

Characterization of Surface Runoff, Soil Erosion and Nutrient Loss on Forest-Agriculture Landscape

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ABSTRACT

The study was aimed to quantify volume of surface runoff, soil erosion and nutrient loss from the forest-agriculture landscape (forest margins) in Lore Lindu National Park Central Sulawesi. Surface runoff volume and soil erosion were measured daily on erosion plots. It was installed on several land use types i.e. forest land, maize, young cocoa, medium cocoa, old cocoa, vanilla, shrub and bush and bareland, on the soil Typic Dystrudepts with slope \pm 40%. The nutrient content in surface runoff and sediments were analyzed from selected surface runoff and sediment samples. Surface runoff and soil erosion from agriculture land were respectively 2.1 to 3.4 and 3.6 to 5.8 times higher than from forest lands. Meanwhile, surface runoff and soil erosion from bareland were respectively 7.0 and 23.7 times greater than forest land respectively. Sediment nutrient contents from forest land were higher than agriculture land. In the contrary, total nutrient lost from agriculture land were higher than forest land ones. Nutrient losses carried by surface runoff were larger than those losses carried by sediments. Dissolved organic carbon (DOC) loss in surface runoff was 6,1 to 8,0 times higher than total organic carbon (TOC) loss in sediments. Likewise, nitrate (NO_3^-) loss in surface runoff was 1.9 to 12.1 times higher than total nitrogen (TN) in sediments as well as potassium, calcium, magnesium and sodium losses. Potassium is dominant cation loss carried by the surface runoff, while calcium is mainly carried by sediment.

Keywords: Dissolve organic carbon, forest-agriculture landscape, nutrient loss, soil erosion, surface runoff

INTRODUCTION

Nutrients loss due to surface runoff and soil erosion carried away from agriculture land is the main cause of soil degradation of agriculture land, particularly on conventionally land management (Bertol *et al.* 2003) and steep slope. Nitrogen, phosphorus, organic carbon, potassium, calcium, magnesium and sodium are the main nutrients loss carried by overland flow and soil erosion (Mello 2002 cited by Bertol *et al.* 2003).

Loss of nutrients can be expressed in terms of nutrient concentrations in surface runoff and transported sediment, or total nutrients loss carried by surface runoff and soil erosion per unit of time (days, seasonal or annual rain). The amount of nutrient loss is influenced by soil type and soil fertility, type fertilizer and application methods, crop canopy cover, slope, and rainfall volume and intensity (Gascho *et al.* 1998), as well as soil and crop managements (Barisas *et al.* 1978).

Conventional land management is usually conducted by clearing weeds and litter of plants, hoeing and smoothing the soils, so that conventionally cultivated lands are characterized by clean, flat and smooth of soil surfaces. Conservation tillage is distinguished by conventional tillage due to presence of litter and crop residues in the soil surface and higher of surface roughness. Therefore the rate of surface runoff and soil erosion can be reduced, and nutrients loss will be lower in conservation tillage systems (King *et al.* 1996).

Loss of nutrients are expected to be reduced by tillage systems and crop management that retain crop residues on soil surface. But, crop residues and decomposed litters can be flush (Burwell *et al.* 1975) and dissolved nutrients can be carried away by surface runoff and soil erosion (Barisas *et al.* 1978; Johnson *et al.* 1979). Similarly most of the nutrients (especially potassium) that resulted from burned crop residues and other vegetations on cultivation system will disappear and is carried by surface runoff and soil erosion.

The research was aimed to quantify volume of surface runoff, soil erosion and nutrients loss from

the forest–agriculture landscape of Lore Lindu National Park, Central Sulawesi.

MATERIALS AND METHODS

Study Site

Descriptive field research (non-experimental design) was conducted to measure surface runoff volume, soil erosion and nutrient loss from several land use types, which were located on an agriculture-forest landscape of Lore Lindu National Park. Administratively research sites was located in Bulili village, Palolo Subdistrict, Central Sulawesi.

Data Collected

Surface runoff and soil erosion were measured daily volume of surface runoff and amount of eroded soil were collected in the tank at down end of erosion plot. The erosion plots were constructed on a 40% slope and several landuse types namely forest, maize, maize + peanut, young cocoa, medium cocoa, old cocoa, young cocoa + banana, young cocoa + maize + cassava, vanilla, shrub and bush, reed (*Imperata Cylindrica*), and bareland. The content of nutrients that were carried by surface runoff and soil erosion were analyzed from selected surface runoff and sediment samples that were collected from July 2004 to May 2005.

Soil Analysis

Analysis of soil physical properties were conducted in the laboratory of Department of Soil Science and Land Resources, Bogor Agricultural University, while soil and sediment chemical characteristics (organic carbon, total nitrogen, exchangeable of calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na)), nutrients content in surface runoff (NO_3^- , dissolve organic and inorganic carbons, calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na)) were analyzed in the Laboratory of STORMA-UNTAD, Faculty

of Agriculture, University of Tadulako. Types and methods of analysis are presented in Table 1.

Data Analysis

Data were analysed descriptively by comparing measured data between land use types. Statistically, a pairwise comparison test (Sudjana 1992) was used to identify significant level of daily data of surface runoff volume and soil erosion.

RESULTS AND DISCUSSION

Surface Runoff and Soil Erosion

Surface runoff and soil erosion from agriculture land were higher than forest land. Surface runoff from young cocoa, medium cocoa, old cocoa, maize, maize + bean, young cocoa + banana, young cocoa + cassava, cocoa + maize + cassava, shrubs and bush, and reeds (*Imperata cylindrica*) were 2.1 to 3.4 times greater than the surface runoff from forest lands. While surface runoff volume of bareland could reach 7 times greater than forest land. Soil erosion from agriculture land and bareland were 3.6 to 5.8 and 23.7 times higher than forest land, respectively (Table 2). The results of pairwise comparison test ($n=72$, $\alpha=0.1$) showed that daily surface runoff volume and soil erosion were significantly different between land use types. Daily surface runoff volume and soil erosion on young cocoa were significantly different than medium cocoa, even though values of accumulated data from September 2004 to May 2005 seemed hardly different.

Low rainfall interception due to low plant canopy cover and low infiltration rate on agriculture land were the major cause of high surface runoff. The increase of surface runoff volume and the increase of sediment transport capacity were linearly correlated so that resulting higher soil erosion on agriculture land. Rainfall interception on agriculture land that ranged between 8.4% (maize) to 10.7% (medium cocoa) were lower than forest land one

Table 1. Types of analysis and method for the soil, sediment, and surface runoff analysis.

Type of Analysis	Type of Sample	Analysis Method
Organic carbon	Soil, Sediment	Walkley-Black (dichromate), titration
Total nitrogen	Soil, Sediment	Micro-Kjeldahl, titration
Exchangeable Ca, Mg, K, and Na	Soil, Sediment	NH_4OAc pH 7, AAS
$\text{N}(\text{NO}_3^-)$	Surface runoff	CFA (continous flow analysis)
DIC (<i>dissolve inorganic carbon</i>)	Surface runoff	CFA
DOC (<i>dissolve organic carbon</i>)	Surface runoff	CFA
Ca, Mg, K, Na	Surface runoff	ICP

Table 2. Surface runoff and soil erosion from agriculture and forest lands on Typic Eutrudepts, slope 40% and rainfall 1,696 mm (Hidayat *et al.* 2010).

Landuses	Surface runoff		Soil erosion	
	mm	CtNF*	kg ha ⁻¹	CtNF*
Natural forest	31.1	-	288.6	-
Bareland (clean weeded)	216.2	7.0	6826.6	23.7
Young cocoa	104.3	3.4	1674.0	5.8
Medium cocoa	103.9	3.3	1391.3	4.8
Old cocoa	68.7	2.2	1543.8	5.3
Maize	66.2	2.1	1548.0	5.4
Maize + peanut	65.7	2.1	1690.7	5.9
Young cocoa + banana	87.0	2.8	1317.5	4.6
Young cocoa + cassava	79.5	2.6	1561.7	5.4
Young cocoa + maize + cassava	81.6	2.6	1551.4	5.4
Shurbs	72.1	2.3	1140.4	4.0
Reeds (<i>Imperata cylindrica</i>)	66.2	2.1	1048.6	3.6

*CtNF: Compared to natural forest (factor higher).

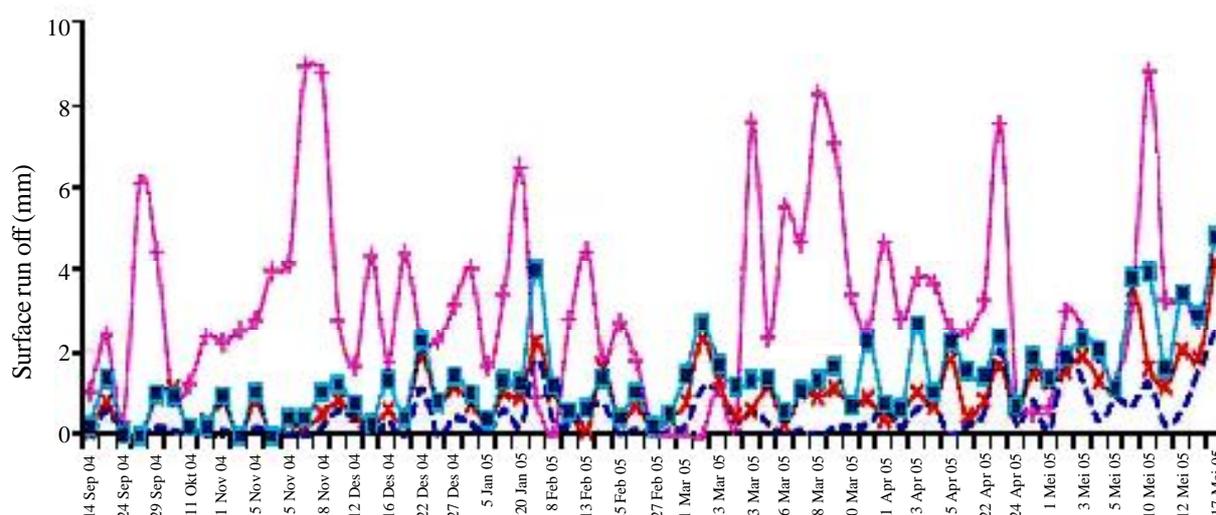


Figure 1. Surface run off from forest, bareland, intercropping maize + peanut, and cocoa September 2004-May 2005). --- = forest, —+— = bareland, —x— = intercrop maize + peanut, and —■— = cocoa.

(28.5%) (Hidayat 2009). Infiltration rate of forest land that was classified as moderate-very fast (7.50 - 40.26 cm hr⁻¹) was higher than on agriculture land (0.75 to 17.96 cm hr⁻¹ (young cacao), 1.02 - 2.05 cm hr⁻¹ (medium cocoa), 0.015-3.00 cm hr⁻¹ (old cocoa), and 4.44 to 9.00 cm hr⁻¹ (maize + peanut)) (Hidayat *et al.* 2008). Performance of surface runoff in several rain days is presented in Figure 1 and 2.

Ground clearing and tillage activities at the time of planting agriculture crops as well as weeding and maintenance activities of plants (bundling surrounding plant stands) were the major cause of high soil erosion on intercropping maize + peanut, maize, and intercropping young cocoa maize +

cassava. It was consistent with the research result of Roose (1986) who showed that clearing of forests (clear felling system) led to increase soil erosion by more than 10-folds.

Nutrient Loss in Transported Sediments

Soil Organic Carbon and Total Nitrogen

Soil organic carbon in transported sediment from forest land was 1.7 - 4.4 times higher than from agriculture land ones. However, the amount of soil organic carbon lost from agriculture land was higher (1.6 to 5.3 times) than forest land. The same pattern was also observed in total nitrogen, where

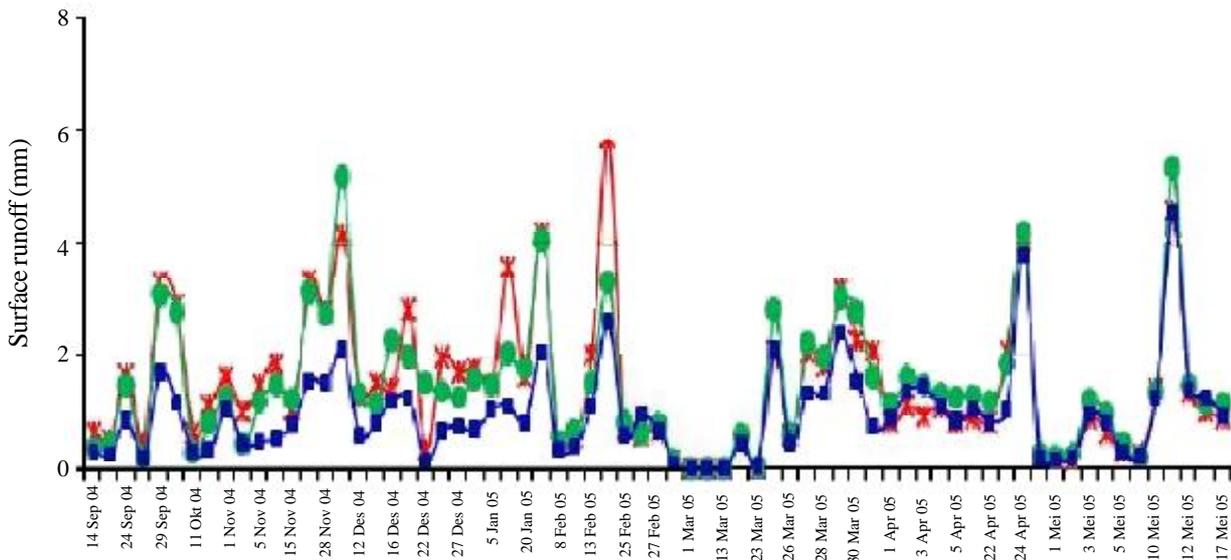


Figure 2. Surface run off from young, medium and old cocoas (September 2004-May 2005). * = young cocoa, ● = medium cocoa, and ■ = old cocoa.

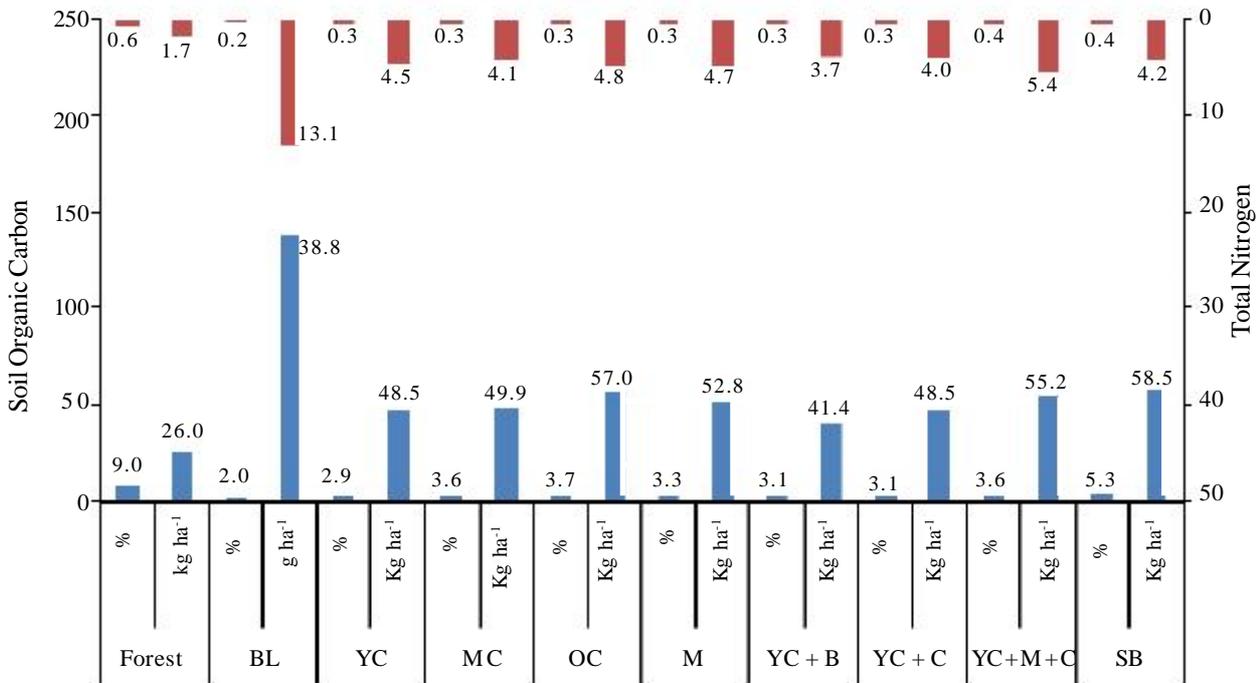


Figure 3. Soil organic carbon and total nitrogen losses carried by sediment from forest land (Forest), bareland (BL), young cocoa (YC), medium cocoa (MC), old cocoa (OC), maize (M), young cocoa + banana (YC + B), young cocoa+cassava (YC + C), young cocoa + maize + cassava (YC + M + C), and shrub and bush (SB).

total nitrogen levels in sediment from forest land was 1.6 to 3.1 higher than agriculture land. Conversely, the total loss of nitrogen from agriculture land was 2.1 to 7.5 times higher than forest land (Figure 3).

The high levels of soil organic carbon and total nitrogen in the sediment of forest land were due to it's fine texture sediment (clay) and the large amount of litter and other organic materials that had been decomposed in forest floor. Conversely sediment

derived from bareland was more coarse-textured (sand) and it had low level of organic matter and other nutrients. Although the levels of organic carbon was high, the amount of soil organic carbon and total nitrogen lost from forest land were much lower than the agriculture and bareland. Loss of total soil organic carbon from forest land was 26.4 kg ha⁻¹ and it only occupied about 18.8% of total soil organic carbon lost from bareland.

Potassium, Calcium, Magnesium and Sodium

Potassium, calcium, magnesium and sodium contents in transported sediments from forest land were 3.91, 38.8, 8.47, and 0.8 cmol kg⁻¹ respectively that were much higher than those contents in the bareland, *i.e.* 0.54, 8.97, 1.64 and 0.57 cmol kg⁻¹. Total potassium, calcium, magnesium and sodium lost by soil erosion from bareland respectively 1.44, 12.26, 1.36, and 0.89 kg ha⁻¹ were higher than total nutrients losses from forest land that were 0.44, 2.22, 0.30, and 0.04 kg ha⁻¹. In other words, converting of forest land into bareland caused increasing loss of potassium, calcium, magnesium and sodium respectively 326.2, 552.6, 457.3, and 2303.4%.

The same pattern was noted for agriculture lands (Figure 4).

Selectivity of soil erosion which mostly transported fine soil particles and colloidal size of organic matter (lighter) caused nutrient content in transported sediments were higher than in the origin soil (top soil). The increase of nutrients content in sediment were highest on forest land but lowest on bareland. Soil organic carbon in transported sediment from forest land (9.02%) increased 2.8 times compared to the soil organic carbon of topsoil (0-10 cm), *i.e.* 3.23%. Total nitrogen and potassium also increased by 2.1 and 2.5 times. The increasing of nutrient contents in transported sediments occurred in bareland, young cocoa, medium cocoa, maize, young cocoa + maize + cassava (Figure 5).

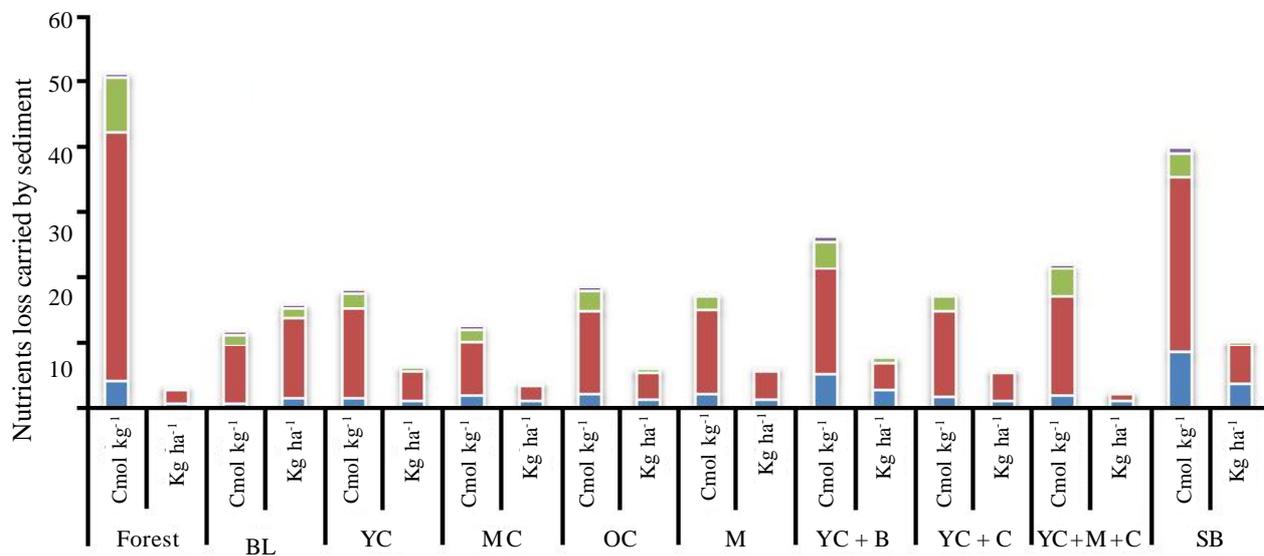


Figure 4. Potassium, calcium, magnesium and sodium loss carried by sediment from forest land (Forest), bareland (BL), young cocoa (YC), medium cocoa (MC), old cocoa (OC), maize (M), young cocoa + banana (YC + B), young cocoa+cassava (YC + C), young cocoa + maize + cassava (YC + M + C), and shrub and bush (SB).

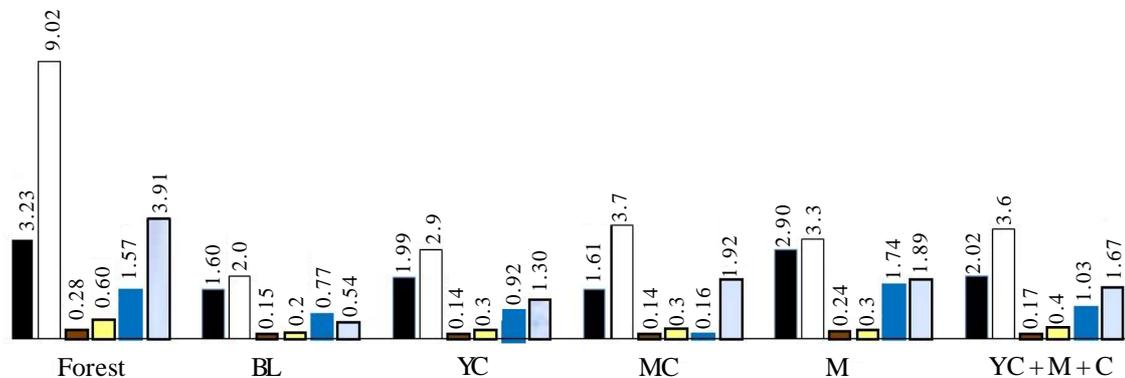


Figure 5. Soil organic carbon (%C), total nitrogen (%N), and potassium (cmol kg⁻¹ K) in topsoil (0-10 cm) and sediments from forest land (Forest), bareland (BL), young cocoa (YC), medium cocoa (MC), maize (M), and intercropping young cocoa+maize+cassava (YC + M + C).

Nutrients Loss in Surface Runoff

Dissolved Carbon

Surface runoff that flows above soil surface transports dissolved nutrients which in turn lead to nutrient loss from the soil (especially agriculture land). Dissolved nutrients then enter into the water bodies and cause nutrients enrichment of the water system (eutrophication). Dissolved organic carbon (DOC) is a major loss of carbon compounds carried by the flow of surface runoff. Compared to dissolved inorganic carbon (DIC), the proportion of DOC was average 74%, while the DIC is about 26% (Figure 6). The highest DOC concentrations was found in forest lands, *i.e.* 57.12 mg l⁻¹, and the lowest (0.10 mg l⁻¹) was in intercropping young cocoa + maize + peanut. Moore *et al.* (2008) showed DOC concentrations of leachate from

incubated soil (forest soil and peat soil) ranged from less than 2 mg l⁻¹ to more than 50 mg l⁻¹.

Loss of carbon carried by flow of surface runoff (DC) was higher than its loss by transported sediment (TOC, total soil organic carbon). Comparison of DC to TOC were 6.1 times on the maize and 8.0 times on forest land (Figure 7).

Nitrate (NO₃⁻)

Nitrate is a major loss of nitrogen compound transported by surface runoff. Loss of nitrate from agriculture land was 2.0 to 14.2 times higher than forest land. The highest nitrate loss was obtained on intercropping of young cocoa + cassava + maize (YC + M + C), *i.e.* 65.7 kg ha⁻¹. Loss of nitrogen transported by surface runoff (NO₃⁻) was 1.9 to 12.1 times higher than its loss carried by sediments (total nitrogen/TN) (Figure 8).

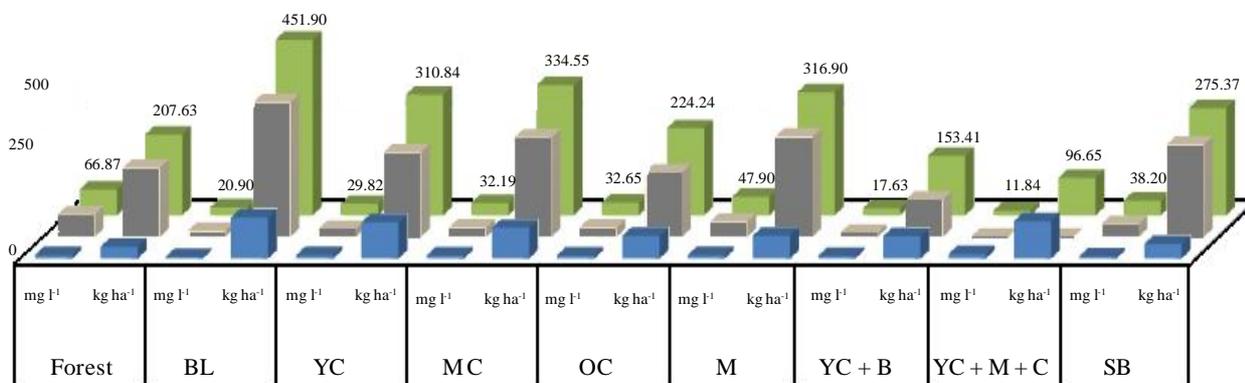


Figure 6. Dissolved inorganic carbons (■), dissolved organic carbons (■), and total dissolved carbons (■) in surface runoff on forest land (Forest), bareland (BL), young cocoa (YC), medium cocoa (MC), old cocoa (OC), maize (M), young cocoa + banana (YC + B), young cocoa + maize + cassava (YC + M + C), and shrubs and bush (SB).

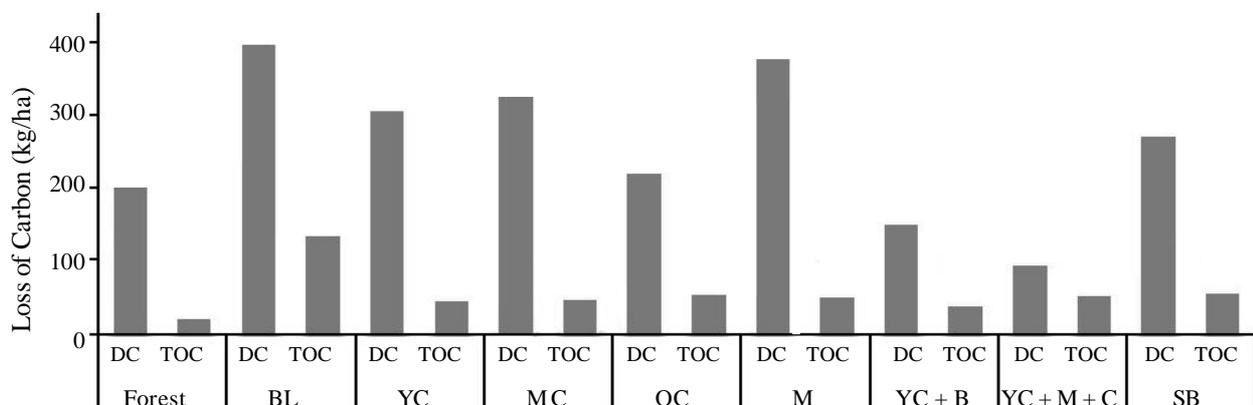


Figure 7. Dissolved carbon (DC) carried by flow of surface runoff and total soil organic carbon (TOC) transported by sediment from forest land (Forest), bareland (BL), young cocoa (YC), medium cocoa (MC), old cocoa (OC), maize (M), young cocoa+banana (YC + B), young cocoa + maize + cassava (YC + M + C), and shrub and bush (SB).

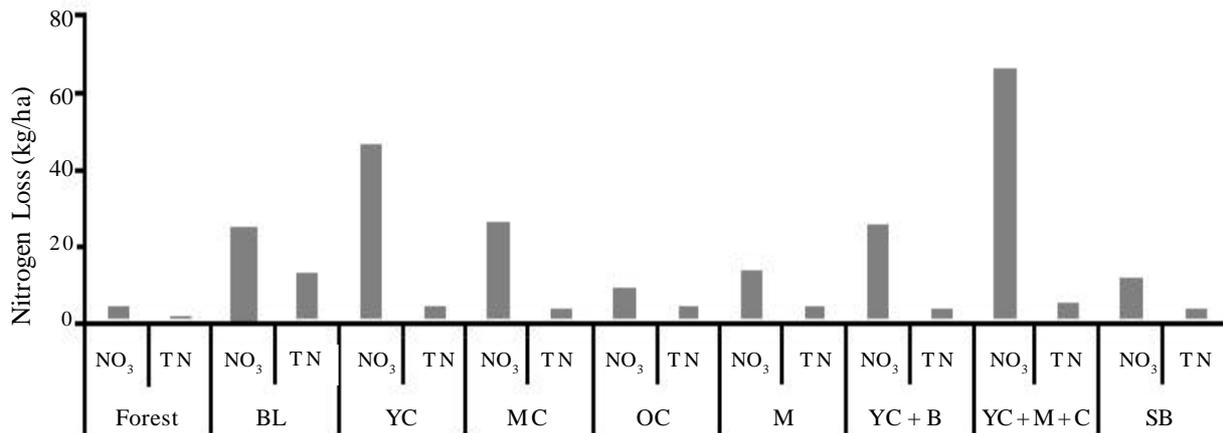


Figure 8. Loss of nitrogen carried by surface runoff (NO₃⁻) and transported by sediment (TN) from forest land (Forest), bareland (BL), young cocoa (YC), medium cocoa (MC), old cocoa (OC), maize (M), young cocoa+banana (YC + B), young cocoa+maize+cassava (YC + M + C) and shrub and bush (SB).

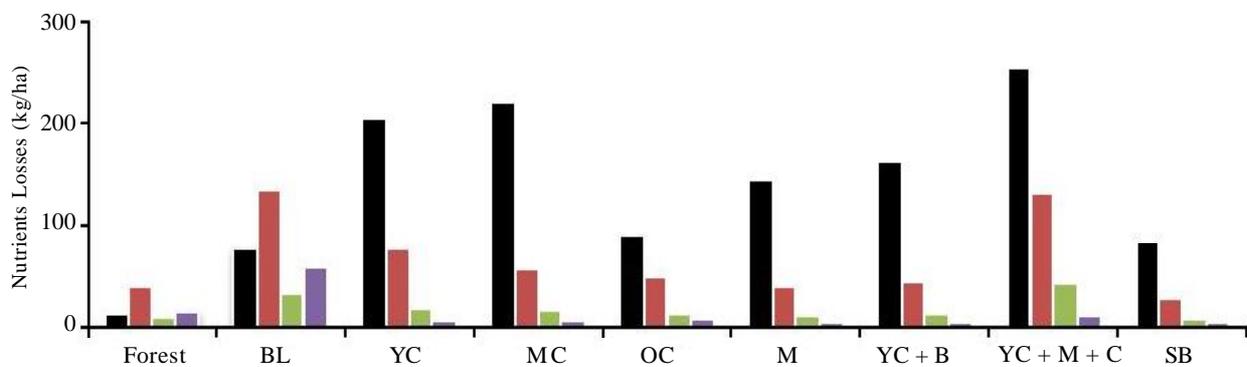


Figure 9. Loss of potassium, calcium, magnesium and sodium transported by surface runoff from forest land (Forest), bareland (BL), young cocoa (YC), medium cocoa (MC), old cocoa (OC), maize (M), young cocoa + banana (YC + B), young cocoa + maize + cassava (YC + M + C), and shrub and bush (SB).

Potassium, Calcium, Magnesium and Sodium

Potassium is the main base cation loss carried by flow of surface runoff. The highest potassium loss was 255.5 kg ha⁻¹ namely in intercropping young cocoa + maize + cassava, but the lowest was 12.6 kg ha⁻¹ on the forest land (Figure 9). Potassium content in top soil was relatively high that resulted from burned materials (wood, shrub, plant litter, and other organic materials above ground surface). Potassium is easily carried by surface runoff because its bound on soil particle more weakly compared to calcium and magnesium. Loss of potassium, calcium, magnesium and sodium transported by surface runoff are higher than it was loss carried by sediments (Hidayat *et al.* 2010).

CONCLUSIONS

Surface runoff and soil erosion from agriculture land were higher than forest land. Low rainfall interception due to low plant canopy cover and low infiltration rate were the major cause of high surface runoff and soil erosion on agriculture land. Concentrations of nutrients lost were inversely proportional to the surface runoff and soil erosion volume.

Nutrients content on transported sediment from forest land were higher than agriculture land, but total nutrients loss from forest land were farly less than agriculture land.

Nutrients loss carried by flow of surface runoff were higher than transported sediments ie. carbon, nitrogen, potassium, calcium, magnesium, and sodium.

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