times higher than that associated with flowers under rain-shelter and tea. The sediments contained high nutrient loads of up to 470 kg N/ha/yr. The N, P and K lost in runoff from cabbage farms was 154 kg/season/ha, whereas in chrysanthemum farms it was 5 kg. In cabbage farms, the N, P, and K lost through leaching was 193 kg/season/ha. The NO_3–N concentration in the runoff from the cabbage farms reached 25 ppm but less than 10 ppm in runoff from rain-shelters. Inorganic pollution in the rivers was within the acceptable limit of 10 ppm. The sustainability of the agro-ecosystems is in the order of tea > rain–shelter ≫ vegetables.

Keywords: agricultural pollution, environment, highland, nutrient loss, sustainable agriculture, soil loss

1. Introduction

1.1. Cameron Highlands: The Environment and Land Use

The district of Cameron Highlands (4°28′N, 101°23′E), Pahang, is located on the main range of Peninsular Malaysia. It lies between 1070 and 1830 m above mean sea level. The total land area is 71,218 ha. Temperatures are mild, with an average daytime reading of 24 °C and an average night-time reading of 14 °C; the average annual rainfall is 2660 mm with peaks in the months of May and October. The climate is thus very conducive to a wide range of sub-tropical crops. However, the land is steeply sloping with 66% of the slopes having gradients of more than 20°. There are two major catchments, i.e. Telom Catchment (11000 ha) in the north and Bertam Catchment (7200 ha) in the south. These catchments provide water resources for irrigation, domestic consumption, recreation and the production of hydroelectric power.

About 86% (60000 ha) of the area is forested, 8% (5500 ha) under agriculture, 4% (2750 ha) occupied by settlements, and the remainder used for recreation and other activities. Two of the main economic activities in the Cameron Highlands are hydroelectric power generation and agriculture. Most of the present agricultural activities lead to serious soil erosion, producing large amounts of sediments. The resulting sediments are transported and deposited in the storage dam, adversely reducing the hydroelectric power generation capacity and shortening its life span (Anon, 1987).

1.2. Agriculture in Cameron Highlands

Although the topography of the Cameron Highlands is steep and highly dissected, the favorable climate has allowed it to become a major producer of vegetables in Malaysia. Of the 5500 ha of agricultural area, vegetables occupy the largest fraction (50%), followed by tea (40%), flowers (7%) and fruits (2%). Most of the tea plantations were established in the 1930s, by planting tea seedlings on slopes. The plantations are managed by large private companies. Tea cultivation is now on the decline due to labour shortages, and in some areas it is being replaced by vegetables. Three popular vegetable types are cabbage, Chinese cabbage and tomato. Flower cultivation has increased recently, sometimes at the expense of vegetables. Three major flower species are Chrysanthemum (52%), Carnation (20%) and Rose (17%).

The annual crops are planted on terraces and platforms built on steep slopes or hilltops, as well as on valley floors. Lands are indiscriminately leveled for intensive agricultural production and related infrastructure. Although the overall agricultural coverage is relatively small, steep slopes, high rainfall and high rate of fertiliser and pesticide inputs have given rise to high levels of soil erosion and environmental pollution. A study was conducted to compare three major agro-ecosystems in Cameron Highlands (tea, vegetables and floriculture) in terms of their relative sustainability, particularly with respect to soil and nutrient losses, and the resulting environmental pollution. The sustainability of these agro-ecosystems will have an impact on land resource use and conservation, including the ability to continuously produce hydroelectricity.

1.3. Open Farms

The procedure of field preparation for crop cultivation in open farms includes deforestation, destumping and burning. In the case of tea and fruit tree cultivation, a 50% burn is normally sufficient. However for annual crops like vegetables, complete destumping and burning is essential. In all cases the initial opening of forest results in extensive soil erosion.

Tea is planted on slopes, with very little earthwork for its cultivation. A higher level of earthwork is required in the cultivation of fruit trees, which are normally planted on terraces or platforms. The cultivation of vegetables requires the most extensive earthworks. Vegetables are planted either on terraces or leveled lands, depending on the terrain and slope of the land available. There are vegetable plots on valley floors, hill-tops, and on gentle or steep slopes on irregularly shaped hills. In addition, the short cropping cycle of vegetables also poses problems. Immediately after harvest, the fields are prepared for the next crop, and this exposes them to further runoff and erosion. Frequently there are as many as three cultivation seasons a year with as many cycles of land preparation.

1.4. Rain-Shelters

Rain-shelters are often used for the cultivation of high-value vegetables and many species of flowers. The land preparation procedure for rain-shelter farming is similar to that for vegetable cultivation, except that for flower cultivation, a plastic rain-shelter is constructed. This is due to the heavy rainfall experienced throughout the year. The plastic roof of the rain-shelters lasts up to 2.5 years. Problems of soil erosion in the flower farms are minimal, as the rain-shelter keeps rainfall out. However, the volume of runoff intercepted by the shelters is enormous, resulting in sudden large surges of water, sometimes causing flash floods and landslides.

1.5. Fertiliser and Pesticide Applications

Due to extensive terracing and land levelling, crops are essentially grown on infertile subsoil surfaces. To overcome this problem, fertility is restored through large inputs of both organic and inorganic fertilisers. A high rate of chicken dung application, up to 80 tons/ha, is common in the newly opened areas. Due to heavy rainfall, a major portion of the applied fertiliser is usually lost through runoff and leaching. Heavy input of fertilisers to the soil also results in the soil becoming toxic for plant growth. Farmers, when faced with an unacceptable yield reduction, often add new soil material over the existing soil or simply obtain fresh surface soil.

Cultivated vegetables and flowers are susceptible to a number of pests and diseases. Chemical control remains the most popular approach for pest and disease management. Although integrated pest management (IPM) strategies are being promoted by the relevant government agencies, the use of pesticides is still significant. The usage of organo-phosphorus and synthetic pyrethroid compounds is popular among vegetable farmers. These include methamidophos, diazinon, dimethoate, malathion, permethrin, cypermenthrin and deltamethrin. Most of these are applied as prophylactic sprays. Herbicides such as glyphosate and paraquat are commonly applied for weed clearing purposes prior to the start of a crop.

2. Materials and Method

The characteristics of selected agro-ecosystems were studied at plot and sub-catchment level. Altogether there were four plots and four sub-catchments, all located in the Cameron Highlands area. The annual rainfall recorded during the study period was 2444 mm in 1997 and 2186 mm in 1998.

2.1. Experimental Plots

The information on the experimental sites, cropping season and instrumentation are given in Table I.

The crops in plots P2, P3 and P4 were grown in the open but in plot P6 they were cultivated under rain-shelter. Details of the characteristics and treatments in the various plots are given below:

Plot 2: The plot, measuring 150 m^2, and with a slope of $<3°$, is located at MARDI station. It was cultivated with sweet peas, followed by cabbage and radish on bunds aligned along the contours. Two lysimeters (L3 and L4) were installed; the details of its construction and sample collection were described by Wan Abdullah *et al.* (2001). For sweet peas, 900 kg of chicken manure was applied, followed by

TABLE I

Location of experimental sites, crop types and instrumentation

Plot	Location	Cropping seasons (S)	Crop	Period (days)	Instrumentation
P2	MARDI station	S1: 7/8–14/10/97	Sweet peas	69	Tipping bucket + recorder; piezometer + recorder; lysimeters
		S2: 16/12/97–13/3/98	Cabbage	88	
		S3: 21/4–19/6/98	Radish	60	
P3	Sg. Palas	S1: 25/8–30/11/97	Cabbage	98	Tipping bucket + recorder; piezometer + recorder; rain gauge
		S2: 18/1–11/4/98	Cabbage	84	
		S3: 1/6–26/9/98	Cabbage	118	
		S4: 7/12/98–18/3/99	Cabbage	102	
P4	Sg. Palas	S1: 25/10/97–7/1/98	Cabbage	75	RBC flume; probe + recorder
		S2: 29/1–6/4/98	Cabbage	68	
		S3: 1/6–20/8/98	Cabbage	81	
P6	Kg. Raja	S1: 6/8/97–12/11/97	Chrysanthemum	99	Tipping bucket + recorder; lysimeter
		S2: 5/12/97–23/3/98	Chrysanthemum	109	
		S3: 6/4/98–16/7/98	Chrysanthemum	102	
		S4: 29/7–2/11/98	Chrysanthemum	97	

2 kg of NPK fertiliser. For cabbage, 20 g of organic fertiliser and 20 g NPK were applied per plant, and later supplemented with foliar fertiliser.

Plot 3: The plot, measuring 150 m^2, and with a slope of 7°, is located at Sg. Palas. It was planted with cabbage for all seasons, on bunds arranged as in plot 2. For each season, 1260 kg of chicken manure was applied, followed by two NPK applications of 56 kg.

Plot 4: The plot, measuring 250 m^2, and with a slope of 7°, is located in Sg. Palas. It was cultivated with cabbage for four seasons on bunds aligned across the contours. Chicken dung was applied at 990 kg followed by two applications of NPK, at 50 g/plot/application.

Plot 6: The plot, measuring 150 m^2, and with a slope of $<3°$, is located under a rain-shelter at Kg. Raja. A lysimeter was installed as in P2. It was cultivated with chrysanthemum for four seasons. Several applications of chicken manure totaling 30 kg were made each season.

For all plots, the following measurements were taken:

(i) suspended and bedload sediments using tipping buckets and RBC flumes (Clemmens *et al.*, 1984);
(ii) N content in the bedload and suspended load; and
(iii) the concentration and the amounts of the inorganics in the runoff (NH_4–N, NO_3–N, P, K Na, Ca and Mg).

The suspended and bedload sediments were measured for three to four seasons, inclusive of the fallow period, and the results were presented on an annual basis. The inorganics were measured for only one season each in plots P2 and P3. The samples of leachates from lysimeters in P2 (L3 and L4) and P6, were collected and analysed for inorganics as detailed in item (iii) above.

2.2. Sub-Catchments

Four sub-catchments – namely tea, flower, vegetable and jungle – were selected for the study. The average slope in the tea sub-catchment is around 20° whereas in all other sub-catchments the landscape is hilly. The areas covered by the sub-catchments are 1.2, 0.6, 6.8 and 0.2 km^2 respectively. Water samples were collected from the sub-catchments during the periods May 1998 to June 1999 and they were analysed for sediment concentration. Stream discharges were measured in the tea and flower sub-catchments for a period of about a month in 1998.

2.3. Sustainability Assessment

Agro-ecosystem sustainability is reflected by several sustainability indicators, namely soil loss, soil productivity, soil degradation, water quality and water discharge (Chiu *et al.*, 2000). In the present study, the loss of soil through erosion was measured as suspended and bed load; water pollution was assessed by measuring the amounts of nutrients and other inorganics in farm runoff; and water discharge was measured by ultrasonic Doppler instruments (UDI).

3. Results

Current agricultural practices in the highlands have disastrous implications on the soil resources of the area, as well as on the water resources both within the area and downstream. The effects of agricultural activities on these resources are discussed in the following sections.

3.1. Soil Loss

3.1.1. *Soil Erosion Under Open Farming*

Erosion studies were conducted for a year in vegetable plots P2, P3 and P4. The total annual soil losses for the respective crops are shown in Table II. The planting practices for vegetables have resulted in huge initial soil erosion in the first season. During a 1-year period, inclusive of fallow, the total soil losses were 24, 25, 42 ton/ha for P3, P2 and P4, respectively. The sediment concentration from the vegetable sub-catchment ranged from 0–3.47 g/L.

3.1.2. *Soil Erosion Under Rain-Shelter*

Soil erosion in a chrysanthemum farm under rain-shelter is attributed to water drops from sprinklers used in irrigation. The results from three planting seasons showed that there was minimal runoff and soil loss (Table II). The total soil loss was 1.34 ton/ha/yr. The sediment concentration from a stream coming through a floriculture sub-catchment ranged from 0–0.07 g/L.

TABLE II

Erosion data from experimental plots under vegetables and chrysanthemum

	Plot P6**		Plot P2		Plot P3		Plot P4	
Season (S)	Soil loss (ton/ha)	Run-off (mm)	Soil loss (ton/ha)	Rain-fall (mm)	Soil loss (ton/ha)	Rain-fall (mm)	Soil loss (ton/ha)	Rain-fall (mm)
S1	0.24	17	7.85	367	12.54	356	21.61	1060
S2	0.35	44	4.60	322	8.27	922	8.27	790
S3	0.52	32	4.32	396	2.43	322	12.49	1179
Off season			8.56	1016	1.00	234	n.a	n.a
Annual values	1.34*	113*	25.33	2101	24.24	1834	42.37	3029

*Expressed as annual equivalent.

**Reproduced from Aminuddin *et al*., 2001.

TABLE III

Average nitrogen (N) contents as percent of bed load (BL), suspended load (SL), and surface soil (SS) and ER values

Plot	N in BL	N in SL	N in SS	ER
P2	0.14	0.29	0.11	1.82, 4.32, 6.10
P3	0.24	0.65	0.26	1.83
P4	0.38	0.93	0.35	1.56, 1.6
P6	0.26	0.45	0.19	1.35, 1.73, 1.84, 2.26

3.1.3. *Soil Erosion Under Tea*

Runoff and soil erosion from the tea plot and the respective sub-catchment were monitored for about a year. From the plot study, there was no significant soil erosion in the tea plantation. The sediment concentration from a stream flowing through the plantation ranged from 0–0.07 g/L.

3.2. Nutrient Load of Sediments

The nutrient content, especially nitrogen, was measured in the bedload and suspended load from the vegetable and flower plots. For comparison, its content in the surface soil was also measured. The nutrient enrichment ratios (ER) for selected sediment samples were also calculated (Table III).

3.3. Water Resources Pollution

3.3.1. *Inorganic Pollution in Open Farming*

The concentration and amount of inorganic elements in the runoff during the peak flow period in cabbage plots are given in Table IV. The loss through leaching is given in the Table V.

3.3.2. *Inorganic Pollution in Rain-Shelter Farming*

The amount of inorganic elements in the runoff from the chrysanthemum plot and their concentration during the peak flow period are given in Table VI.

TABLE IV

The concentration and amount of the inorganics in runoff from cabbage plots

	NH_4–N	NO_3–N	P	K	Na	Ca	Mg
P2, Season 2 conc. (ppm)	2	11	5	30	11	34	5
Amount (g)	165	527	91	2379	982	2622	625
P3, Season 2 conc. (ppm)	<1	10	16	25	5	61	9
Amount (g)	119	3032	612	2961	541	5002	773

TABLE V
The loss of inorganics (g) due to leaching under sweet peas, and their concentrations (in ppm) during the peak removal period

	NH_4–N	NO_3–N	P	K	Na	Ca	Mg
Lysimeter L3 losses (g/plot)	110	1883	2	955	2075	1692	259
Conc. (ppm)	2	71	tr	29	35	22	11
Lysimeter L4 losses (g/plot)	81	266	2	342	348	1248	76
Conc. (ppm)	2	10	tr	7	11	27	2

Note. g/plot = 0.067 kg/ha; tr: trace.

TABLE VI
The amount and concentration of inorganics in leachate from chrysanthemum plot (P6), under rain-shelter

	NH_4–N	NO_3–N	P	K
Losses (g/plot/yr)	49	250	1.5	850
Concentration (ppm)	2	10	1	13

Note. g/plot = 0.067 kg/ha.

4. Discussion

4.1. Soil Loss

The plot studies showed that the erosion rate in the vegetable plots ranged from 25–42 ton/ha/yr. Large differences in soil loss under vegetables is partly due to differences in rainfall, which was highest (about 3000 mm/yr) in plot P4 as compared to plots P2 and P3 (about 2100 and 1800 mm, respectively). Higher loss in plot P4 is also attributed to the slope-wise bund arrangement, in contrast to P2 and P3 where the bunds were constructed across the slope. A higher loss (82 ton/ha) from a vegetable plot has also been reported (Aminuddin *et al.*, 2001). For all opened land in the study area, Midmore *et al.* (1996) estimated the average soil loss at 23.5 ton/ha. For areas where erosion rates are high, Morgan (1986) proposed a rate of 25 ton/ha/yr as tolerable. The soil losses recorded in vegetable areas are either similar or higher than this limit, implying that it ranges from marginally sustainable to unsustainable, depending on the farm practices adopted. In comparison, soil loss in floriculture under rain-shelter is much lower (1.34 ton/ha/yr), implying that this agro-ecosystem is highly sustainable.

The trend in soil loss is also reflected by sediment concentration in the sub-catchment studies. The maximum sediment concentration in the suspended load in the tea and flower sub-catchments (at 0.07 g/L) was 50 times lower than that in the vegetable sub-catchment (at 3.47 g/L). This again illustrates the relative sustainability of both tea and rain-shelter agro-ecosystems.

4.2. Soil Degradation

Soil loss has resulted in soil degradation through reduced soil depth, increased soil stoniness and compaction, and reduced soil permeability. The organic matter and nutrient contents were also depleted. The nutrient loss was determined by comparing the nutrient content of the surface soils and sediments. Chemical analyses of a number of samples of surface soil, bed load and suspended load at various farms revealed important differences between these materials (Table VI). The sediment samples, both suspended load and bedload, tended to have higher nutrient contents than the topsoil, indicating their enrichment due to nutrient loss from the farms. As shown in the table, suspended load was relatively richer in nutrients than bed load. The enrichment ratios (ER) for nitrogen for several events show some variations but all are greater than 1, confirming enrichment.

A long history of intensive vegetable cultivation using high fertiliser input in excess of crop requirement has resulted in the development of soil salinity. Wong and Jaafar (1993) reported that there were significant residual accumulation of salts, P, K, Ca and Mg in the soils under open vegetable farming in the study area. The effect of salt and nutrient accumulation is aggravated in the flower cultivation under rain-shelter (Wong *et al.*, 2000). Under this condition highly saline soils have developed due to the absence of surface wash by rainfall, although some losses by leaching do occur (Table VI). Under rain-shelter, Wong (*ibid.*) indicated that the pH increased from 3.9–8.0, and EC increased from 0.4–6.4 dS/m, exceeding the acceptable limit of 2 dS/m. There were also abnormal levels of Mn, Cu, Zn and Cd in the cultivated soils, and these could cause soil toxicity.

4.3. Water Pollution

4.3.1. *Loss of Inorganic Elements in Surface Runoff*

The nutrient loss in runoff is equivalent to 43 kg N, 2 kg P and 109 kg K/season/ha. The high losses were attributed to high rates of chicken dung application. The N input ranged from 740–1580 kg/season/ha while the K input ranged from 820–1940 kg/season/ha. In terms of water quality, the concentration of NO_3 in the surface runoff from the farm exceeded the acceptable limit of 10 ppm. During the peak removal period, the concentration of NO_3 was as high as 25 ppm. In chrysanthemum cultivation under rain-shelter, the amount of pollutants removed was far lower than those removed from open cabbage farms (Aminuddin *et al.*, 2001). The losses were equivalent to about 0.7 kg N, 1 kg P and 3.5 kg K per ha per season. The concentration of NO_3 was also within the acceptable limit of 10 ppm.

4.3.2. *Loss of Inorganic Elements Through Leaching*

The loss of applied nutrients through leaching was also high, mainly due to high leaching rates in the sandy textured, granitic soils. In cabbage farms about 55 kg N and 138 kg K/season/ha were lost through leaching while the loss of P was negligible. The amount of N leached had the potential of polluting the groundwater as its concentration at the maximum leaching period was 40 ppm. The pollution of groundwater is rather persistent as the applied nutrients took some time to move through the soil profile before reaching the ground water table. In chrysanthemum farm under rain-shelter, the leaching losses of nutrients were lower than in open farms but their concentrations were comparable (Table VI).

4.4. Water Discharge

It was found that under open vegetable farming, about 69% of rainfall converted into runoff, whereas under rain-shelter about 15% of irrigation water ended up as runoff. The rainfall intercepted by the shelter produced large amounts of runoff. The water discharge patterns in flower and tea sub-catchments are shown in Figure 1. In the tea sub-catchment, the discharge was low and stable whereas in the flower sub-catchment, the discharge after heavy rainfall was high and immediate. This resulted in flash floods. Therefore, proper management of this runoff water is required.

4.5. Relative Sustainability of the Current Agro-Ecosystems

The results indicated that tea is the most sustainable form of agriculture in the Cameron Highlands. The soil loss in tea farms was lower than in other agricultural

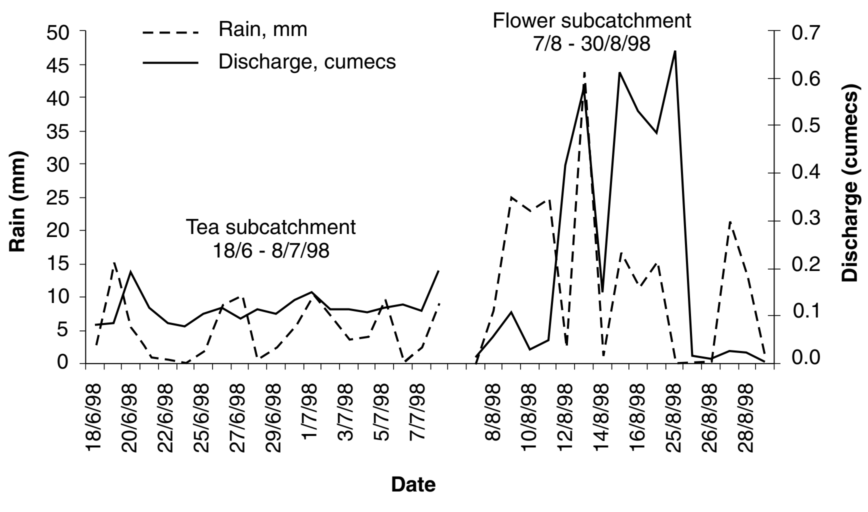

Figure 1. Rainfall and stream discharge for the tea and flower sub-catchments.

systems, and the water in its catchment was the least polluted by sediments, nutrients and applied chemicals. The water discharge in the tea farm was stable as heavy rains were buffered by the tea plants.

Flower cultivation under rain-shelter resulted in low soil loss ($<$1.5 ton/ha/yr). The runoff from the farms contained pollutants from the applied nutrients, although the pollution levels were within the permissible limits. However, past research indicated that the soils under rain-shelter were polluted due to the accumulation of nutrients. Another negative effect of flower cultivation is the resulting high runoff due to intercepted rainfall (Figure 1), which contributed to riverbank erosion and flash floods.

The vegetable agro-ecosystem is the most unstable. It is associated with high soil loss. Losses as high as 83 ton/ha/yr have been reported (Aminuddin *et al.*, *ibid*). Nutrients are also removed in large quantities, resulting in water pollution. The nitrate contents in both the runoff and leachate from vegetable plots were well above the acceptable limit of 10 ppm. The water in the vegetable sub-catchment was the most polluted. The pollution levels in flower and tea sub-catchments were relatively lower.

4.6. Land-Use Options in the Steeplands

Sustainable development is threatened by both over-exploitation and neglect (Anon, 1995). In Cameron Highlands the main threats to sustainability are accelerated erosion, landslides, depletion of soil fertility, increased salinity, biological degradation of areas currently under annual crops and surface and groundwater pollution. To overcome these problems, proper land-use planning and land management should be implemented. In steeplands, land-use planning begins with correct land inventories, classification, and delineation for promising land-use types (agriculture, hydroelectric generation, water use, recreation) to suit the landscape (Sheng, 1999). This will ensure productivity maintenance, continuous usage, minimum degradation, pollution prevention and economic viability. In this respect, the current study indicated that the cultivation of annual crops under rain-shelter, with very low soil erosion, could form the basis of a promising agriculture system in steep, mountainous environments.

5. Conclusions

The current agricultural practices in the Cameron Highlands have partly contributed to the land degradation which has reduced the ability of the resources to support future agricultural production. The worst scenario is seen in vegetable farms where there is extensive degradation in the form of deterioration of the landscape and reduction in soils and water quality. Under floriculture, there is high initial soil degradation during farm preparation, but subsequently the farm stabilises, and the resulting soil loss and reduction in water quality are within acceptable limits. Nevertheless, the soil is prone to salinity development. The more sustainable form of farming is tea cultivation where soil loss is minimal and a high water quality is maintained. However, the steep terrain subjects the farm to landslides.

Sustainable land use in steeplands remains a formidable challenge to policy makers, relevant government agencies and farmers. Contributions from all sectors are required to attain a high level of sustainability in such a fragile environment. Most of the required technical information is currently available but, unfortunately, the adoption and enforcement of the relevant guidelines are lacking.

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