Soil Erosion: Perennial Crop Plantations

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INTRODUCTION

Plantation agriculture is an important form of land-use in the tropics. Large areas of natural and regenerated forest have been cleared for growing oil palm, rubber, cocoa, coffee, and other perennial tree crops. These crops grown both on large scale plantations and by smallholders are important source of income for many farmers in tropical regions.

It is generally assumed that a perennial tree cover protects the soil better against erosion than do annual crops. But tree crops may require several years to close their canopy, whereas most annual crops provide adequate cover within six weeks after planting. During the immature phase of tree crops, there may be insufficient soil cover. The effects of tree crops on soil erosion have been fairly well documented. Soil erosion and sediment transport from catchments with natural forests are minimal (<1 Mg ha/yr), but levels of soil erosion tend to increase when natural forest is changed to tree crop plantations. Considerable differences have been found between crops and sites, and much depends on the soil, site factors (slope, rainfall, etc.), and management practices. In this entry, the main findings for oil palm, coffee, cocoa, and tea plantations in tropical regions are reviewed.

EROSION UNDER OIL PALM

Several soil erosion studies under oil palm have been conducted in Malaysia (Table 1). Soil erosion from Oxisols ranged from 13 to 78 Mg ha/yr and depended on the slope of site. Soil erosion on Ultisols ranged from 1 to 28 Mg/ha/yr and the erosion was higher in harvesting paths. In mature oil palm plantations, soil erosion losses chiefly depend on slope of site and soil management practices. Under young oil palm, soil erosion is usually limited because of the cover crop protecting the soil and the limited erosion is not attributable to the palms. This was also reported from rubber plantations (Fig. 1).[1] As the cover crop disappears after the closure of the palm canopy, harvest paths become exposed and compacted which enhances run-off and soil erosion. Therefore, soil erosion may not necessarily decrease when the palms get older and the canopy is closed. Chew,Kee, and Goh[2] reviewed and published soil erosion data for moist forest and tree crop systems. Erosion under mature oil palm ranged from 7 to 21 Mg/ha/yr. These values are lower than those reported in Table 1, but the review showed that soil erosion could be considerable at oil palm plantations in Malaysia.

The effects of erosion under oil palm is that the soil is removed from between the tertiary and quaternary feeding roots near the soil surface, in particular in the weeded circle. Exposed roots dry up and die, so that the water and nutrient uptake capacity of the root system is reduced. Although no experimental evidence is available, it is obvious that oil palms growing under these conditions undergo water deficits and nutritional deficiencies.[3] Moreover, the nutrient use efficiency of applied fertilizers is reduced because of the lower uptake capacity of the roots.

EROSION UNDER COFFEE AND COCOA

Soil erosion losses can be considerable in coffee plantations that have no adequate shade or a low planting density with little natural mulch formed by litter. This is especially important for coffee grown in highlands on steep slopes and in new coffee plantations. Research in Colombia showed that annual soil N losses from unprotected areas exceeded the amount extracted by a good crop of coffee, but on well-developed coffee plantations that are adequately shaded or with a high planting density, erosion can be reduced to less than 2% of the losses that occur on unprotected plots.[4]

In Venezuela, where since the mid-1970s the government has actively promoted the removal of shade trees from coffee plantations, low erosion losses were found.[5] Under shaded coffee, total erosion losses were very low and less than 2 Mg soil ha/yr, whereas under coffee without shade, erosion losses were 7 Mg soil/ha in the first year after the shade was removed. Erosion losses of unshaded coffee after two years were comparable to that of shaded coffee,

Encyclopedia of Soil Science DOI: 10.1081/E-ESS-120041234

Table 1 Soil erosion losses under oil palm in Malaysia

Soil order	Palm age (yr)	Slope (%)	Condition	Soil erosion (Mg/ha/yr)
Tropeptic Hapludox (Oxisols)	2–4	2	With legume cover crop	18.8
		5	With legume cover crop	24.0
		9	With legume cover crop	35.4
		15	With legume cover crop	50.0
	12	<5	Uncovered	12.5
Typic Hapludox (Oxisols)	2–4	2	With legume cover crop	23.5
		5	With legume cover crop	38.8
		9	With legume cover crop	57.1
		15	With legume cover crop	77.6
Orthoxic Tropudult (Ultisols)	11	5	Harvesting path	14.9
			Palm row	7.4
			Beneath row	1.1
Typic Paleudult (Ultisols)	12–16	3–5	Uncovered	28.0
			Plots with fronds cut	19.7
			Plots with extra fronds cut	16.3

(Adapted from Refs.[16,17] based on several studies conducted on peninsular Malaysia between 1979 and 1990.)

whereas in general runoff and soil loss are lower in shaded than in unshaded plantations.[6] The research in Venezuela showed that soil erosion correlated positively with agricultural activities (i.e., harvesting, pruning, and weeding).

Under monocropping cocoa in Malaysia, soil erosion losses were 11 Mg/ha/yr, but losses were considerably lower when cover crops such as *Indigofera spicata* were planted.[7] When the cocoa was intercropped with banana, and clean weeding with herbicide was practiced, soil losses up to 70 Mg soil/ha/yr were measured, which are high losses based on a general rating of tolerable soil erosion losses.[8,9]

EROSION UNDER TEA

In mature tea plantations erosion is negligible (Fig. 2) because of the complete soil cover. Some soil erosion may occur directly after pruning and when the prunings are removed. Othieno[10] reported from Kericho (Kenya) erosion losses up to 168 Mg soil/ha in the first year after the establishment of a tea plantation. In the second year, soil losses were up to 81 Mg/ha, whereas in the third year losses were less than 7 Mg soil/ha. Three-quarter of the total erosion over the three-year period of the experiment occurred between planting and the time when the canopy had developed to 30%. Soil erosion can also be a problem when plantations run-down. This was found to occur in Sri Lanka where tea plantations have been neglected since the mid-1970s, causing serious soil erosion of vacant patches.[11]

THE EFFECTS OF SOIL EROSION ON SOIL CHEMICAL PROPERTIES

The on-site and off-site effects of soil erosion are well documented. In tropical regions where many soils suffer from an inherent low fertility that is mostly concentrated in the topsoil, loss of topsoil by soil erosion means a serious reduction in soil chemical fertility.[12–14] Moberg[15] compared soil fertility properties of Oxisols developed from sandstone in eroded and noneroded coffee plots and in virgin land near Lake Victoria, Tanzania. Coffee gardens where erosion occurred were more acid and had lower levels of soil fertility than noneroded soils with coffee, the levels of which were comparable to virgin soils (Table 2).

EROSION CONTROL

Soil erosion is likely to occur during land preparation and when the tree crop is immature, but several well-established measures exist and are being used. On oil palm plantations, soil erosion is commonly checked by early cover crop establishment, strategic placement and treatment of pruned fronds, and old palm trunks with felling, terracing, construction of silt pits, and mulching with empty fruit bunches.[16] Research in Kenya indicated that soil erosion in fields with young tea can be effectively controlled by either mulching or inter-row planting of oats, although oats may compete with young tea for water and nutrients.[10]

Fig. 1 Young rubber trees with cover crop in North Sumatra. *(View this art in color at www.dekker.com.)*

In general, cover crop establishment and terracing sufficiently control erosion in tree crop plantations in tropical regions.

CONCLUSIONS

Soil erosion under perennial crops is relatively low, provided the crops are well managed.[17] Measured data show that erosion could be high in oil palm,[16] cocoa,[7] and tea[10]– particularly during establishment or when plantations are neglected. Agroforestry research has accumulated considerable evidence confirming lower erosion in land-use systems with tree crops than with perennial plantation crops.[18,19] The available data confirm that soil erosion is lower in land-use systems with perennial crops than under annual cropping: land-use systems with perennial crops form better protection against soil erosion than annual crops, simply because they cover the soil throughout the whole year. The risks of soil erosion under plantation crops differ among crop species depending upon their canopy characteristics and soil management system.[20,21] As soil erosion affects the soil chemical fertility, the fertility of the soil should be taken into account when interpreting erosion losses. In general, tolerable losses from acid and poor fertility

Fig. 2 Mature tea plantation in the Papua New Guinea highlands. *(View this art in color at www.dekker.com.)*

Table 2 Soil chemical properties in eroded and noneroded Oxisols under coffee and in virgin Oxisols near Lake Victoria, Tanzania

					CEC and exchangeable cations (mmol/kg)			
Land-use	**Sampling depth (m)**	**pH**	**Organic C (g/kg)**	**Available P (mg/kg)**	**CEC**	**Ca**	**Mg**	**K**
Virgin	0–0.15	5.2	25.2	12	259	61	40	1.8
	0.15–0.30	4.2	14.5	3	249	22	8	1.0
Coffee (noneroded)	0–0.15	5.2	25.9	33	160	52	21	3.2
	0.15–0.30	4.8	12.2	3	128	23	18	1.8
Coffee (eroded)	0–0.15	4.1	19.0	5	256	23	14	1.9
	0.15–0.30	3.9	13.1	<2	259	8	3	1.6

CEC, cation exchange capacity.
(Adapted from Refs.[15,17].)

soils should be appraised much lower than losses from inherently fertile soils.

REFERENCES

1. Morgan, R.P.C. *Soil Erosion and Conservation*; Longman: Harlow, 1995.
2. Chew, P.S.; Kee, K.K.; Goh, K.J. Cultural practices and their impact. In *Oil Palm and the Environment—A Malaysian Perspective*; Singh, G., Huan, L.K., Leng, T., Kow, D.L., Eds.; Malaysian Oil Palm Growers' Council: Kuala Lumpur, 1999; 55–81.
3. Ferwerda, J.D. Oil palm. In *Ecophysiology of Tropical Crops*; Alwim, T.P., Kowlowski, T.T., Eds.; Academic Publisher: New York, 1977; 351–382.
4. Bornemisza, E. Nitrogen cycling in coffee plantations. Plant Soil **1982**, *67*, 214–246.
5. Ataroff, M.; Monasterio, M. Soil erosion under different management of coffee plantations in the Venezuelan Andes. Soil Technol. **1997**, *11*, 95–108.
6. Beer, J.; Muschler, R.; Kass, D.; Somarriba, E. Shade management in coffee and cacao plantations. Agroforestr. Syst. **1998**, *38*, 139–164.

7. Hashim, G.M.; Ciesiolka, C.A.A.; Yusoff, W.A.; Nafis, A.W.; Mispan, M.R.; Rose, C.W.; Coughlan, K.J. Soil erosion processes in sloping land in the east coast of Peninsular Malaysia. Soil Technol. **1995**, *8*, 215–233.
8. Hudson, N. *Soil Conservation*; B T Batsford Limited: London, 1986.
9. Hartemink, A.E. Nutrient stocks, nutrient cycling, and soil changes in cocoa ecosystems—a review. Adv. Agronomy **2005**, *86*, 227–253.
10. Othieno, C.O. Surface run-off and soil erosion on fields of young tea. Trop. Agric. **1975**, *52*, 299–308.
11. Botschek, J.; Neu, A.; Skowronek, A.; Jayakody, A.N. Agricultural suitability of degraded Acrisols and Lixisols of former tea lands in Sri Lanka. Zeitschrift fur Pflanzenernahrung und Bodenkunde **1998**, *161*, 627–632.
12. Lal, R. Soil degradative effects of slope length and tillage method on Alfisols in Western Nigeria. 2. Soil chemical properties, plant nutrient loss and water quality. Land Degrad. Dev. **1997**, *8*, 221–244.
13. Ruppenthal, M.; Leihner, D.E.; Steinmuller, N.; Elsharkawy, M.A. Losses of organic matter and nutrients by water erosion in cassava-based cropping systems. Exp. Agric. **1997**, *33*, 487–498.
14. Zobisch, M.A.; Richter, C.; Heiligtag, B.; Schlott, R. Nutrient losses from cropland in the central highlands of Kenya due to surface runoff and soil erosion. Soil Tillage Res. **1995**, *33*, 109–116.
15. Moberg, J.P. Some soil fertility problems in the west lake region of Tanzania, including the effects of different forms of cultivation on the fertility of some Ferralsols. East Afr. Agric. Forestry J. **1972**, 35–46.
16. PORIM. *Environmental Impacts of Oil Palm Plantations in Malaysia*; Palm Oil Research Institute of Malaysia: Malaysia, 1994.
17. Hartemink, A.E. *Soil Fertility Decline in the Tropics—with Case Studies on Plantations*; ISRIC-CABI Publishing: Wallingford, 2003.
18. Young, A. *Agroforestry for Soil Management*, 2nd Ed.; CAB International: Wallingford, 1997.
19. Sanchez, P.A. Science in agroforestry. Agroforestry Syst. **1995**, *30*, 5–55.
20. Lal, R. *Soil Erosion in the Tropics—Principles and Management*; McGraw-Hill: New York, 1990.
21. Lal, R. A brief review of erosion research in the humid tropics of south east Asia. In *Soil Conservation and Management in the Humid Tropics*; Greenland, D.J., Lal, R., Eds.; John Wiley: Chichester, 1979; 203–212.