ISBN 978-602-6997-70-8

Agroforestry of The Plantation Crops and its Ecosystem Characteristics

Suria Darma Tarigan[1] and Bejo Slamet[2]

[1]*Researcher at CRC990-EFForTS (Research collaboration between Goettingen University-UNJA-UNTAD and Bogor Agricultural University -* https://www.uni-goettingen.de/de/415335.html*);* [2]*North Sumatra University*
surya.tarigan@yahoo.com

ABSTRACT

While oil palm expansion in South East Asia continues, the consequences of this rapid expansion for hydrological functioning and other ecosystem services remain uncertain. In-depth knowledge on this issue is scarce as there have been only few studies addressing hydrological impacts of oil palm plantations. Wecompared theecosystemcharacteristicsof the monoculture plantation, rubber agroforestry and secondary forest. We found that ecosystem characteristics of the plantationcrop agroforestry are similar to that of secondary forest showing among other favorable lowsurface runoff. Other study in our study area, investigating the implementation of the agroforestry in monoculture oil palm showed promising result that agroforestry in oil palm can improved biodiversity and other environmental parameters of the monoculture plantation. The results of this experiment are encouraging for further research aiming to identify more diversified management strategies for plantation crops for sustainable agriculture practice that reconcile green growth strategy.

Keywords**:** Agroforestry, ecosystemcharacteristics, green growth strategy,plantation crops.

Introduction

Over the last decades, South East Asia has undergone dramatic land-use changes. Particularly the area of oil palm agriculturehas increased, often at the cost of forested land. Indonesia, the world's biggest producer of palm oil has currently8.5 million hectaresland under oil palm cultivation(Setiadiet al.,2011). Due to the increasing global demand of oil as source for food and energy, this development will continue in the future. Current plans of the Indonesian government entail18 million hectares under oil palm cultivation by 2020(Setiadiet al.,2011, Koh and Ghazoul, 2010, Colchester, 2006).Apart from oil palm,another prevalent plantation crop in Indonesia is rubberwith 3.5 million hectares (Dirjen Perkebunan, 2013). Rubber is either grown in monoculture plantations or extensively within secondary forest (so-called rubber agroforestry).The consequences of these large-scale land-use changesfor hydrological and other ecosystem functions are uncertain.

Deforestation, urbanization, and other land-use activities can significantly alter the seasonal and annual distribution of streamflow(Dunne, 1978).Hydrological processes within oil palm and rubber plantationsare still not fully understood and studies carried out in oil palm plantations at a watershed scale are scarce. Farmers in our study region, the Jambi Province of Sumatra (Indonesia), reported that they experienced water resource problemssince the extensive conversion of forest to oil palm in the area. This is apparently due to drying out ofswampy areas, small rivers, and pondsand to drastic changes instreamflowpatterns(personal communication withseveral farmers).

It has been put forward that thehigh wateruse (evapotranspiration)of oil palmsmay be the primary cause of water resourceproblems. In contrast, Comte et al. (2012) suggest similar evapotranspiration rates from mature oil palm plantations compared to tropical forest.Given the vast areas that are under oil palm cultivation, there is an urgent need to studythe degreeto which oil palm plantations are responsiblefor water resource limitations and to identify which components of the hydrological cycle are responsible for these problems. Thismightenable the development of appropriate mitigation measures.Important hydrological components in oil palm plantations are evapotranspiration, stemflow, interception, runoff and baseflow.

Baseflowdepends mainly onthe amount of rainfall that infiltrates into the soil and it dominantly regulates streamflowduring the dry season.Yusop et al. (2007) studied the runoffcharacteristics of an oil-palm catchment in Malaysia and measured a baseflow of 54% of total flow, which is lower compared to baseflow values of forested catchments (Rahim and Harding, 1992). Annual runoff can increase after forest conversion due to the reduction of tree stand evapotranspiration, whilebaseflow decreases due to the lower infiltrationrate in deforested areas (Dinoret al. 2007).Bruijnzeel (2004) stated that thetotal annual runoff appears to increase withthe percentage of forest biomass removed.Rainfall infiltration is often reduced tothe extent that insufficient rainy season replenishmentof groundwater reserves results in strong declines ofdry season flows (Bruijnzeel 2004). Annual runoff increased up to 200% when a dipterocarp secondary forest was converted into oil palm and cocoa plantations in Sabah, Malaysia (Yayasan Sabah Forest Management Area, 2000).Similarly, Sunarti et al. (2008) confirmed for our study region Jambi that surface runoff from oil palm and rubber plantation crops was much higher than from a forested landscape.Plantation establishment and harvesting activities involve soil disturbance and compaction, which in turn affect infiltration rates. Sunartiet al. (2008) found that infiltration capacity in oil palm plantations in Bungo, Jambi, Indonesia was only half of that in natural forest.In Papua New Guinea, Banabasetal. (2008) recorded significant spatial variability when comparing water infiltration rates in soil beneath the palm circle, harvest path, and frond piles. Infiltration rate increased in the order path < circle < frond pile. Theyascribed the lower values found in the weeded circle and harvest-path zones to topsoil compaction from falling bunches in the weeded circle, wheel and foot traffic in the harvest paths, and sparse understory vegetation.

We investigateddirect runoff, stemflow, throughfall, and soil bulk density at the plot scale. To obtain a broader view of the hydrological effects of land conversion, we investigated these parametersin different plantationcrops (oil palm and rubber)under different management practices such as agroforestry andin secondary forest.

Methods

Study area

The research was carried out in the Jambi Province of Sumatra, Indonesia (see Fig. 1). Field measurements were carried out around BungkuVillage(1^{o}54’31.4’’S,103^{o}16’7.9’’ E)in the Batanghari District. Average yearly rainfall in the area is 2.000 – 3.000 mm, with 8 – 10 wet months and 2 – 4 dry months. Average monthly rainfall is 179 –279 mm and 68 – 106 mm during wet and dry months, respectively (Sunarti et al., 2008). Clay loam is the dominant soil texture in the study area.

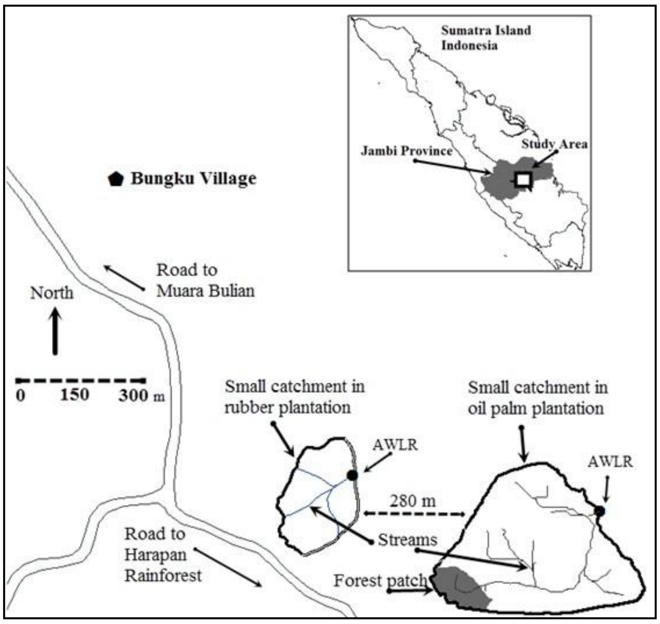

Fig. 1. Study area and small catchments (Jambi Province, Indonesia).AWLR: automatic water level recorder.

Eightplots 8 m × 12 m in size were established in: a) 14-year-old weededand unweededoil palm (14y-OP(w) and 14y-OP(uw)), b) 8-year-old weeded and unweededoil palm (8y-OP(w) and 8y-OP(uw)), c)8-year-old rubber monoculture (RP), d) rubber agroforestry (JR) with 10-year-old rubbertrees , and e) secondary forest (SF).

Fig.2.Exemplary pictures of studied land-use types: weeded (a) and unweeded oil palm (b), rubber monoculture (c) and rubberagroforestry (d).

All plots were similar in soilcharacteristics and slope steepness.

The texture of the soil was dominantly clay loam and the slope steepness in all plots ranges from 15% to 25%. Plot characteristics are listed in Table 1.

Table 1.Plot characteristics

Land use type	Plot name	Number of trees, dbh of trees, planting distance in plot	Harvesting activity on the plot
14-year-old weeded oil palm	14y-OP(w)	Two trees,dbh 65.4 cm and 81.5 cm, planting distance 8 m.	Harvest activity every two weekswith distinct footpath
14-year-old	14y-	Two trees,dbh58.9 cm and	Harvest activity

unweeded oil palm	OP(uw)	60.5 cm,planting distance 8 m	every two weeks with distinct footpath
8-year-old weeded oil palm	8y-OP(w)	Two trees, dbh65.9 cm and 79.6 cm, planting distance 8 m	Harvest activity every two weekswith distinct footpath
8-year-old unweeded oil palm	8y-OP(uw)	Two trees, dbh59.3 cm and 69.4 cm, planting distance 8 m	Harvest activity every twoweeks with distinct footpath
8-year-old rubberplantation	RP	Six trees, meandbh = 21.3 cm with sd = 6.2 cm, regular planting distance 4 m.	Harvest activity everyday with distinct foot path
8-year-old rubber plantation		Six trees, mean dbh = 22.2 cm with sd = 8.9 cm, regular planting distance 4 m.	Harvest activity everyday with distinct foot path
Rubber agroforestry	JR	Six trees (including three rubber trees), mean dbh = 27.9 cmwith sd 4.9cm	Harvest activity, but no distinct foot path
Secondary Forest (logged over in 1987)	SF	Six trees, mean dbh = 28.3 cm with sd 17.4 cm	No human activity

dbh:Treediameterat breast height

We measured and compared ecosystemcharacteristics in each of the land-use types (including stemflow, throughfall, interception, andsurface runoff).

Stemflow

Stemflow was measured by circling and sticking half circle-shapedmetal sheetsfrom the top to the bottom of the trunk. The circling ended50 cm above ground to allow for the placement of water collectors beneath it. In oil palm only one tree for each plot was selected forstemflow measurement. In rubber, jungle rubber and secondary forest, three trees were selected per plot for stemflow measurements.

Throughfall

The throughfallcollectors under oil palm were placed between the two adjacent trees at every 1 m, i.e. at 1 m, 2 m, 3 m, and 4 m distancefrom the closest tree.Throughfall measurements were carried out in weeded and unweeded plots for bothages.In rubber plantations,throughfall collectors were placed between rubber treesat distances of 1 m and 2 m from the closest tree. The distance between adjacent oil palm treesand rubber treeswas 8 m and 4 m, respectively.In both jungle rubber and forest, five throughfall collectorswere installed following both diagonal plot axes. In the open area around the plots, rainfall measurementswere also carried out bythree rain collectors each.

Interception

Interception in oil palm,rubber, jungle rubber,and forest trees was calculated by subtractingstemflow andthroughfall from rainfall at the plot scale. Given that

ISBN 978-602-6997-70-8

interception is based on the area ofa palm tree canopy, stemflow data were normalized withcanopy area before subtraction.Throughfall values on the canopy level were obtained by averaging measurements from all throughfall distances in one tree.

Bulk Density

Bulk density is an indicator for soil compaction. Soil samples were collected from four different land use typesfor bulk density measurement, i.e. 14y-OP(w), RP, JR and SF. In each sampling point, 8 undisturbed soil samples were collected for bulk density measurement. The samples were taken at 15 cm depth using ring samples. The volume of soil in the ring was measured and then the soil was dried up to 105^{o} C. The bulk density was based on the weight of the dry soil divided by the volume of the soil before drying.

Surface runoff

Surfacerunoff was measured in each plot using multidivisor runoff collectors mounted at thelower end of each plot.

Data analysis

Data are presented using box and whisker plots. The box marks the upper and lower quartile; the medianisshown as a line in the box. Additionally the mean is shown as a point. ANOVA tests and Bonferoni corrected post-hoc t-testswere carried out to test the relationships between plantation crop dominated land use types and surface runoff, stemflow, interception, infiltration, andstreamflow.

Results and Discussion

Stemflow

Stemflow was distinctly lower in the rubber agroforestry and secondary forest (Fig.3). This can be explained by the canopy architecture of oil palm, where layered leaf fronds channel rainfall towards the oil palm trunk. From the trunk, the water reaches the ground as stemflow and leads to higher surface runoff under oil palm compared to that of rubber agrofrestry.

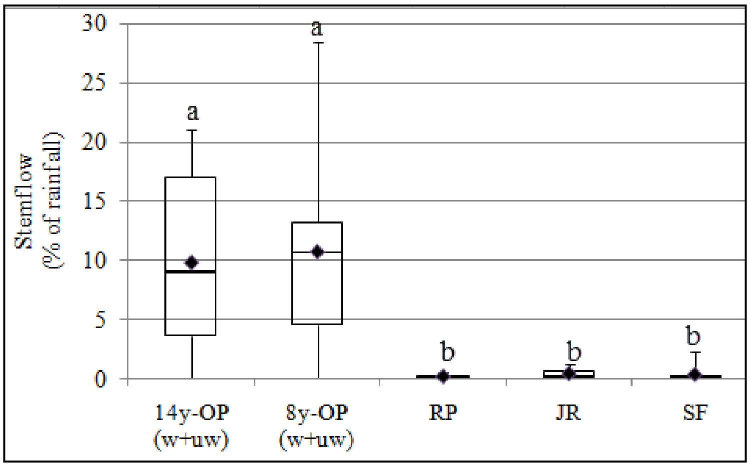

Fig.3. Stemflowof trees in different plantations and forest. Different letters indicate significant differences of averages according to a Bonferroni-corrected posthoc t-test based on an ANOVA (p< 0.05)

 ISBN 978-602-6997-70-8

Throughfall

Throughfall in oil palm plantations was considerably smaller atone meterdistance from the stemcompared to the four-meter distance (~30% and almost 90%, respectively;Fig.4), irrespective of the age-class. The reason for this distinct throughfall patternwasprobably the palm canopy structure: In 1 m distance from the trunk,rainfallwas intercepted by dense and multi-layered leaf fronds and in large partchanneled to the trunk as stemflow (see also Fig. 4),whereas four meters from the trunk leaf fronds were less dense. It is somewhat surprising that we found no difference between oil palmages. In younger oil palm trees, a highproportion of leaf fronds sloped towards the trunk forming a funnel-like canopy. In older palm trees, the leaf fronds started to bend down at the outer end. Therefore, throughfallat4-m-radius was expected to be higher in 14-yr oil palm compared to that of 8-yr oil palm.

Rubber agroforestry showed a more even throughfalldistribution reflecting a more homogenous canopy with ~ 85% throughfallat both radii.Throughfall was significantly higher in jungle rubber and forest compared to throughfall close to oil palm trees (1 m) but was similar tothroughfallat all other locations (except 14-y-OP at 4 m).Throughfall characteristics of the rubber agroforestry and secondary forest showed similar characteristics.

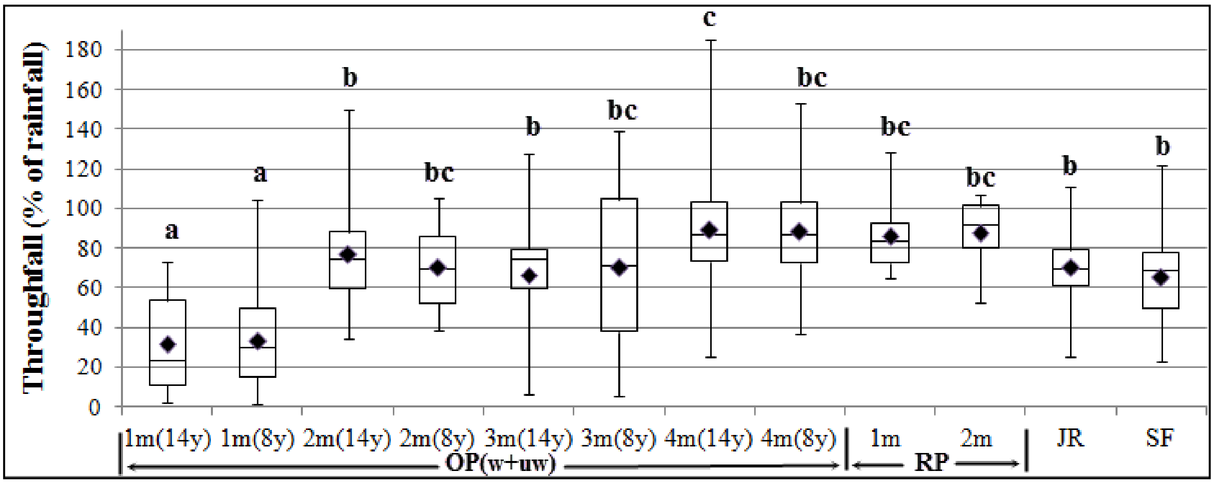

Fig. 4.Throughfallat 1 m, 2 m, 3 m, and 4 m distance from the treein 8 and 14-years-old oil palm , forest and jungle rubber.Different letters indicate significant differences of averages according to a Bonferroni-corrected posthoc t-test based on an ANOVA (p< 0.05)

Interception

Interception reduces the amount of water reaching the ground and consequently reducesstreamflow. There were trends of higher interceptionin oil palm plantationscompared torubber. In oil palm, rainfall is usually not only intercepted by leavesand branches but also by hollow spaces between fronds and trunk. Thistype of interception is called trunk storage (Tarigan and Sunarti, 2012) and may have led to the slightly increased interception in oil palm. Interception in oil palm wasrather similar to interception in jungle rubber but slightly lower than interception in forest (Fig. 5).Interception in rubber was significantly lower than in forest (p< 0.05, Fig. 5).

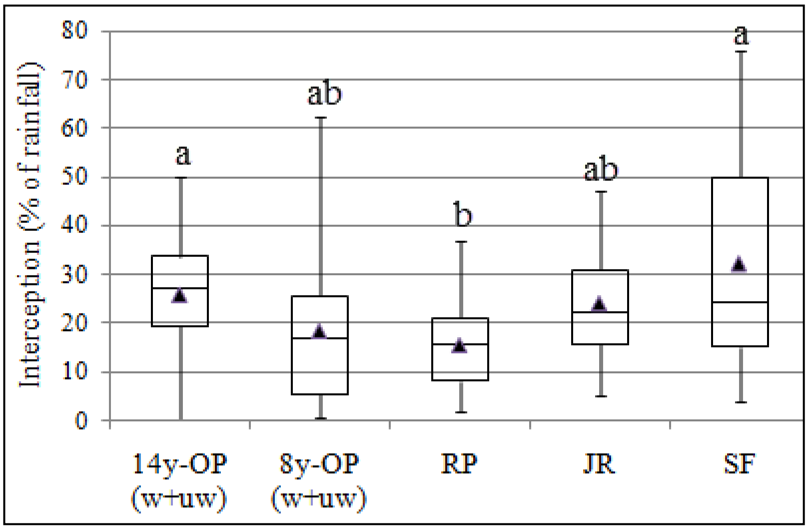

Fig. 5.Interception ofdifferent plantation crops and forest.Different letters indicate significant differences of averages according to a Bonferroni-corrected posthoc t-test based on an ANOVA (p< 0.05).

ISBN 978-602-6997-70-8

Bulk density

In general, bulk densityvalues in our study area were rather high in all land-use types (> 1.2 g cm^{-3}) due to the heavy soil texture (clay loam).**Oil** palm and rubber plantation soils showed significantly higher bulk densities than soils in forest (Fig. 6). There was a trend of oil palm and rubber having a slightly higher bulk density than rubber agroforestry (Fig. 6).Higher bulk density in monoculture plantationcan be explained by compaction due to frequent harvest activities taking place at least 2 times per month under oil palm and several days a weekinrubber plantations.Similar to our findings, Sunartiet al.(2008)found thatbulk density in forest soil (0.81 gr cm^{-3}) was significantly lower than in oil palm (1.05 $grcm^{-3}$) and rubber plantation (1.14 $grcm^{-3}$) in Bungo District, Jambi. Tanaka et al. (2008) also found higher soil bulk density in oil palm plantations compared to secondary forest in Sarawak, Malaysia. In contrast to our findings, Tanaka et al. (2008) report similar soil bulk densities for rubber plantations compared to forest.

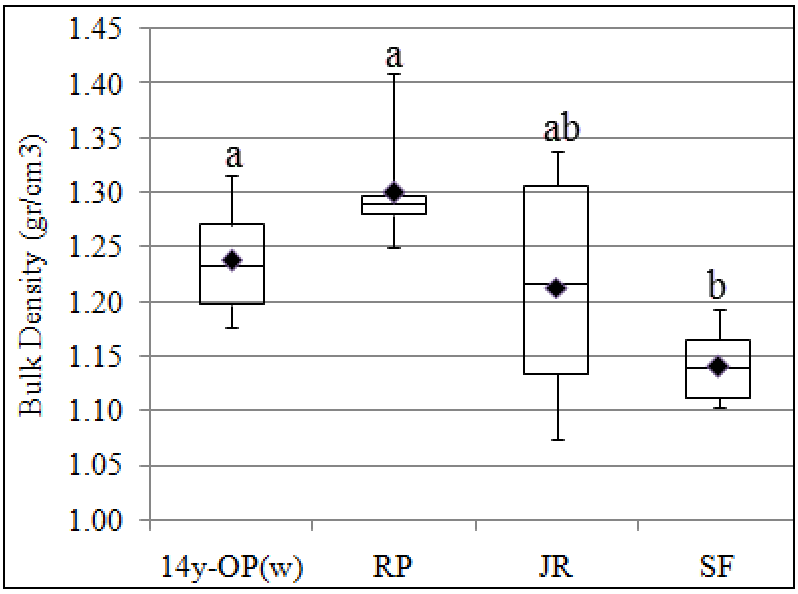

Fig.6. Bulkdensity in the study area under different land use types.Different letters indicate significant differences of averages according to a Bonferroni-corrected posthoc t-test based on an ANOVA (p< 0.05)

Surface Runoff

Mean surface runoff in rubberagroforestry and secondary forestwas very lowcompared to other monoculture plantation (Fig. 7).

 ISBN 978-602-6997-70-8

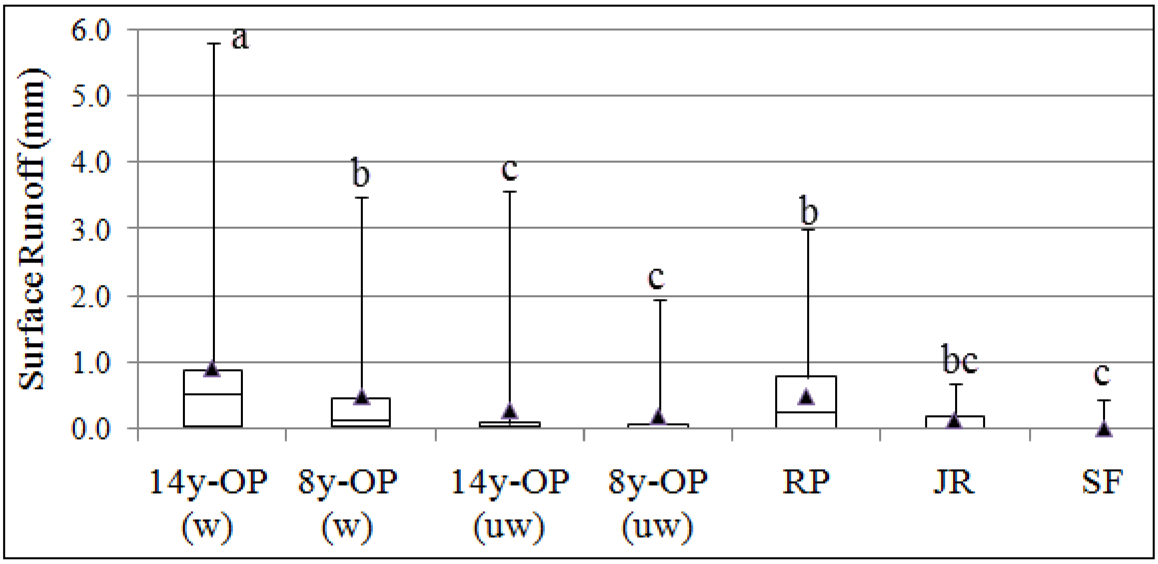

Fig. 7.Surface runoff invariousland-usetypes.Different letters indicate significant differences of averages according to a Bonferroni-corrected posthoc t-test based on an ANOVA (p< 0.05)

Conclusions

We compared the ecosystem characteristics of the monoculture plantation, rubber agroforestry and secondary forest. We found that ecosystem characteristics of the plantation crop agroforestry are similar to that of secondary forest showing among other favorable low surface runoff. Other study in our study area, investigating the implementation of the agroforestry in monoculture oil palm showed promising result that agroforestry in oil palm can improved biodiversity and other environmental parameters of the monoculture plantation. The results of this experiment are encouraging for further research aiming to identify more diversified management strategies for plantation crops for sustainable agriculture practice that reconcile green growth strategy.

Acknowledgements

This study was conducted in the framework of the joint Indonesian-German research project EFForTS-CRC 990. The study was funded by the Directorate General of Higher Education and by Deutsche Forschungsgemeinschaft(DFG) - Germany.

References

Banabas, M., Turner, M. A., Scotter, D. R., and Nelson, P. N., 2008. Losses of nitrogen fertilizer under oil palm in Papua New Guinea: 1. Water balance, and nitrogen in soil solution and runoff.Aust. J. Soil Res. 46, 332–339.

Blume, T., Zehe, E., Bronstert, A., 2007. Rainfall–runoff response, event-based runoff coefficients andhydrograph separation.Hydrological Sciences–Journal–des Sciences Hydrologiques, 52(5) October 2007.

Bruijnzeel, L. A., 2004. Hydrological functions of tropical forests: Not seeing the soil for the trees? Agric. Ecosyst. Environ. 104, 185–228.

Carr, M.K.V., 2011. The Water Relations and Irrigation Requirements of Oil Palm (*ElaeisGuineensis*): A Review. Experimental Agriculture, 47, Pp 629-652. Doi:10.1017/S0014479711000494.

Colchester, M., Jiwan, N., Andiko, Sirait, M., Firdaus, A.Y., Surambo, A., Pane, H., 2006.Promised Land: Palm Oil and Land Acquisition in Indonesia - Implications for Local Communities and Indigenous Peoples. Forest Peoples ProgrammeEngland.p. 26. ISBN: 979-15188-0-7

Comte, I., Colin, F., Whalen, J.K., Gruenberger, O., Calliman, J.P., 2012. Agricultural Practices in Oil Palm Plantations and Their Impact on Hydrological Changes, Nutrient Fluxes and Water Quality in Indonesia: A Review. Advances in Agronomy, Volume 116, 2012 Elsevier Inc. ISSN 0065-2113.

Dietz, J., Hoelscher, D., Leuschner, C., Hendrayanto, 2006. Rainfall partitioning in relation to forest structure in differently managed montane forest stands in Central Sulawesi, Indonesia. Forest Ecology and Management 237 (2006) 170–178.

Dinor. J., Zakaria, N.A., Abdullah, R., Ghani, A.A.B., 2007. Deforestation Effect to the RunoffHydrograph at Sungai Padas Catchment. 2nd International Conference on Managing Rivers in the 21st Century: Solution toward Sustainable River Basins. Riverside Kuching, Sarawak Malaysia.

Dirjen Perkebunan. 2013. Statistik Perkebunan Indonesia (in Bahasa Indonesia).Directorate General for Plantations, Ministry of Agriculture Indonesia.

Dunne, T. and Leopold, L.B., 1978. Water in Environmental Planning, W.H. Freeman& Co., New York, NY, pp 818.

Hewlett, J.D., Hibbert, A.R., 1967. Factors affecting response of small watersheds to precipitation in humid areas. In: Forest Hydrology, ed. W.E. Sopper and H.W. Lull, Pergamon Press, New York.

Koh, L.P., Ghazoul, J., 2010. Spatially explicit scenario analysis for reconciling agricultural expansion, forest protection, and carbon conservation in Indonesia.Proc. of the National Academy of Sciences 17(2), 11140–11144 .

Rahim, A.and Harding, D., 1992. Effects of selective logging methods on water yield and streamflowparameters in Peninsular Malaysia. J. Trop. For. Sci., 5(2), 130–154.

Setiadi,B., Diwyanto, K., Puastuti, W., Mahendri, I.G.A.P., Tiesnamurti, B., 2011. PetaPotensidanSebaran Areal Perkebunan KelapaSawit di Indonesia.PusatPenelitiandanPengembanganPeternakan, BadanLitbangPertanian, KementerianPertanian (*Area distribution of oil palm plantation in Indonesia, Center for Research and Development, Ministry of Agriculture Indonesia*).ISBN 978-602-8475-45-7

Sharma, K.D. 1986. Runoff behaviour of water harvesting microcatchments.Agric. Water Management.11, 137–144.

Sinukaban, N. 2007.Soil and Water Conservation in Sustainable Development. 1st Ed. Published by Directorate General of Land Rehabilitation and Social Forestry, Ministry of Forestry, Republic of Indonesia. ISBN:978-979-97118-3-0

Squire, G.R., 1984.Techniques in environmental physiology of oil palm. 2. Partitioning of rainfall above ground. PORIM Bull. 9, 1–9.

Sunarti, Sinukaban, N., Sanim, B.,Tarigan, S.D.,2008. Forest conversion to rubber and oil palm plantation and its effect on runoff and soil erosion in BatangPelepat watershed, Jambi. J. Tanah Tropika, Vol 13. No.3, ISSN 0852-257X. Lampung.

Tanaka, S., Tachibe, S., Bin Wasli, M.E., Lat, J., Seman, L.,Kendawang, J.J., Iwasaki, K., Sakurai, K.2009. Soil characteristics under cash crop farming in upland areas of Sarawak, Malaysia. Agriculture, Ecosystems and Environment 129, 293-301

Tarigan, S.D., Sunarti. 2012. Quantifying water balance component of oil palm.Proc. of 1st International Conference in Oil Palm.UniversitiTeknologi Mara Malaysia – Bogor Agriculture University.

Yang, H.H., Jaafar, O., El-Shafie, A., Mastura, S., 2011.Impact of land-use changes toward base-flow regime in Lui and LangkatDengkil sub-basin.Int.J.of the Physical Sciences Vol. 6(21), pp4690-4976.ISSN 1992-1950.

Yayasan Sabah Forest Management Area, 2000.Impact Prediction and Evaluation.*In* SEIA for Proposed Sino-Malaysia JV Forest Plantation at Kalabakan and GunungRara Forest Reserves, Tawau District, Sabah

Yusop, Z., Chan, C. H., Katimon, A. 2007. Runoff characteristics and application ofHEC-HMS for modellingstormflow hydrograph in an oil palm catchment. Water Sci.Technol. 56, 41–48.

Zulkifli, Y., Geogfery, J., Saw, A.L., Shahran, T.N., 2006. Preliminary study on throughfall spatial variability and stemflow characteristics of oil palm catchment. Paper presented in National Conference – Water for Sustainable Development towards a developed nation by 2020, 13–14 July2006, Guoman Resort P.D.