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Impact of intensive highland agriculture on the ecosystem

(Kesan pertanian intensif di kawasan tanah tinggi terhadap ekosistem)

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Key words: highland agriculture, water resources, water pollution, environment

Abstrak

Tanah tinggi di Malaysia adalah satu ekosistem yang mudah terjejas disebabkan oleh cerun yang curam, tanah berpasir dan kadar hujan yang tinggi. Persekitaran di tanah tinggi sesuai untuk penanaman tumbuhan separa tropika. Sayur-sayuran dan bunga-bungaan ditanam dengan intensif di atas teres dan pelantar, yang akhirnya menyebabkan degradasi tanah. Projek ini mengkaji kehilangan tanah dan nutrien dalam tiga sistem penanaman yang berbeza di Cameron Highlands iaitu kubis dan teh di kawasan terbuka, dan bunga-bungaan di bawah pelindung hujan. Kadar hakisan yang tinggi (82 t/ha) dan penggunaan baja serta racun perosak yang berlebihan telah menyebabkan pencemaran air yang ketara di kawasan tanaman sayur. Keadaan ini menyebabkan penanaman sayur tidak mapan. Sebaliknya, pertanda yang sama menunjukkan tanaman bunga di bawah pelindung hujan dan tanaman teh adalah jauh lebih mapan; kadar hakisan di bawah pelindung hujan hanyalah sekitar 1 t/ha setahun. Bagaimanapun pelindung hujan mestilah dibina sesuai dengan keadaan muka bumi, dan air larian pintas yang berlebihan mestilah diurus dengan cekap, untuk mengelakkan tanah runtuh dan hakisan di tebing sungai. Penggunaan baja di bawah pelindung hujan mestilah juga diuruskan dengan baik untuk mengelakkan berlakunya kemasinan tanah yang berlebihan.

Aras pencemaran organik di dalam air pada peringkat ladang adalah tinggi. Bagaimanapun aras menurun di dalam kawasan tadahan kecil dan semakin berkurangan di dalam kawasan tadahan, disebabkan oleh kesan pencairan. Antara kesemua racun perosak, hanya endosulfan didapati terus wujud di dalam kawasan tadahan melebihi tahap yang dibenarkan.

Abstract

The highlands in Malaysia are fragile ecosystems due to steep slopes, sandy soils and high rainfall. Condition in the highlands is ideal for planting sub-tropical crops. Vegetables and flowers are cultivated intensively on terraces and platforms, resulting in land degradation. This project examined the soil and nutrient losses for three different cropping systems in the Cameron Highlands i.e. cabbage and tea in open areas, and flowers in rainshelter. High erosion rate (82 t/ha/yr) and high water pollution due to the applied fertilizers and pesticides were

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observed in open vegetable plots, making cultivation unsustainable. In contrast, similar indicators suggest that tea cultivation and floriculture under rainshelter are far more sustainable; the erosion rate under rainshelter is only about 1 t/ha/yr. Nevertheless rainshelters must be constructed in conformity to the landscape and the excess intercepted runoff water must be properly managed to avoid landslide risk and riverbank erosion. The fertilizer application under rainshelter must also be properly managed to avoid excessive soil salinization.

The level of organic water pollution at the farm level is high. Nevertheless it is much reduced in the subcatchment and it is even lesser in the catchment waters, due to the dilution effect. Among all pesticides, only endosulfan persists beyond permissible limit in the catchment.

Introduction

Intensive agriculture is being practised in Cameron Highlands, in spite of the very fragile ecosystem. It is mountainous, with elevation between 1 070 m and 1 830 m a.s.l., and more than 66% of the land has gradients of more than 20° (Macken and Ong 1979). The soils are mostly sandy, being developed from granitic rocks, and the average annual rainfall is high (2 660 mm). All the above factors could lead to high potential soil erosion.

The climate of Cameron Highlands is mild, making it favourable for the cultivation of sub-tropical crops. Agriculture is one of the main economic activities although about 86% of the land is still under forest (Roslan et al. 1997). Of the 5 250 ha of the land currently used for agriculture, area cultivated with vegetables is the most extensive (47%), followed by tea (44%), flowers (7%) and fruits (1%) (Anon. 1997). In the near future the agricultural activity in Cameron Highlands is projected to increase to about 23 000 ha, excluding land to be developed in the adjacent areas in Lojing, Kelantan.

Annual crops and tea are planted on sloping land ranging from flat to slightly more than 40° (Midmore et al. 1996). They are usually planted on terraces and on levelled lands built on valley floors, slopes and hilltops. These activities, however, affect surface and subsurface hydrology, making the overall impact on agricultural land resource and the environment quite significant. Large amounts of sediments and other pollutants are produced, and these destabilize and pollute the ecosystem. A study was conducted to monitor the pollution of water resources by the three major agro-ecosystems in Cameron Highlands i.e. vegetables, floriculture and tea. This encompasses the inorganic and organic water pollution at the farm, sub-catchment and catchment levels. The study was undertaken to alert water users, the farming community and the public at large on the causes and effects of deteriorating water quality due to agricultural activities.

Common agricultural practices

The normal practice in opening new areas for vegetables in highlands begins with deforestation followed by complete destumping, burning, land levelling or terracing, bed preparation and planting. Besides soil loss during the initial land developmental stages, the seasonal soil preparation and its prolonged exposure during the cultivation of vegetables pose constant problems of repeated runoff and erosion.

Prior to vegetable planting, the land undergo extensive levelling and terracing, causing extensive soil erosion, leaving vegetables growing essentially on infertile subsoil surfaces. To ensure that crops are adequately supplied with essential nutrients, large inputs of organic fertilizers (chicken dung), up to 84 t/ha initial application in the newly opened areas, followed by another 28 t/ha during each subsequent season are practised. In addition, cultivated vegetables are susceptible to a number of pests and diseases. Chemical control remains the most popular approach for pest and disease management, and the use of pesticides is extensive. There are large fertilizer and pesticide losses during erosion and leaching due to heavy rainfall. Continued high fertilizer application also inevitably results in toxic fertilizer accumulation in the soils, and as a result, farmers often resort to removing the toxic soils.

In flower cultivation, similar land preparation procedure is adopted, except that flower growing is done under plastic rainshelters. Problems of soil erosion in the flower farms are minimal, due to the rainshelters. However, soil salinization is more acute. In addition, water runoff from the plastic rain shelters is enormous. This can cause landslides, flash floods and river bank erosion. Whereas in tea cultivation, most of the tea areas are on slopes and very little earthwork is involved.

Materials and methods

The investigation on soil erosion and nutrient losses was conducted at plot, sub-catchment and catchment levels. At the plot level, investigations were focussed on cultivation of (i) vegetable (cabbage) in open farms, and (ii) floriculture (chrysanthemum) under rainshelter. In both cases, the farming practices as carried out by farmers were adopted. At the sub-catchment level, each site was selected to represent the dominant land use type i.e. forest, tea, vegetables or flowers. The catchment level represents a mixture of the above land use, including recreational areas and settlements. A summary of the study plots/areas is given in *Table 1*.

The experimental plots P1 and P2 were 150 m^2 in size. Runoff was measured using a tipping bucket system. A capacitance water level recorder with logger was used to record water levels. In both plots, lysimeters and piezometers were installed.

There were several types of sample collected i.e. runoff water, suspended load and bedload from plots, streams and rivers; leachate (from lysimeters) and soil/core samples from plots. In plot P1, water and sediment samples were collected daily and bulked by week, whereas at plot P6 and at sub-catchment and catchment levels, water and sediment samples were collected weekly. All forms of water samples were analyzed for inorganic contents (P, NH_4-N,

Table 1. Location of experimental sites, type of crops and instruments installed

Site	Location	Crop	Area	Slope	Instrument installed
Plots					
P1	MARDI	Cabbage (open)	150 m^2	<3°	Tipping bucket + recorder; piezometer + recorder; lysimeters
P6	Kg. Raja	Flower (rainshelter)	150 m^2	<3°	Tipping bucket + recorder
Sub-catchment					
SCT (tea)	Sg. Palas	Tea	1.2 km^2	20°	UDI ; probe + recorder
SCF (flower)	Batu 51	Flower	0.6 km^2	Hilly	UDI; probe + recorder
SCV (vegetable)	Tringkap	Vegetables	6.8 km^2	Hilly	UDI ; probe + recorder
SCJ (jungle)	MARDI	Jungle	0.2 km^2	Hilly	UDI; probe + recorder
Catchment					
C1	Sg. Telom		88.7 km^2	Hilly	UDI; probe + recorder
C2	Sg. Bertam		20.4 km^2	Hilly	UDI; probe + recorder

NO_3-N, K, Na, Ca, Mg and Cl). P was measured by colorimetric Mo blue method; Na, K, Ca and Mg were measured by atomic absorption spectrometry and Cl using ion selective electrode (Page et al. 1982). Water discharged from catchments and sub-catchments was measured along major streams or rivers within them, using an ultrasonic doppler instrument (UDI) and a capacitance water level recorder with logger.

Pesticide content in water and soils was analyzed, and the USEPA multi-residue method (USEPA 1997) for the analysis of organochlorine and organophosphorous insecticide residues was used. Analysis of synthetic pyrethroids was conducted as detailed by Cheah (1996). The method of analysis of fipronil was provided by May and Baker (Study Ref. P 92/197).

Results and discussion

Soil erosion and nutrient loss

Erosion studies were conducted for three seasons in an open cabbage plot (P1), and in a chrysanthemum plot under rainshelter (P6). The results obtained are presented in *Table 2*. To calculate annual loss, a fallow period of one week between seasons was assumed (or 345 planting days a year).

The plot studies showed that the erosion rate in open vegetable farms can reach 82 t/ha/yr. This is extremely high, implying that this cropping system is unsustainable. In contrast, soil erosion under rainsheltered chrysanthemum farms is only about 1 t/ha/yr, and there was no significant net soil erosion under tea plantation, making both systems sustainable. A similar trend was manifested by the sub-catchment studies, although the magnitude of soil loss was smaller. Sediment concentration ranges from 0 to 0.8 g/L for the vegetable sub-catchment and 0 to 0.7 g/L for the flower sub-catchment.

The lowest value was observed in the tea sub-catchment, which ranged from 0 to 0.5 g/L. This is because the large areas of the subcatchments, which consist of natural depressions and vegetated areas, induced sediment deposition. The sediment concentrations in Bertam river and Telom river vary between 23–1407 and 24–520 mg/L, respectively, depending on seasonal activities in their catchments. They result in high sediment yields of 13–27 t/ha/yr for Bertam river, and 3–10 t/ha/yr for Telom river (Baharudin et al. 1996). This has caused major siltation of the hydroelectric dam located downstream in the Bertam river, which has to be cleared at a high cost, as already discussed by many workers (e.g. Midmore et al. 1996).

Table 2. Soil loss for three seasons in cabbage plot and chrysanthemum plot

Season	Days	Runoff (mm)	Rain (mm)	Bed-load (kg/plot)	Susp. load (kg/plot)	Susp. load (%)	Total soil loss	
							(kg/plot)	(t/ha)
Cabbage plot, P1								
First	110	441	733	163	464	74	627	42
Second	83	547	754	15	227	94	242	16
Third	122	400	401	30	218	88	248	17
Total	315	1 388	1 888	208	909	81	1 117	75
Annual loss							1 222	82
Chrysanthemum plot, P6								
First	99	17		1.4	2.2	61	3.6	0.2
Second	102	44		3.0	2.4	45	5.4	0.4
Third	101	32		5.3	2.6	33	7.8	0.5
Annual loss							19.2	1.3

1 kg/plot = 0.067 t/ha

Eroded soil or sediment from farms contains relatively high amounts of nutrients that ultimately contribute to water pollution. For example, sediment from a cabbage farm contained 0.57% N or 2.2 times more than the surface soil. Hence for a soil loss of 82 t/ha/yr, the loss of N through soil erosion is about 474 kg/ha/yr.

Under open vegetable farming, about 69% of the rainfall become runoff whereas under rainshelter the runoff is about 15% of irrigation water. Besides that, almost all of the rainfall outside the shelter is intercepted, producing large amounts of runoff. Proper management of this runoff water is required to minimize riverbank erosion and up-swelling of rivers.

Water pollution by fertilizers

Loss of inorganic elements in surface runoff The average concentration of inorganic elements in the runoff water during the peak flow period, and the amounts removed in various plots are given in *Table 3*. To calculate annual loss, a fallow period of one week between seasons was again assumed. The runoff losses in streams and rivers are given in *Table 4*.

The loss of inorganic constituents in surface runoff is closely related to the time of fertilizer application. As expected, a lot of nutrient runoff loss occurs during or soon after fertilizer application, whereas in between fertilizer applications, the rate of loss is much lower.

Under open cabbage farming, the nutrient loss per season per hectare is equivalent to 43 kg N, 2 kg P and 109 kg K. The high amount of N and K lost are attributed to the high initial input of chicken dung, which is up to 84 t/ha. The average composition of chicken dung is about 2.1% N, 2.6% P, 3.1% K, 7.2% Ca and 1.0% Mg. In terms of water quality, the concentration of NO_3 in surface runoff from the farm exceeds the acceptable limit of 10 mg/kg (Ahmad et al. 1994). During the peak removal period, the concentration of NO_3 can be as high as 25 mg/kg.

In chrysanthemum cultivation under rainshelter, the amount of pollutants

Table 4. Maximum values of inorganic pollutants recorded in sub-catchments and catchments

	NH_4	NO_3	P	K
SCV	0.3	1.3	0.5	9.1
SCF	0.1	0.7	0.1	7.6
SCT	0	0.8	tr	4.9
SCJ	0	0	0	2.2
Sg. Bertam	0.4	1.2	0.1	3.4
Sg. Telom	0.7	2.0	1.0	3.9

SCV, SCF, SCT and SCJ represent vegetable, flower, tea and jungle sub-catchments respectively

Table 3. Nutrient loss and its concentration in cabbage plot and chrysanthemum plot

	NH_4	NO_3	P	K	Na	Ca	Mg
Cabbage plot, P1							
Season 1: (110 days)							
Losses (g)	35	617	29	1 637	715	2 457	559
Conc. (mg/kg)	1.4	25	1	20	10	26	9
Season 2: (83 days)							
Losses (g)	1	350	74	686	318	1 698	312
Conc. (mg/kg)	0.4	10	2	32	6	44	7
Annual losses (kg/ha/yr)	4	115	12	278	123	497	104
Chrysanthemum plot, P6							
Season 2: (102 days)							
Losses (g)	1	9	15	52	27	199	30
Conc. (mg/kg)	0.7	3	3	17	6	33	5
Annual loss (kg/ha/yr)	0.2	2.0	3.4	11.8	6.1	45.1	6.8

1 g/plot = 0.067 kg/ha

removed in runoff is very low at about <1 kg N, 3.4 kg P and 11.8 kg K per hectare per year. The concentration of NO_3 is also within the acceptable limit of 10 mg/kg.

Loss of inorganic elements through leaching Leaching losses were estimated from the lysimeters (L1 and L2) located in the cabbage plot, P1. The results are presented in *Table 5*.

The loss of applied nutrients through leaching is also high. The results of lysimeter studies showed that the amounts of inorganic elements (except for P and Ca) lost through leaching were comparable to the amounts lost through surface runoff. The occurrence of pollutants is more persistent in the groundwater than in runoff. The amount of inorganic elements lost through leaching first increased, and then decreased with time. This indicates that the applied nutrients will take some time to move through the soil profile before it reaches the ground water table.

In cabbage farms the leaching loss is equivalent to 55 kg N and 138 kg K/season/ha. The loss of P is negligible at only about 1.3 kg P/season/ha. The amount of N leached is capable of polluting the groundwater as its concentration at the maximum leaching period is 40 mg/kg.

Pollutants in streams and rivers Some degree of agricultural pollution was detected in the waters within streams and rivers *(Table 4)*. In the sub-catchments, the highest pollution level was observed in the vegetable area, followed by that in the flower area. Nevertheless the level of pollution, except for P and K, is well below the permissible limits. Some indications of pollution (NH_4-N, P) have been occasionally observed in the catchments, however, in most cases the pollution level is rather low. It is expected that with the anticipated expansion of agricultural areas, the pollution level in both the sub-catchments and catchments will increase.

Soil contamination

In addition to water pollution, the continuous cultivation of flowers under rainshelter may lead to soil salinization (Wong 1993). Electrical conductivity value of up to 3 mS/cm has been recorded, which is higher than the accepted value (2 mS/cm). Therefore, a package of sustainable practices needs to be introduced. This should include judicious and precise application of nutrients and other farm inputs.

Organic pollution

The level of pesticide pollution at various locations is given in *Table 6*. Although the pollution at the farm level is high, it is drastically reduced in the sub-catchment, and even more so in the catchment waters. The persistence of pollution varies according to the type of pesticides.

Ubiquitous occurrence of high endosulfan concentrations in the farm runoff water and water bodies of the sub-catchment and catchment areas demonstrates its high leaching potential. It is the only pesticide pollution that persists beyond the permissible limit at the catchment level.

Table 5. Leaching loss of inorganics under cabbage, and its concentration during the peak removal period

	NH_4	NO_3	P	K	Na	Ca	Mg	Cl
Lysimeter 1								
Losses (g)	69	494	7	1 357	550	2 680	463	5 447
Conc. (mg/kg)	4	25	1	23	10	44	8	90
Lysimeter 2								
Losses (g)	28	821	20	2 076	692	2 658	573	3 301
Conc. (mg/kg)	2	40	1	34	12	55	17	96

1 g/plot = 0.067 kg/ha

Table 6. Pesticides detected at farm level, catchments and sub-catchments

Pesticide	Concentration (ng/mL)		
	Runoff water	Sub-catchment	Catchment
Endosulphan	0.059–958	0.0033–1.92	<0.069–0.34
Dimethoate	<0.03–0.038	<0.03	<0.03
Chlorophyrifos	<0.03–0.23	<0.03–0.25	<0.03–0.02
Cypermethrin	<0.05–0.80	<0.05	<0.05
Fipronil	0.68–108	<0.005–0.70	<0.005
Methamidophos	<0.1	<0.1–1.39	<0.1
Diazinon	<0.03–0.18	<0.03–0.27	<0.03

Note: The maximum permitted level of a single pesticide for drinking water in the EU is 0.1 ng/mL

Among the organophosphorous insecticides examined, diazinon and chloropyrifos were occasionally found in the sub-catchment with residue levels ranging from <0.03–0.27 ng/mL and <0.03–0.25 ng/mL respectively, but in the catchments, their concentrations are insignificant. Based on the experimental results, the potential of leaching of these organophosphates can be considered as moderate. Moderate leaching of fipronil was also evident, as residues of the insecticide were commonly detected in the runoff water (0.68–108 ng/mL) at the farm and at the sub-catchments (<0.005–0.70 ng/mL). It was however, not found in the catchments.

Leaching of pyrethroid compounds such as permethrin, cypermethrin and deltamethrin was not apparent. These insecticides were not found in the sub-catchment and catchment areas. This was most probably due to their short half lives in the environment.

Application of Pesticide Impact Ranking Index (PIRI) Model (Kookana et al. 1999) shows comparable experimental and modelling results of the leaching potential of the pesticides examined.

Conclusion

Erosion, runoff and leaching are major processes for the transport of soils, nutrients and pesticides from the agricultural areas in the highlands to downstream areas. Much of the soil and nutrient losses are related to the type of crops grown and the farming practices adopted. Open vegetable farms in the highlands are not sustainable due to high soil erosion as well as high water pollution from the applied fertilizers. In contrast, similar indicators suggest that the cultivation of a perennial crop (tea) and floriculture under rainshelter are relatively far more sustainable agrosystems.

The use of rainshelter was effective in controlling soil erosion. Nevertheless rainshelters must be constructed in conformity to the landscape, and the excess runoff must be properly managed. Appropriate fertilization techniques, such as judicious application of fertilizer, need to be adopted to avoid unnecessary water pollution and accumulation of the applied nutrients in the soils.

The study demonstrated the leaching potential of endosulfan, chlorpyrifos, diazinon and fipronil, and the use of the pesticides may lead to surface water contamination even up to the sub-catchment level.

The extent of water contamination is severe at the plot level but as expected, it decreases in the sub-catchments and the catchments. The current status of contamination of water resouces in the catchments is related to the extent of existing farm areas. Should the agricultural activities in the future be increased, one would expect that the pollution of the water resources by sediments, fertilizers and pesticides in the catchments would become more severe.

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