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Soil erosion control in immature oil palm plantation

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Abstract

The objectives of developing oil palm plantations should feasible economically and without causing massive erosion. This research proposes soil and water conservation strategies that are ideal and optimal for oil palm cultivation depending on land capability class. The conservation test for plants was performed according to land capability classes on a plot measuring 22 m × 4 m. Runoff and erosion rates were measured using Multislot Divisor Method. Nutrient leaching was analysed based on the content of C-organic (C_{tot}) (Walkley–Black method), total nitrogen (N_{tot}) (Kjeldahl method), P-available (Bray-1 method) and K_2O (extraction with 1N NH_4OAc at pH 7.0). From the results, land capability class III, cover crops (soybean) + manure (P3) treatment effectively reduced runoff and soil erosion (22.63 $m^3 \cdot ha^{-1} \cdot y^{-1}$ and 13.04 $Mg \cdot ha^{-1} \cdot y^{-1}$), as well as nutrient leaching, compared to other treatments. Furthermore, sediment trap + cover crop + manure (P3) controlled runoff, erosion and nutrient leaching on land capability class IV, producing the lowest runoff (129.40 $m^3 \cdot ha^{-1} \cdot y^{-1}$), soil erosion (11.39 $Mg \cdot ha^{-1} \cdot y^{-1}$), C-organic (1.3%), and P (1.95 mg kg^{-1}). Soil conservation treatment significantly reduced erosion and runoff ($p < 0.05$) on land capability class VI. The bench terrace + cover plants + manure treatment-controlled runoff, erosion, and soil nutrient leaching.

Key words: *cover crops, erosion, nutrient leaching, oil palm plantation, sediment trap, surface runoff, terraces*

INTRODUCTION

Oil palm is widely grown in the fast-weathered tropical areas, including Indonesia, which has 18.2 mln ha land potential for crop cultivation. In 2010, the country planted 9 mln ha of oil palm [PUTRA *et al.* 2012], rising to 10 mln ha in 2016 [PIRKER *et al.* 2016]. In 2015, the oil palm plantation area in Aceh Province was 208,124 ha, down from 396,644 in 2013 [BPS 2014]. In Bireuen Regency, however, oil palm plantations have developed rapidly in recent years. For example, by 2012, the potential oil palm plantation in 14 regions was 27,434 ha [BPS Bireuen 2014]. Out of this, approximately 4,372 ha of land had been planted, of which 3,109 ha were community plantations. Soil and water conservation in oil palm cultivation is strengthened because this plant is globally associated with environmental damage.

Aceh's oil palm is mostly cultivated on newly cleared or converted land with a slope of 15–60%. Generally, this land falls under capability class III–VII [SATRIAWAN *et al.* 2017]. Lands in capability classes III and IV are agriculturally viable under adequate conservation. In contrast, lands in capability classes V–VII are agriculturally unsuitable owing to their damage vulnerability [SAIDA *et al.* 2013].

Intensive agricultural activities on unsuitable land triggers massive erosion exceeding 21.26 $Mg \cdot ha^{-1} \cdot y^{-1}$ [SATRIAWAN *et al.* 2015b]. This becomes a serious global threat to food security and sustainable development [SUI *et al.* 2016]. The massive soil erosion leads to loss of essential nutrients for growth and production in oil palm plantation. Numerous studies have been conducted on soil erosion in oil palm plantations in Indonesia. However, there are no studies on soil losses based on land capability classes. Soil erosion in oil palm plantations in Sumatera varies with age and conservation techniques ranging within 3.3–56.4 $Mg \cdot ha^{-1} \cdot y^{-1}$ [YENI *et al.* 2016], 12.20–18.66 $Mg \cdot ha^{-1} \cdot y^{-1}$ [SATRIAWAN *et al.* 2015a], and 23–793 $Mg \cdot ha^{-1} \cdot y^{-1}$ [DASTUR SYAH *et al.* 2013]. Therefore, this problem could be overcome through technological innovation. Mechanical soil conservation technology has been applied in oil palm plantations using individual terraces and sedimentation [HARIBOWO *et al*. 2019; SATRIAWAN *et al*. 2017].

Soil erosion reduction in immature oil palm cultivation requires several conservation practices, including vegetative and mechanical methods. SATRIAWAN *et al*. [2016] and HARIBOWO *et al*. [2019] established that vegetation stabilizes soil against strong erosion flows, especially when using a combination of several plants such as Leguminosae. The research proposed the most effective soil and water conservation techniques according to capability classes.

MATERIALS AND METHODS

SITE DESCRIPTION AND EXPERIMENTAL DESIGN

The research took place in Peusangan Siblah Krueng Subdistrict, Bireuen Regency of Aceh Province (5°4'30" N and 96°45'18" E with 116 m elevation), with the previously determined land capability classes (III, IV and VI). Land capability class III was located on slopes (gradient 8–15%), having a soil solum depth of 85–125 cm, with a mild-moderate erosion. In this area, 25% of topsoil had been eroded, exposing the surface rocks. Land capability class IV was on slopes (15–30%), but in a moderate soil solum depth (80–90 cm). Also, a 50% of the upper layer was eroded. Land capability class VI was on the sloping area (>45%), where 75% of the upper layer had been lost.

This experiment lasted two years, from August 2014 until March 2016. The object of the research was immature plantations, 1–2 years old, with uniform land class groups. Oil palm trees are grown 8 × 8 m apart, based on the slope direction. The soil in the study region is classified as Typic Paleudults [USDA 2010], dominated by andesite rocks and sandy clay. The subsoil solum had a 0.5 m depth of argillic horizon, with clay content between 19 and 37%.

The research used the experimental method (standard of plot erosion) [SATRIAWAN *et al*. 2015a; 2016]. The study involved a standard plot erosion test. Soil conservation practices for oil palm were applied to the land capability classes previously determined. Different technologies were applied based on the recommendation of the individual classes [ARSYAD 2010].

In land capability class III, 4 treatments with 3 replications were analysed, including:
P0 = no soil conservation,
P1 = individual terrace (IT),
P2 = individual terrace + cover crop (soybeans),
P3 = individual terrace + cover crop (soybeans) + manure 15 $Mg \cdot ha^{-1}$.

In land capability class IV, 4 treatments with 3 replications were examined, including:
P0 = no soil conservation,
P1 = sediment trap (ST),
P2 = sediment trap + vertical mulch (VM),
P3 = sediment trap + cover crop (soybeans) + manure 15 $Mg \cdot ha^{-1}$.

In land capability class VI, 4 treatments with 3 replications were tested, including:
P0 = no soil conservation,
P1 = bench terrace (BT),
P2 = bench terrace + cover crop (*Mucuna bracteata*),
P3 = bench terrace + cover crop (*Mucuna bracteata*) + manure 15 $Mg \cdot ha^{-1}$.

OBSERVATION AND DATA COLLECTION

Data was collected on runoff, suspended sediment (soil erosion), the concentration of C-organic, N, P, and K in the sediment.

The experiment was conducted on a plot of 22 × 4 m facing the slope. Surface runoff and erosion were measured using the multi-slot divisor method. The experimental plot boundary was set using an embedded plastic trap +20 cm into the ground and +20 cm above of soil surface. The runoff and erosion sediment collector was at the depth = 2 m, a width = 0.5 m, and a length = 0.5 m with 7 holes, each with a diameter of 5 cm. The middle hole was connected with a PVC pipe, 5 cm in diameter, to channel the overflow into a small 0.5 m × 0.5 m × 0.5 m container (Fig. 1c). In the course of the research, rainfall was recorded using an ombrometer installed near the experimental plot. Erosive rainfall was calculated after each rainfall by directly checking the runoff collector. According to EL KATEB *et al*. [2013], rainfall is non-erosive when precipitation cannot generate measurable runoff, producing no runoff and sediment. Erosive rainfall was characterized by runoff and sediment inside the collector.

Individual terraces have a length and width 1.5 × 1.5 m and a depth of 20 cm (Photo 1, Fig. 1). Sediment traps are long and wide soil trenches, measuring 1.5 m long, 1 m wide, and 0.5 m depth, made in the midst of planting rows perpendicular to slope direction (Photos 2a, b). The community designed the bench terraces, perpendicular to slope direction, with 3 m width and 1.5–2 m height (Photo 3). Bench terraces were constructed when preparing land for oil palm planting. Leguminous cover crops were grown with spacing of 20 cm × 30 cm.

Photo 1. Individual terrace in plot of land capability class III (phot. Fauzan)

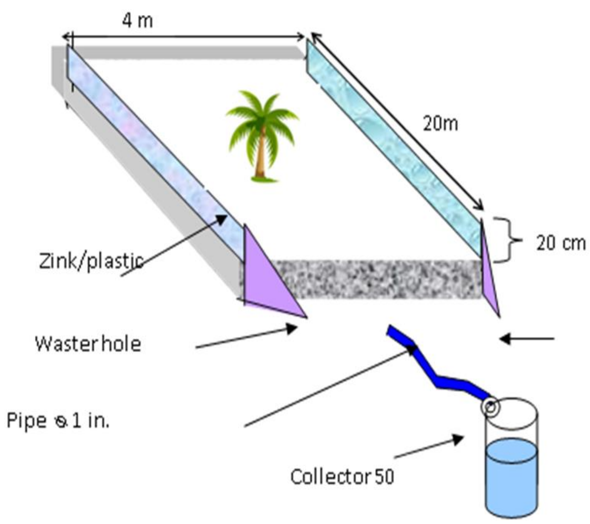

Fig. 1. Sediment collector; source: own elaboration

Photo 2. Soil conservation technologies applied in the experiment of land capability class IV: a) sediment trap, b) sediment trap + cover crop + manure (phot. Fauzan)

Soybeans are planted between rows of oil palm trees as cover crops. They are planted throughout the year, planting 3 times a year by burying. During the period of growth, soybeans are treated from pests and diseases and harvesting is

Photo 3. Bench terrace land capability class VI (phot. Fauzan)

done. The interval between planting time and harvest is 3 weeks, allowing preparation time for the new crop. Application of manure was conducted 1 week before the soybeans were planted. The dose given is 15 Mg·ha^{-1} by sprinkling on the surface of the soil and mixing with the soil using a hoe. This step is done so that cattle manure is be distributed evenly, making it easier to plant the soybeans.

MEASUREMENT OF SURFACE RUNOFF AND SOIL EROSION

Soil erosion is analysed through the filtration of water samples from the reservoir. The residue is dried in an oven at a constant 60°C. The measured sediment weight represents soil erosion, calculated as [SATRIAWAN *et al*. 2015a]:

$$E = \frac{C_{ap} \cdot V_{ap} \cdot 10^{-3}}{A} \quad (1)$$

where: E = eroded soil (Mg·ha^{-1}), C_{ap} = concentration of sediment load (kg·m^{-3}), V_{ap} = runoff volume (m^3), A = eroded area (ha), 10^{-3} = conversion from kg to Mg.

Sediment nutrients were analysed to determine C-organic (C_{tot}) (Walkley–Black method), total nitrogen (N_{tot}) (Kjeldahl method), P-available (Bray-1 method) and K_2O (extraction with 1N NH_4OAc at pH 7.0).

Data on surface runoff volume, erosion, and nutrient loss from erosion sediment were analysed by ANOVA. The mean separation was tested using the least significant difference (*LSD*) test at 5% significance level.

RESULTS

RAINFALL DURING STUDY

Within the experiment period, the total amount of rainfall recorded was 3,053 mm, with the highest values being recorded from October to December 2014 and September to December 2015. There were 24 erosive rainfall events during the observation period, in which a total of 1,895 mm was recorded (Fig. 2).

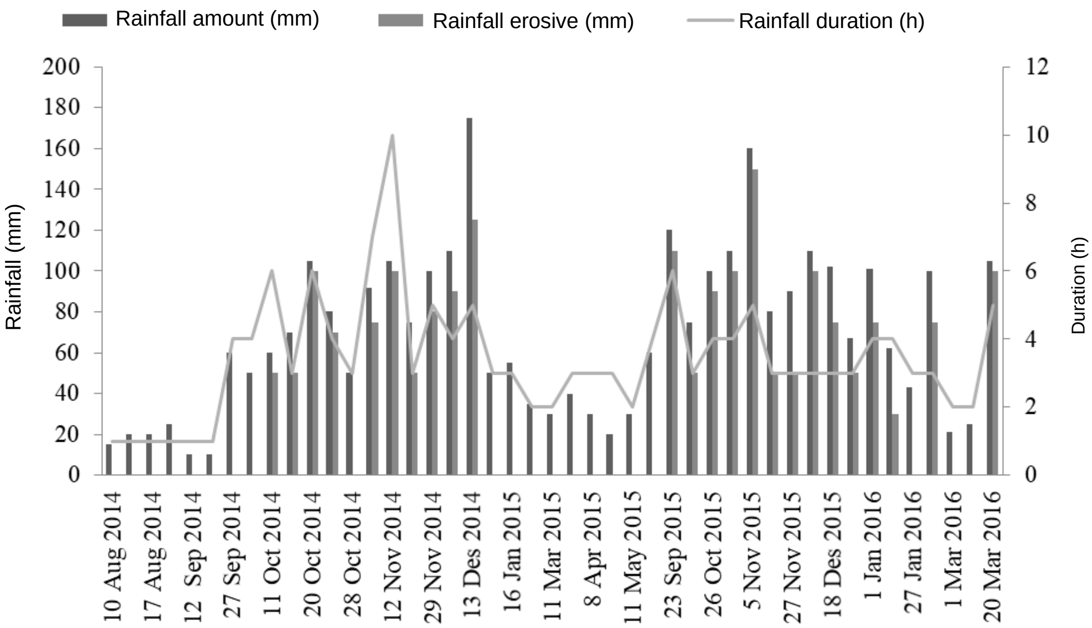

Fig. 2. Rainfall events over the rainy season in experiment duration (Aug 2014–March 2016); source: own elaboration acc. to rainfall and erosive rainfall data

RUNOFF, SOIL EROSION, AND NUTRIENT LEACHING

The soil conservation technologies applied in this study included single individual terraces (creating dishes around the oil palm canopy), individual terraces combined with crop strips, and cover crop (soybeans) together with manures. The treatment applied to oil palm plantations on land capability class III significantly influenced surface runoff, soil erosion, and C-organic and nitrogen leaching. However, there was no effect on the leaching of phosphate and potassium (Tab. 1). Soil conservation treatment significantly affected surface runoff volume and soil erosion. The P3 treatment was the most effective on surface runoff and soil erosion (22.63 $m^3 \cdot ha^{-1} \cdot y^{-1}$ and 13.04 $Mg \cdot ha^{-1} \cdot y^{-1}$) compared to other treatments ($p < 0.05$). The volumes of surface runoff were in the order, P3 < P2< P1 < P0. Compared to control treatments, surface runoff in P1, P2, and P3 decreased by 30.25, 47.78, and 69.66%, respectively, with significantly different treatments. Soil erosion had a similar trend order as surface runoff, with a reduction of 19.02%, 28.86%, and 47.65%. The P3 was effective for runoff intercept, due to the high density and large ground soybean coverage, resulting in the lowering of raindrop splash erosion compared to other treatments. Soil conservation treatment influenced nutrient leaching, runoff, and erosion (Tab. 1), in which the percentage of C-organic and total nitrogen were significantly affected by the P3 treatment. Phosphate and potassium leaching were not affected by soil conservation treatment.

The treatment on land capability class IV involved the use of sediment trap (P1), sediment trap combined with vertical mulch (P2), as well as a sediment trap, cover crops, and manure (P3). Results showed that treatment with sediment traps cover crops, and manure (P3) significantly reduced surface runoff, soil erosion, and nutrient leaching (Tab. 2).

The treatment by sediment trap, cover crops, and manure (P3) on class IV land was appropriate in controlling surface runoff and soil erosion (129.40 $m^3 \cdot ha^{-1} \cdot y^{-1}$ and 11.39 $Mg \cdot ha^{-1} \cdot y^{-1}$) compared to others ($p < 0.05$). Surface runoff volumes were in the order of P3 < P2 < P1 < P0. Compared with the control treatment, the runoff of P1, P2, and P3 reduced by 9.03, 23.19, and 37.95%, respectively, with significantly different treatments, except for P0 and P1. The soil conservation treatment reduced soil erosion by 50.80, 52.52, and 63.97%, respectively, and the P1, P2, and P3 treatments significantly differed with P0. Soil nutrient leaching, runoff, and erosion were affected by the treatment (Tab. 2), in which the percentage of C-organic and phosphorus were significantly affected. However, the treatment did not affect nitrogen and potassium nutrient removal. In this group, the sediment trap + cover crop + manure (P3) treatment did not prevent nutrient leaching.

Table 1. Runoff, soil erosion and nutrient leaching in sediment on land capability class III

Soil conservation technology	Runoff ($m^3 \cdot ha^{-1} \cdot y^{-1}$)	Erosion ($Mg \cdot ha^{-1} \cdot y^{-1}$)	C-organic (%)	N (%)	P (mg kg^{-1})	K (cmol kg^{-1})
Control (P0)	74.66^{d}	24.91^{d}	4.39^{b}	0.43^{ab}	2.47	0.44
Individual terrace (P1)	52.07^{c}	20.17^{c}	3.70^{ab}	0.42^{ab}	2.04	0.42
Individual terrace + cover crop (P2)	38.98^{b}	17.72^{b}	3.40^{ab}	0.29^{ab}	1.37	0.28
Individual terrace + cover crop + manure (P3)	22.65^{a}	13.04^{a}	2.70^{a}	0.22^{a}	1.20	0.23
$LSD_{0.05}$	2.01	1.64	1.20	0.20		

Explanations: *LSD* = least significant difference; different letter notations in the same column show significant differences on the 0.05 *LSD* test.
Source: own study.

Table 2. Runoff, soil erosion and nutrient leaching in sediment on land capability class IV

Soil conservation technology	Runoff ($m^3 \cdot ha^{-1} \cdot y^{-1}$)	Erosion ($Mg \cdot ha^{-1} \cdot y^{-1}$)	C organic (%)	N (%)	P ($mg\ kg^{-1}$)	K ($cmol\ kg^{-1}$)
Control (P0)	208.55^c	31.61^b	2.72^b	0.24	4.07^b	1.16
Sediment trap (P1)	189.70^c	15.55^a	1.65^a	0.15	3.93^b	1.10
Sediment trap + vertical mulch (P2)	160.18^b	14.06^a	1.47^a	0.14	2.39^a	0.91
Sediment trap + cover crop + manure (P3)	129.40^a	11.39^a	1.30^a	0.17	1.95^a	0.90
$LSD_{0.05}$	21.18	11.02	0.9		1.08	

Explanations: *LSD* = least significant difference; different letter notations in the same column show significant differences on the 0.05 *LSD* test.
Source: own study.

Table 3. Runoff, soil erosion and nutrient leaching in sediment on land capability class VI

Soil conservation technology	Runoff ($m^3 \cdot ha^{-1} \cdot y^{-1}$)	Erosion ($Mg \cdot ha^{-1} \cdot y^{-1}$)	C organic (%)	N (%)	P ($mg\ kg^{-1}$)	K ($cmol\ kg^{-1}$)
Control	318.59^b	60.38^b	2.83^b	0.56^b	2.49	0.71
Bench terrace	174.37^a	29.58^a	1.67^a	0.33^a	1.70	0.54
Bench terrace + cover crop	139.66^a	22.50^a	1.41^a	0.27^a	2.33	0.56
Bench terrace + cover crop + manure	115.98^a	21.29^a	1.32^a	0.24^a	1.67	0.67
$LSD_{0.05}$	63.2	5.2	0.85	0.17		

Explanations: *LSD* = least significant difference; different letter notations in the same column show significant differences on the 0.05 *LSD* test.
Source: own study.

Photo 4. Individual terrace + cover crop + manure in plot of land capability class III (phot. Fauzan)

Photo 5. Bench terrace + cover crop in plot of land capability class VI (phot. Fauzan)

Soil conservation treatment on land capability class VI significantly reduced erosion and runoff more than the control treatment ($p < 0.05$) – Table 3. The bench terrace + cover crop + manure treatment significantly reduced surface runoff by 63.59%, compared to the control treatment, followed by bench terrace + cover crop (56.16%) and bench terrace (45.26%), respectively (Photo 4). The bench terrace + cover crop + manure (P3) reduced soil erosion more than other treatments, 64.73% compared to other erosion controls. Soil nutrient leaching, runoff, and erosion were greatly influenced by the conservation treatment applied (Tab. 3 and Photo 5), in which the percentage of C-organic and total nitrogen were significantly affected by the P3 treatment. However, phosphate and potassium leaching was not affected by the treatment. In this group, bench terrace + cover crop + manure (P3) was the most effective in preventing nutrient leaching.

DISCUSSION

Erosion is caused by forced movement of the groundmass by water, wind, or gravity. The humid and tropical climate in Indonesia increases the risk of water erosion [ARSYAD 2010]. Erosion is accelerated by the intense rainfall, combined with the relatively steep-sloped topography. Intense agricultural activities in these areas also increase soil erosion [SATRIAWAN, FUADY 2014].

Mitigation of surface runoff and soil erosion in agricultural land use, especially on a new oil palm plantation, is the key to soil protection [ZUAZO, PLEGUEZUELO 2008]. In this study, the use of soybeans as cover crops between rows proved to be efficient in managing surface runoff and soil erosion (Photo 4). The dense soybean canopy reduces the erosivity of rainfall, therefore limiting soil loss. Cover crops, therefore, play an essential role in soil conservation. They positively affect physical soil characteristics, including infiltration, moisture, and bulk density [HULUGALLE *et* *al*. 1986]. Ground leguminous cover plants increase the content of organic matter, naturally provide nitrogen (N) by using N_2 binding legumes, providing critical nutritional contributions to oil palm plants, which influences their growth [IBEWIRO *et al*. 2000; ILE *et al*. 1996; OBIAGWU 1995; SALAKO, TIAN 2003].

Related to the improvement of soil physical properties, manure helped form stable aggregates in this study. Maintenance of soil particles from the detachment of rainfall erosivity is best achieved using the stable aggregates. Organic matter binds soil particles, yielding microaggregates further bound by plant roots and fungal hyphae. As a result, the primary and secondary soil grains are compacted together [OADES 1984].

Manure stabilizes and increases the size of soil aggregates, raising hydrophobicity and inter-particle cohesion [CHENU *et al*. 2000]. Stable aggregates increase soil porosity, facilitate water absorption and improve the capacity for water retention. Furthermore, soil aggregation and aggregate stability are critical aspects contributing to limiting erosion. JUARSAH *et al*. [2008] established the importance of organic matters to the physical and chemical soil characteristics, including increasing aggregation, preventing aggregate destruction by water, making the soil more tillable, improving porosity and aeration, as well as increasing infiltration and percolation capacities.

Soil conservation systems significantly lowered C-organic, nitrogen, and phosphate loss due to limited surface runoff ($p < 0.05$), although the impact depended on the treatment (Tab. 1). The P3 treatments were appropriate, leading to minimum C-organic, nitrogen, and phosphate, with the lowest concentrations (2.7%, 0.22%, and 1.22 mg kg^{-1}, respectively). According to (Tab. 1), runoff and nutrient concentrations influenced nutrient loss on oil palm cultivated land, since Nitrogen was correlated with C-organic. In general, soil conservation on modified land surface roughness through individual terraces and maximized land cover, therefore preventing nutrient loss through erosion.

Based on land capability class IV in this project, sediment traps collected water and controlled the sediment moved by surface runoff. Apart from cover plants, the soil helped in controlling runoff, with improved aggregation and soil physical properties. This is consistent with previous results that the application effectively suppressed erosion by 71%, based on soil structure and land cover condition. The shorter the distance between the sediment trap on the same slope, the more it reduced erosion and runoff and increased groundwater [BRATA 1998; MONDE 2010; MURTILAKSONO *et al*. 2008].

Sediment trap + cover crop (soybean) and manure treatment reduced organic C, N, P, and K loss. Based on Table 2, the lowest level of C-organic, nitrogen, there were phosphate and potassium in the P3 treatment. The lower loss of nutrients in sediment trap + cover crop + was attributed to cover crops' role, which appropriately utilized nutrients. Furthermore, the sediment trapping availed nutritious water to the plant roots. However, the P2 treatment was not significantly different from P0. This is because the P elements, which are mobile and highly soluble in water, were mainly evident in the control and sediment trap treatment.

In sloping land, the conservation measures considerably influenced erosion by changing the soil surface [MAETENS *et al*. 2012]. Cover crops and strip plants benefit plantation trees because they minimize rainfall erosivity and surface runoff, as well as adding to the soil's organic matter through the stems, twigs, and fallen dead leaves. They transpire, reducing soil water content. Cover plants reduce the strength of the rainwater dispersion and the quantity and speed of runoff, enhancing infiltration. As a result, they lessen erosion and nutrient leaching. According to BAH *et al*. [2014], nutrient loss through runoff and sediments relates to oil palm age, surface feature, land clearing, and adequate soil conservation measures.

Soil and water conservation influenced nutrient loss of land capability class VI, especially to C-organic, nitrogen, and phosphate. The greatest loss was in the control treatment, without soil and water conservation. Of all the treatments, soybean as cover crops and strip plant highly suppressed soil nutrient loss than the other treatments.

Based on the socio-economic benefits of oil palm plantations, land cover crops, and simple conservation buildings effectively reduced surface runoff and erosion, improving farming sustainability in the area. However, in general, soil erosion largely depends on the management system.

CONCLUSIONS

The study conclusions are based on empirical analysis and field discussions. The results show that the soil conservation techniques applied in every land capability class-controlled surface runoff and erosion. In terms of land capability, class III cover crops + manure (P3) treatment effectively reduced runoff and soil erosion (22.63 m^3·ha^{-1}·y^{-1} and 13.04 Mg·ha^{-1}·y^{-1}) and nutrient leaching, compared to other treatments. In land capability class IV, sediment trap + cover crop+ manure (P3) reduced runoff, erosion and nutrient leaching, producing the lowest runoff (129.40 m^3·ha^{-1}·y^{-1}), soil erosion (11.39 Mg·ha^{-1}·y^{-1}), C organic (1.3%), and P (1.95 mg kg^{-1}). Finally, on land capability class VI, located on the sloping area (>45%), with heavily eroded soil, the conservation treatment significantly reduced erosion and runoff. Bench terrace + cover crop + manure minimized runoff, erosion, and soil nutrient leaching, reducing surface runoff by 63.59%.

Based on the findings of this study, in the cultivation of oil palm on sloping land in Aceh and Indonesia in general, the application of soil conservation techniques is absolutely necessary, given the potential for soil erosion in the tropics is very large. It is important to communicate this policy as negative issues on oil palm becoming global.

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