

# Erosion and Surface Runoff on Forest and Oil Palm Plantation in Jalemu Watershed, Gunung Mas Regency, Central Kalimantan Province

Adi Jaya<sup>\*1</sup>, Cakra Birawa<sup>1</sup>, Fengky Florante Adji<sup>1</sup>, Mochamad Anwar<sup>1</sup> and Irwan Sukri Banuwa<sup>2</sup>

<sup>1</sup>Faculty of Agriculture, Universitas Palangka Raya, Jl. Yos Soedarso, Palangka Raya, Indonesia  
<sup>\*</sup>e-mail: adijaya@agr.upr.ac.id

<sup>2</sup>Department of Soil Science, Faculty of Agriculture, University of Lampung, Jl. Sumantri Brojonegoro No. 1  
Bandarlampung 35145, Indonesia, e-mail: irwanbanuwa@yahoo.com

Received 06 Februari 2018/ accepted 15 August 2018

## ABSTRACT

Changes of land cover from forest to non-forest areas affect the hydrological cycle and water quality in watershed ecosystems, such as the change of forest into oil palm plantation areas. Increased production and extension of oil palm plantations have impacts on the environment and water quality, which have become one of the environmental issues. The study was conducted to provide an overview of the erosion and surface runoff from forest and oil palm plantations and their impacts on the water quality. Erosion plots with the size of 15 m × 25 m were made on Jalemu Watershed, Gunung Mas Regency, Central Kalimantan Province. The research was conducted to study the impact of land cover changes on erosion and surface runoff and nutrient loss into the Jalemu River Basin. Sampling of sediments and runoff water was carried out from the erosion plots, including water sampling from Jalemu watershed. The results showed that the erosion and surface runoff that occurred in the 5 years old oil palm area were higher than in the forest area, which implied the loss of nutrients from oil palm plantation areas and the potential for water pollution by the nutrients.

---

**Keywords:** Erosion, nutrient loss, oil palm, surface runoff

## ABSTRAK

Perubahan tutupan lahan dari kawasan hutan menjadi kawasan non hutan diyakini akan berpengaruh pada kondisi hidrologi dan kualitas air dalam ekosistem daerah aliran sungai (DAS), salah satunya adalah konversi hutan menjadi kawasan perkebunan kelapa sawit. Peningkatan produksi dan perluasan perkebunan kelapa sawit memberikan dampak pada lingkungan dan kerusakan perairan yang disebabkan oleh perkebunan kelapa sawit tersebut, dan telah menjadi salah satu isu lingkungan. Penelitian ini dilakukan untuk memberikan gambaran besarnya erosi dan aliran permukaan dari perkebunan kelapa sawit dan dampaknya pada perairan. Plot erosi yang berukuran masing-masing 15 m × 25 meter dibuat pada kawasan DAS Jalemu, Kabupaten Gunung Mas, Provinsi Kalimantan Tengah, yang mencakup kawasan perkebunan kelapa sawit dan hutan, untuk mempelajari dampak perubahan tutupan lahan terhadap tingkat erosi dan aliran permukaan serta hara yang hilang dalam kedua proses tersebut yang akan mengalir ke DAS Jalemu. Sampling sedimen dan air dilakukan dari bak penampung erosi dan aliran permukaan serta dilakukan pula sampling air dari DAS Jalemu. Hasil penelitian menunjukkan bahwa erosi dan aliran permukaan yang terjadi pada kawasan perkebunan kelapa sawit yang berumur 5 tahun lebih besar daripada erosi dan aliran permukaan yang terjadi di kawasan hutan. Hal ini juga berimplikasi pada hilangnya unsur hara dari kawasan perkebunan kelapa sawit dan potensi pencemaran perairan oleh unsur hara tersebut.

---

**Kata Kunci:** Aliran permukaan, erosi, kehilangan hara, kelapa sawit

## INTRODUCTION

Production of oil palm (*Elaeis guineensis*) has grown rapidly in the tropics over the last decades. As the world's largest palm oil producer since 2007, the Indonesian Government plans to increase the production to 40 million tons of crude palm oil by 2020, mainly in Sumatra, Kalimantan and West Papua (IMA 2010). Riau Province in Central Sumatra is the largest producer of palm oil in Indonesia, around 24% of the total national production. From 2004 to 2009, the area of oil palm plantation in Riau Province increased by 21% (IMA 2010; Susanti and Burgers 2012), and during its development, the area of oil palm cultivation and production in Central Kalimantan also increased. The development of the area of oil palm plantations in particular in Central Kalimantan is quite large and the production has increased very rapidly. Palm oil is one of the major industrial commodity in Indonesia that contributes to the economy of Indonesia as the largest non-oil and gas product for exports (Susila 2004). Rapid expansion of the palm oil industry shows that extraordinary land use changes are taking place in Indonesia, which raise concern for the environment and human health.

Various environmental issues continue to occur in relation to the development of oil palm plantations, including issues related to the water conditions and water quality in the regions surrounding the oil palm plantations. Regarding to the water crisis in various regions, some people have accused that oil palm companies have largely contributed to the waste water discharge to run their plantations. Issues concerning disruption of regional water systems caused by the development of oil palm plantations have become serious environmental issues. Oil palm plantations are considered to contribute to the decrease of groundwater level and availability. These challenges can affect the productivity and export volumes of palm oil and its derivative products. The issues of oil palm plantations are being one of the environmental issues due to the impact of oil palm plantations for the surrounding area, however, there are no data to support these allegation. Along with the erosion and surface runoff that occur on oil palm plantations, there are indications that they will lead to changes in water quality in the aquatic ecosystem around the oil palm plantations related to the dissolved and transported nutrients in the sediments. The water loss and disruption of the water system in the oil palm plantation area are probably caused mainly by the loss of water storage function on the plantations, and not by the consumption of palm oil.

Most activities related to the development of oil palm plantations and exploitation (*e.g.* forest clearing, road construction and drainage channels, use of agricultural chemicals and the release of wastewater) present risks to land surface and groundwater quality (ECD 2000; Goh *et al.* 2003). Hydrological conditions and aquatic ecosystems close to the plantation area are very risky to have a decrease water quality because fertilization is applied on the plantations at a relatively high amount (Sheil *et al.* 2009). Runoff and drainage water on oil palm plantations can be controlled by the legume cover crops that are grown in the plantation area. Furthermore, the decomposition of the legume cover crops under the plant canopy releases nitrogen that previously derived from nitrogen fixation (Breure 2003; Campiglia *et al.* 2010; Goh *et al.* 2003) and this condition will increase the amount of nutrients carried by the surface runoff. Goh and Chew (1995) indicated that the nitrate loss through leaching from legume cultivation is influenced by soil texture, and the greater loss occurs in sandy soils. However, the understory vegetation is disappeared due to the effect of the large canopy of oil palm plants, in which the legume cover crops contrarily can control the excess of water and nutrient-rich sediments. Land use change, especially from forests to agricultural land or grassland, greatly influences nutrient fluxes in the watersheds (Vitousek *et al.* 1997). The effect of converting forests to plantations on nitrogen and phosphorus in soil has not been completely understood. Vegetation changes by logging practices might have an impact on the river water quality through loss of biomass, the amount of logging on the forest floors, and accelerated soil erosion and N mineralization (Nykvist *et al.* 1994).

The objective of this research was to study the magnitude of erosion and surface runoff in the watershed area covering the oil palm plantations. The results of this study is expected to be able to indicate the causes of the potential damage of watershed area due to land degradation of the surrounding area.

## MATERIALS AND METHODS

### Study Sites

The research was carried out on forests and oil palm plantations owned by PT. KHS, which are located in the Jalemu Watershed, Manuhing Subdistrict, Gunung Mas Regency as presented in Figure 1. The study was conducted for 4 months consisting of 2 stages, namely data collection in June-September 2017, and analysis

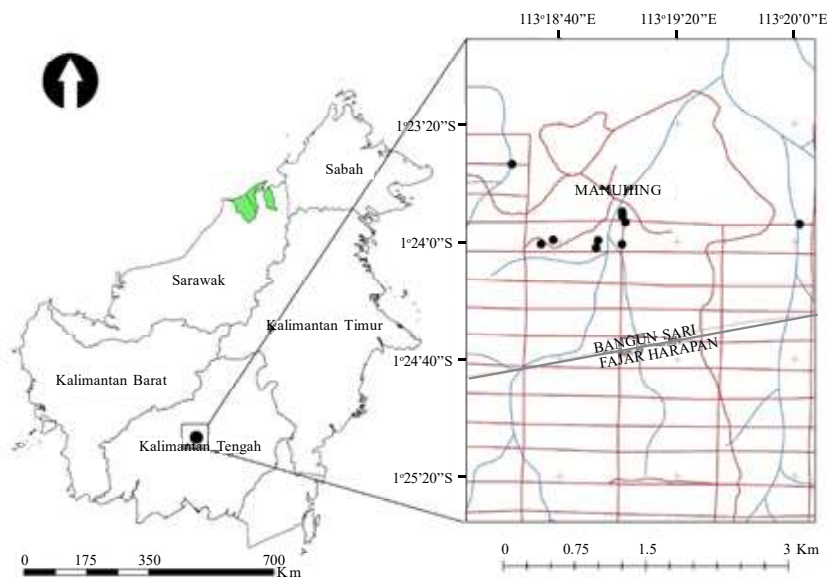


Figure 1. Location of the study in Jalemu Watershed that is mainly dominated by oil palm plantations.

of sediment samples and runoff water samples in the Analytical Laboratory, Universitas Palangka Raya.

**Experimental Set Up and Measurements**

This research was conducted in the field with two factors of land cover and two replications. The

research plots consisted of forests and oil palm area with the 5 years old of oil palm plants. An erosion plot with the size of 15 m × 25 m were made at each trial site in which each side of the plot was bordered with a 20 cm height of galvanized steel. The size of collection box of sediment and runoff water was 5 m × 0.5 m x 0.5 m, consisting of 7 holes with the diameter of each hole was 2.5 inches. The middle hole was connected by a 2.5 inch pipe (Figure 2). Measurements of erosion and surface runoff were carried out following each rainfall event during the the study. The amount of sediment (E) collected was weighted in the field. The moisture content of the sediment samples were determined by drying the samples in the oven at 105°C for 24 hours. The volume of surface runoff was determined in the field, and the nutrient content in the runoff water samples was measured. The collected data were analyzed using descriptive analysis in order to compare each factor.

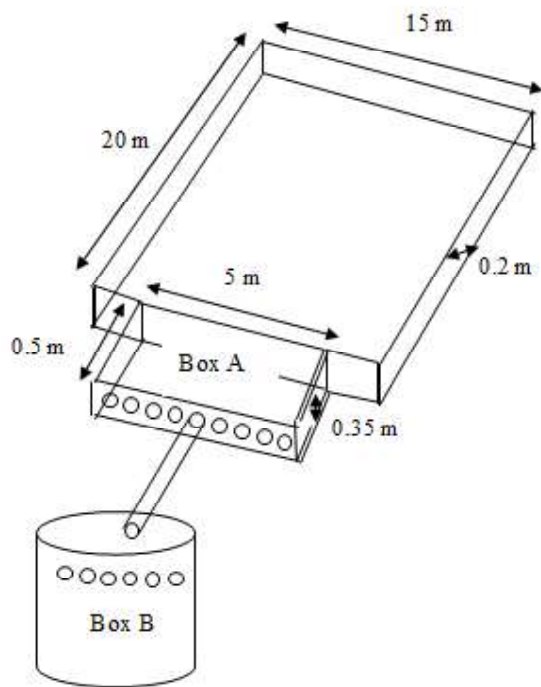


Figure 2. Illustration of erosion plots used in the study.

**Analyses of Sediments and Runoff Water Samples**

The analyses of water and sediment samples were carried out at the Analytical Laboratory, Universitas Palangka Raya. The contents of total-N (Kjeldhal), available-P (Bray I with spectrophotometer), and exchangeable-K (NH<sub>4</sub>OAc pH 7.0 with a flamephotometer) in the sediments were measured. The nutrient content in the runoff water samples was also determined, which included NH<sub>4</sub><sup>+</sup> (Kjedhal), NO<sub>2</sub><sup>-</sup> (Sulfanilamide) and NO<sub>3</sub><sup>-</sup> (Colorimetric), P (Spectrophotometer) and K

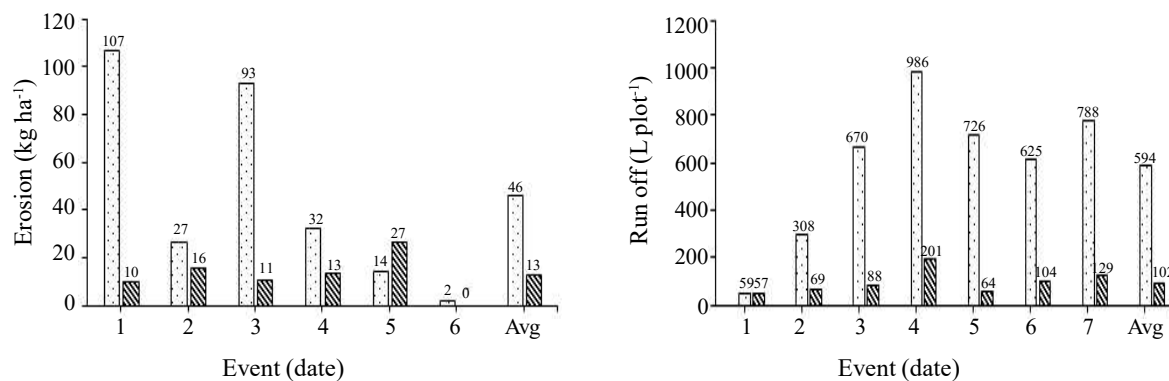


Figure 3. Erosion (A) and surface runoff (B) occurred in forest areas and 5 years old oil palm plantations. □: OP 5 Yrs, ▨: Forest.

(Atomic Absorption Spectrophotometer, AAS). The losses of total-N, available-P and exchangeable-K through erosion or surface runoff were calculated using the following equation:

$$X = Y \times E$$

Note:

- X = N, P and K losses due to erosion (kg plot<sup>-1</sup> or g plot<sup>-1</sup>) or surface runoff (kg ha<sup>-1</sup>)  
 Y = Total N (%), P (mg kg<sup>-1</sup>) and K (me 100 g<sup>-1</sup> soil) concentrations in sediment or surface runoff (mg L<sup>-1</sup>)  
 E = Total soil erosion (kg plot<sup>-1</sup>) or volume of surface runoff (liters)

## RESULTS AND DISCUSSION

### Rainfall

Rainfall data were recorded during the study using a tipping bucket rain gauge (ombrometer). About 117 rainy days were recorded in the period of May 2017 to February 2018. Patterns of rainfall were decreased in each treatment in the dry season period, namely in May and June. The highest rainfall during the study period occurred in October amounting of 459.5 mm, while the lowest rainfall occurred in June 2017. The highest number of rainy days took place in November, which was 24 days while the lowest number of rainy days occurred in May, which was 7 days.

### Erosion and Surface Runoff

The results of the calculation of erosion and surface runoff that occurred in the erosion plots of forest areas and 5 years old oil palm plantations for several rainfall events are presented in Figure 3.

Figure 3 showed that the level of erosion on 5 years old oil palm plantations was greater than that

in forest areas, and this trend occurred in every event of rain. The average erosion that occurred in oil palm plantations was 46 kg ha<sup>-1</sup>, and in forest areas was 13 kg ha<sup>-1</sup>. The amount of the erosion in various rain events was strongly related to the rainfall that occurred on that date, including the amount and intensity of the rain.

Greater erosion in the oil palm plantations is mainly related to canopy cover. In the 5 years old oil palm plantation area, the vegetation canopy is smaller than the canopy of the forest area. As many literature stated that the amount of erosion is affected by vegetation cover. The tree canopies in the forest areas are able to catch the raindrops (interception) and reduce the effects of raindrops on the dispersion of soil particles. On the contrary, in the area of oil palm plantations the percentage of canopy cover is lower, allowing more raindrops to reach the soil. In addition to the canopy cover, the cover crops also affect the amount of soil erosion that occurs on the land. In the forest area, the cover crops are dominated by understory plants, and the forest has better canopy stratification. The cover crops can reduce soil dispersion and the amount and velocity of surface runoff, therefore reducing soil erosion (Arsyad 2006; Arsyad 2010).

The results of surface runoff calculations for some rainfall events in the forest and 5 years old oil palm plots are presented in Figure 3A. Figure 3A shows that the surface runoff on oil palm plantations was larger than that in the forest areas, and this pattern occurred in every event of rain. The average surface runoff that occurred in the 5 years old oil palm plantations was 594 L plot<sup>-1</sup>, and in the forest area was 102 L plot<sup>-1</sup>.

Rainfall can cause surface runoff. If the rainfall on an area exceeds the infiltration capacity of soil, then the excess rainwater will turn into surface runoff. Although in general the increase of rainfall

Table 1. The contents of N, P and K in the sediments collected from the erosion plots.

Date	Code	Total N (%)	Total P (mg kg <sup>-1</sup> )	Total K (me 100 g <sup>-1</sup> )
May 12 <sup>th</sup>	P1	0.28	16.20	0.10
	P2	0.17	16.14	0.14
May 22 <sup>nd</sup>	P1	0.18	11.11	0.08
	P2	0.15	10.49	0.06
June 01 <sup>st</sup>	P1	0.30	18.14	0.06
	P2	0.16	10.47	0.05
June 20 <sup>th</sup>	P1	0.21	5.45	0.12
	P2	0.19	10.73	0.05
May 12 <sup>th</sup>	P3	0.20	171.72	0.90
May 22 <sup>nd</sup>	P3	0.33	35.94	0.18
June 01 <sup>st</sup>	P3	0.17	16.30	0.14
June 20 <sup>th</sup>	P3	0.17	16.08	0.08
Minimum	5 years old OP	0.15	5.45	0.05
	Forest	0.17	16.08	0.08
Maximum	5 years old OP	0.30	18.14	0.14
	Forest	0.33	171.72	0.90
Average	5 years old OP	0.21	12.34	0.08
	Forest	0.22	60.01	0.33

Note: P1 and P2: five years old oil palm (OP) plantations, P3: forest.

is followed by the increase of surface runoff, there are several other factors that also influence the surface runoff, so that the amount of rainfall is not the main parameter in determining the amount of surface runoff. Rainfall and initial groundwater level also affect the amount of surface runoff produced. If the initial ground water level is low, then the raindrops will be more infiltrated into the soil until reaching the field capacity condition, so the amount of water coming out as surface runoff becomes smaller. This can occur in the event of low rainfall, in which the amount of raindrops is less than the soil infiltration capacity. Conversely, if the rainfall exceeds the infiltration capacity of the soil, the soil will reach water saturation faster. This condition results in only a small part of the falling rain being infiltrated into the soil and the rest will fill the basins on the soil surface and eventually increase the amount of surface runoff.

### Nutrient Losses Through Erosion and Surface Runoff

The amounts of N, P and K measured in the sediments and runoff water samples are presented in Table 1 and 2, respectively. While the calculated amounts of N, P and K carried by erosion and surface runoff in each treatment plot are presented in Table 3 and 4, respectively.

Table 1 indicated that the total N content in the sediments in 5 years old oil palm plantations ranged

from 0.15% to 0.30% with an average of 0.21%, while the amount of available-P ranged between 5.45-18.14 mg kg<sup>-1</sup> with an average of 12.34 mg kg<sup>-1</sup>. The contents of exchangeable-K in the sediments of oil palm plantations were 0.05-0.14 me 100 g<sup>-1</sup> with an average of 0.08 me 100 g<sup>-1</sup>. The total N content in the sediments from forest area plots ranged from 0.17% to 0.33% with an average of 0.22%, while the available-P ranged from 16.08 to 171.72 mg kg<sup>-1</sup> with an average of 60.01 mg kg<sup>-1</sup>. The contents of exchangeable-K in the sediments of forest area were 0.08-0.90 me 100 g<sup>-1</sup> with an average of 0.33 me 100 g<sup>-1</sup>. Thus, overall, the contents of N, P and K carried by the soil particles from forest areas were higher than from 5 years oil palm areas.

Table 2 showed that the total content of N in surface runoff in 5 years old oil palm plantations ranged from 0.02 to 0.69 mg L<sup>-1</sup> with an average of 0.17 mg L<sup>-1</sup>, with the largest portion of N was present in the form of nitrate (NO<sub>3</sub><sup>-</sup>). The amount of P ranged between 0.01-0.12 mg L<sup>-1</sup> with an average of 0.04 mg L<sup>-1</sup>. The K contents in the surface runoff from oil palm plantations were 0.36-4.55 mg L<sup>-1</sup> with an average of 0.77 mg L<sup>-1</sup>. The total N content in the surface runoff of forest area ranged from 0.22 to 0.29 mg L<sup>-1</sup> with an average of 0.17 mg L<sup>-1</sup>, while the amount of P ranged from 0.02 to 0.24 mg L<sup>-1</sup> with an average of 0.09 mg L<sup>-1</sup>. Total K contents in the surface runoff from forest areas were 0.59-4.55 mg L<sup>-1</sup> with an average of 2.36 mg L<sup>-1</sup>. Thus, overall,

Table 2. The amounts of N, P and K in the surface runoff collected from the erosion plots.

Date	Code	Nutrient Content					
		NH <sub>4</sub> <sup>+</sup> (mg L <sup>-1</sup> )	NO <sub>2</sub> <sup>-</sup> (mg L <sup>-1</sup> )	NO <sub>3</sub> <sup>-</sup> (mg L <sup>-1</sup> )	N-Total (mg L <sup>-1</sup> )	P total (mg L <sup>-1</sup> )	K Total (mg L <sup>-1</sup> )
5 years old oil palm							
May 12 <sup>th</sup>	AP1	0.00	0.01	0.15	0.16	0.03	0.77
	AP2	0.00	0.01	0.03	0.04	0.12	1.22
May 22 <sup>nd</sup>	AP1	0.00	0.01	0.31	0.32	0.03	0.49
	AP2	0.00	0.01	0.01	0.02	0.01	0.74
June 01 <sup>st</sup>	AP1	0.00	0.01	0.13	0.14	0.02	0.36
	AP2	0.00	0.02	0.02	0.04	0.02	1.02
June 20 <sup>th</sup>	AP1	0.27	0.01	0.02	0.30	0.03	0.92
	AP2	0.63	0.01	0.05	0.69	0.05	0.59
July 09 <sup>th</sup>	AP1	0.00	0.09	0.01	0.10	0.05	0.91
	AP2	0.06	0.02	0.02	0.10	0.03	0.7
Forest							
May 12 <sup>th</sup>	AP3	0.00	0.01	0.25	0.26	0.11	1.41
	AP4	0.00	0.02	0.17	0.19	0.24	3.73
May 22 <sup>nd</sup>	AP3	0.00	0.01	0.12	0.13	0.02	0.64
	AP4	0.00	0.01	0.15	0.16	0.04	0.59
June 01 <sup>st</sup>	AP3	0.00	0.01	0.28	0.29	0.04	1.43
	AP4	0.08	0.02	0.01	0.11	0.12	3.66
June 20 <sup>th</sup>	AP3	0.00	0.01	0.01	0.02	0.06	1.77
	AP4	0.12	0.04	0.05	0.21	0.13	4.35
July 09 <sup>th</sup>	AP3	0.00	0.02	0.05	0.07	0.12	4.55
	AP4	0.25	0.01	0.03	0.29	0.06	1.44
Minimum	5 years old OP	0.00	0.01	0.01	0.02	0.01	0.36
	Forest	0.00	0.01	0.01	0.02	0.02	0.59
Maximum	5 years old OP	0.63	0.09	0.31	0.69	0.12	1.22
	Forest	0.25	0.04	0.28	0.29	0.24	4.55
Average	5 years old OP	0.10	0.02	0.08	0.19	0.04	0.77
	Forest	0.05	0.02	0.11	0.17	0.09	2.36

Note: P1 and P2: 5 years old oil palm (OP) plantations, P3: forest.

the contents of N, P and K carried by the surface runoff from forest areas were higher than from 5 years of oil palm areas.

Table 3 indicated that the total N loss through erosion in 5 years old oil palm plantations ranged from 0.30 to 0.87 kg plot<sup>-1</sup>, with an average of 0.54 kg plot<sup>-1</sup>, while the amount of available-P loss ranged from 10.90 to 80.67 g plot<sup>-1</sup> with an average of 35.20 g plot<sup>-1</sup>. The loss of exchangeable-K through eroded sediments in the plot of oil palm plantations was 0.03-0.27 kg plot<sup>-1</sup> with an average of 0.10 kg plot<sup>-1</sup>. The loss of N carried by eroded sediments in the forest area ranged from 0.04-0.34 kg plot<sup>-1</sup> with an average of 0.13 kg plot<sup>-1</sup>, while the available-P loss ranged from 6.27- 32.16 g plot<sup>-1</sup> with an average of 19.59 g plot<sup>-1</sup>. The loss of exchangeable-K carried by eroded sediments in the forest area was 0.01-0.07

kg plot<sup>-1</sup> with an average of 0.04 kg plot<sup>-1</sup>. Thus, overall, the losses of N, P and K carried by soil erosion in the 5 years old oil palm plantation area were higher than in the forest area.

Table 4 showed that the loss of N through surface runoff in the 5 years old oil palm plantations ranged from 2.68 to 517.50 mg plot<sup>-1</sup> with an average of 121.46 mg plot<sup>-1</sup>, with the largest portion of N was lost in the form of ammonium (NH<sub>4</sub><sup>+</sup>). The loss of P through surface runoff ranged from 1.50 to 43.75 mg plot<sup>-1</sup> with an average of 19.12 mg plot<sup>-1</sup>. The loss of K via the surface runoff from oil palm plantations was 0.38.50-999.60 mg plot<sup>-1</sup> with an average of 451.23 mg plot<sup>-1</sup>. The N loss through surface runoff of forest area ranged from 1.68-104.40 mg plot<sup>-1</sup> with an average of 19.72 mg plot<sup>-1</sup>, while the loss of P ranged from 1.04-24.00 mg

Table 3. The amounts of N, P and K carried by soil erosion in the 5 years old oil palm plantation plots and forest areas.

Date	Code	N (in erosion) (kg plot <sup>-1</sup> )	P (in erosion) (g plot <sup>-1</sup> )	K (in erosion) (kg plot <sup>-1</sup> )
5 years old oil palm				
May 12 <sup>th</sup>	P1	0.51	29.61	0.07
	P2	0.85	80.67	0.27
May 22 <sup>nd</sup>	P1	0.37	22.77	0.06
	P2	0.87	60.65	0.14
June 01 <sup>st</sup>	P1	0.42	25.41	0.03
	P2	0.30	19.37	0.04
June 20 <sup>th</sup>	P1	0.42	10.90	0.09
	P2	0.57	32.19	0.06
Forest				
May 12 <sup>th</sup>	P3	0.04	32.11	0.07
May 22 <sup>nd</sup>	P3	0.06	6.27	0.01
June 01 <sup>st</sup>	P3	0.08	7.82	0.03
June 20 <sup>th</sup>	P3	0.34	32.16	0.06
Minimum	5 years old OP	0.30	10.90	0.03
	Forest	0.04	6.27	0.01
Maximum	5 years old OP	0.87	80.67	0.27
	Forest	0.34	32.16	0.07
Average	5 years old OP	0.54	35.20	0.10
	Forest	0.13	19.59	0.04

Note: P1 and P2: 5 years old oil palm (OP) plantations, P3: forest.

plot<sup>-1</sup> with an average of 7.93 mg plot<sup>-1</sup>. The loss of K via the surface runoff of forest area was 20.65-910.00 mg plot<sup>-1</sup> with an average of 236.91 mg plot<sup>-1</sup>. Thus, overall, the losses of N, P and K carried by the surface runoff from the 5 years old oil palm area were higher than from the forest area. The losses of N, P, and K through surface runoff of forest area measured in the current study are lower than those in the study of Ariesca (2004) in which the losses of N, P, and K in the surface runoff of forest area were 393.75 mg plot<sup>-1</sup> (1,050 g ha<sup>-1</sup>), 8.13 mg plot<sup>-1</sup> (21.69 g ha<sup>-1</sup>) and 406.5 mg plot<sup>-1</sup> (1,084 g ha<sup>-1</sup>), respectively.

Leaching of nutrients on oil palm plantations can be influenced by soil type and rainfall intensity, age of oil palm plants, agricultural practices, type and level of fertilizers applied, and water management. In oil palm plantations that received chemical fertilizers, loss of nutrients through leaching and concentrations of nutrients in groundwater are generally reported to be low. Higher nutrient losses are expected on mature plantations due to lower nutrient uptake by oil palm roots and higher application of fertilizers is recommended in the mature plantations, which can lead to absolute higher losses (Comte *et al.* 2012). Barnabas *et al.* (2008)

found that the total loss of N is between 0.3 and 2.2 kg N ha<sup>-1</sup> yr<sup>-1</sup> in Papua New Guinea, which is lower than the loss of N in Malaysia, *i.e.* 5–22 kg N ha<sup>-1</sup> yr<sup>-1</sup> as reported by Kee and Chew (1996). Kurniawan *et al.* (2018) found that in smallholder oil palm plantations, losses of K and other nutrients such as Na, Ca, Mg and total Al through leaching in the fertilized area are higher due to the application of inorganic fertilizer and liming.

Several studies indicated that the loss of N in the watersheds with forest vegetation is predominantly in the form of dissolved organic N (DON), *i.e.* about 55%, while nitrate (NO<sub>3</sub><sup>-</sup>) contributed about 34% to the loss of N. The loss of NO<sub>3</sub><sup>-</sup> in a yr is lower in the catchment area with native forests compared to the catchment with plantations in which the output of the river discharge exceeds the input from rainfall (Carlos *et al.* 2007).

## CONCLUSIONS

The highest rainfall measured during the study occurred in October 2017 amounting to 459.5 mm, while the lowest rainfall occurred in June 2017. The highest number of rainy days took place in November 2017, *i.e.* 24 days, while the lowest

Table 4. The amounts of N, P and K carried by the surface runoff in the 5 years old oil palm plantation plot and forest area.

Date	Code	Nutrients in Surface Runoff (mg plot <sup>-1</sup> )					
		NH <sub>4</sub> <sup>+</sup>	NO <sub>2</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	N-Total	P-Total	K-Total
5 years of oil palm							
May 12 <sup>th</sup>	AP1	0.00	0.50	7.50	8.00	1.50	38.50
	AP2	0.00	0.67	2.01	2.68	8.04	81.74
May 22 <sup>nd</sup>	AP1	0.00	5.80	179.80	185.60	17.40	284.20
	AP2	0.00	7.60	7.60	15.20	7.60	562.40
June 01 <sup>st</sup>	AP1	0.00	9.92	128.96	138.88	19.84	357.12
	AP2	0.00	19.60	19.60	39.20	19.60	999.60
June 20 <sup>th</sup>	AP1	135.00	5.00	10.00	150.00	15.00	460.00
	AP2	472.50	7.50	37.50	517.50	37.50	442.50
July 09 <sup>th</sup>	AP1	0.00	78.75	8.75	87.50	43.75	796.25
	AP2	42.00	14.00	14.00	70.00	21.00	490.00
Forest							
May 12 <sup>th</sup>	AP3	0.00	0.92	23.00	23.92	10.12	129.72
	AP4	0.00	0.42	3.57	3.99	5.04	78.33
May 22 <sup>nd</sup>	AP3	0.00	1.40	16.80	18.20	2.80	89.60
	AP4	0.00	0.35	5.25	5.60	1.40	20.65
June 01 <sup>st</sup>	AP3	0.00	3.60	100.80	104.40	14.40	514.80
	AP4	3.36	0.84	0.42	4.62	5.04	153.72
June 20 <sup>th</sup>	AP3	0.00	2.00	2.00	4.00	12.00	354.00
	AP4	0.96	0.32	0.40	1.68	1.04	34.80
July 09 <sup>th</sup>	AP3	0.00	4.00	10.00	14.00	24.00	910.00
	AP4	14.50	0.58	1.74	16.82	3.48	83.52
Minimum	5 years old OP	0.00	0.50	2.01	2.68	1.50	38.50
	Forest	0.00	0.32	0.40	1.68	1.04	20.65
Maximum	5 years old OP	472.50	78.75	179.80	517.50	43.75	999.60
	Forest	14.50	4.00	100.80	104.40	24.00	910.00
Average	5 years old OP	64.95	14.93	41.57	121.46	19.12	451.23
	Forest	1.88	1.44	16.40	19.72	7.93	236.91

Note: P1 and P2: 5 years old oil palm (OP) plantations, P3: forest.

number of rainy days was occurred in May 2017, *i.e.* 7 days. The amounts of erosion and runoff in the 5 years old oil palm plantations were greater than in the forest areas, and this phenomenon occurred in every event of rain. The average soil erosion measured in the 5 years old oil palm plantations and forest area were 46 kg ha<sup>-1</sup> and 13 kg ha<sup>-1</sup>, respectively. The average surface runoff in the 5 years old oil palm plantations and forest area were 594 L plot<sup>-1</sup> and 102 L plot<sup>-1</sup>, respectively. The losses of N, P and K carried by soil erosion and surface runoff from the 5 years old oil palm plantation area were higher than from the forest

area. The total N, P and K losses through eroded sediments both in 5 years old oil palm plantations and forest area were higher compared to the losses through surface runoff.

Further research needs to be carried out by applying soil and water conservation techniques on oil palm plantations.

#### ACKNOWLEDGEMENTS

The authors expressed their gratitude to the Ministry of Research, Technology, and Higher Education of Indonesia for the financial support that



was given in the Financial Year of 2017. In addition, authors thank the LPPM of Universitas Palangka Raya, which has encouraged and provided opportunities for UPR staff to conduct the study.

## REFERENCES

- Ariesca R. 2004. Studi Tentang Terjadinya Erosi, Aliran Permukaan, dan Hilangnya Unsur Hara Dalam Aliran Permukaan Pada Lahan hutan Sekunder 1 Tahun BekasTerbakar. Skripsi. Bogor: Departemen Manajemen Hutan Fakultas Kehutanan Institut Pertanian Bogor. (Online). (<http://repository.ipb.ac.id/bitstream/handle/123456789/19012/E04RAR.pdf?sequence=2>, diakses 11 Oktober 2012) (in Indonesian).
- Arsyad S. 2006. Konservasi Tanah dan Air, Fakultas Pertanian IPB. IPB Press, Cetakan Ketiga. Gedung Lembaga Sumberdaya Informasi Lt. 1 Kampus Darmaga, Bogor (in Indonesian).
- Arsyad U. 2010. Analisis Erosi Pada Berbagai Tipe Penggunaan Lahan dan Kemiringan Lereng di Daerah Aliran Sungai Jeneberang Hulu. Disertasi Program Pascasarjana Universitas Hasanuddin, UNHAS. Makassar (in Indonesian).
- Barnabas M, MA Turner, DR Scotter and PN Nelson. 2008. C Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 1. Water balance, and nitrogen in soil solution and runoff. *Aust. J Soil Res* 46: 332-339.
- Breure K. 2003. The search for yield in oil palm: Basic principles. In: T Fairhurst and R Hardter (eds.). *Oil Palm: Management for Large and Sustainable Yields*. Potash & Phosphate Institute/Potash Institute of Canada and International Potash Institute, Singapore. pp. 59-98.
- Campiglia E, R Mancinelli, E Radicetti and S Marinari. 2010. Legume cover crops and mulches: effects on nitrate leaching and nitrogen input in a pepper crop (*Capsicum annuum* L.). *Nutr Cycl Agroecosyst* 89: 399-412.
- Carlos O, C Aracena, P Rutherford, R Godoy and An Deschrijver. 2007. Effects of Land Use Conversion from Native Forests to Exotic Plantations on Nitrogen and Phosphorus Retention in Catchments of Southern Chile. *Water Air Soil Pollut* 179: 341-350.
- Comte I, JK Whalen, O Grunberger, F Colin and JP Caliman. 2012. Agricultural Practices in Oil Palm Plantations and Their Impact on Hydrological Changes, Nutrient Fluxes and Water Quality in Indonesia: A Review. In: DL Sparks (eds). *Advances in Agronomy*, Burlington: Academic Press, 2012, 116: 71-124.
- ECD [Environment Conservation Department]. 2000. Environmental impact assessment (EIA) guidelines on oil palm plantation development. Environmental Conservation Department, Sabah, Malaysia. Available at: <http://www.sabah.gov.my/jpas/programs/ecd-cab/technical/OP211100.pdf>. (Consulted on Apr 13th, 2011).
- Goh KJ and PS Chew. 1995. Managing soils for plantation tree crops. 1. General soil management. In: S. Paramanathan (eds). *Course on Soil Survey and Managing Tropical Soils*. MSSS and PASS, Kuala Lumpur. pp. 228-245.
- Goh KJ, R Härdter and T Fairhurst. 2003. Fertilizing for maximum return. In: Fairhurst T and R Hardter (eds). *Oil Palm: Management for Large and Sustainable Yie*. Potash & Phosphate Institute/Potash & Phosphate Institute of Canada and International Potash Institute (PPI/PPIC and IPI, Singapore, pp. 279-306.
- IMA [Indonesian Ministry of Agriculture]. 2010. Area and production by category of producers: palm oil, Direktorat Jenderal Perkebunan. Kementerian Pertanian. Available at: <http://ditjenbun.deptan.go.id/index.php/direktori/3-isi/4-kelapa-sawit.html>. (Consulted on April 13th, 2011)
- Kee KK and PS Chew. 1996. Nutrient losses through surface runoff and soil erosion—Implications for improved fertilizer efficiency in mature oil palms. In: A Ariffin, MB Wahid, N Rajanaidu, D Tayeb, K Paranjothy, SC Cheah, KC Chang and S Ravigadevi (eds). *Proceedings of the PORIM International Palm Oil Congress*. Palm Oil Research Institute of Malaysia, Kuala Lumpur pp. 153-169.
- Kurniawan S, MD Corre, SR Utami and E Veldkamp. 2018. Soil Biochemical Properties and Nutrient Leaching from Smallholder Oil Palm Plantations, Sumatra-Indonesia. *Agrivita J of Agric Sci* 40: 257-266.
- Nykvist N, H Grip, B Liang Sim, A Malmers and FK Wong. 1994. Nutrient Losses in Forest Plantations in Sabah, Malaysia. *Ambio* 23: 210-215.
- Sheil D, A Casson, E Maijaard, M van Noordwijk, J Gaskell, JS Groves, K Wertz and M Kanninen. 2009. The impacts and opportunities of oil palm in Southeast Asia. Center for International Forestry Research, Bogor.
- Susanti A and PPM Burgers. 2012. Oil palm expansion in Riau province, Indonesia: serving people, planet, profit? Background Paper to the 2011/2012 European Report on Development: Confronting Scarcity: Managing Water, Energy and Land for Inclusive and Sustainable Growth. European Union, Brussels. Available at: [http://erd-report.eu/erd-report\\_2011/documents/researchpapers\\_susanti-burgers.pdf](http://erd-report.eu/erd-report_2011/documents/researchpapers_susanti-burgers.pdf) (Consulted on January 27th, 2015).
- Susila WR. 2004. Contribution of Oil Palm Industry to Economic Growth and Poverty Alleviation in Indonesia. *J Litbang Pertanian* 23: 107-114.
- Vitousek PM, JD Aber, RW Howarth, GE Likens, PA Matson and DW Schindler. 1997. Technical report: Human alteration of the global nitrogen cycle: Sources and consequences. *Ecol App* 7: 737-750.