# Tree-based Water Footprint Assessment on Established
# Oil Palm Plantation in North Sumatera, Indonesia

## Kajian Jejak Air Berdasarkan Populasi Tegakan pada
## Perkebunan Kelapa Sawit di Sumatera Utara, Indonesia

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### ABSTRACT

In a long life cycle of oil palm plantation, sustainable water management is mandatory because irrigation is rarely applied. In order to develop water management for sustainable palm oil production, tree-based water footprint of well-established oil palm plantation was assessed. Field data were collected from February to June 2016 in Dolok Ilir managed by PTPN IV, North Sumatera, Indonesia. Additional data were obtained from interviews on the site and the surrounding estates, reports and references. Results showed that water footprint (WF) for production of fresh fruit bunch (FFB) was 510.69 $m^3$ tonne$^{-1}$ and crude palm oil (CPO) was 517.79 $m^3$ tonne$^{-1}$. Green, blue and grey water contributed 94.78%, 0.71% and 4.50% in FFB, and 93.48%, 1.66% and 4.85% in CPO productions, respectively. All green WF was calculated basen on actual value of tree evapotranspiration, therefore, the value was mostly lower than other researchs. Low amount of blue water indicates that the oil palm tree in North Sumatera extracts low amount of ground water. On the other hand, grey water for pollution dilution of fertilizers, pesticides and herbicides were high, i.e., 15.15 $m^3$, 4.77 $m^3$, 3.07 $m^3$ tonne$^{-1}$ FFB, respectively. It implies that reduction of grey water should be implemented in the near future through precission farming.

Keywords: CPO, Elaeis guineensis, precission farming, sustainable production, water footprint

### ABSTRAK

Tanaman kelapa sawit memiliki daur hidup yang panjang sehingga manajemen sumberdaya air menjadi penting untuk menjamin keberlanjutan usaha. Namun, kajian hal tersebut di Indonesia masih terbatas. Penelitian bertujuan mengevaluasi jejak air di perkebunan kelapa sawit yang sudah mapan berdasarkan populasi tegakan dalam rangka mengembangkan manajemen sumberdaya air berkelanjutan. Data dikumpulkan pada Februari-Juni 2016 di Kebun Dolok Ilir PTPN IV, Sumatera Utara, Indonesia. Data tambahan diperoleh dari wawancara, laporan dan pustaka. Nilai jejak air untuk memproduksi tandan buah segar (TBS) adalah 510.69 $m^3$ ton$^{-1}$ dan memproduksi minyak sawit (CPO) adalah 517.79 $m^3$ ton$^{-1}$. Jejak air hijau, biru dan abu-abu berturut-turut menyumbang 94.78%, 0.71% dan 4.50% pada total jejak air pada produksi TBS, dan  93.48%, 1.66% dan 4.85% pada produksi CPO. Sehingga, jejak air hijau merupakan komponen terbesar pada produksi TBS dan CPO. Dibandingkan penelitian lain, nilai jejak air hijau tersebut lebih rendah, diduga karena dihitung berdasarkan evapotranspirasi populasi aktual. Jejak air biru termasuk rendah, yang menunjukkan bahwa tanaman kelapa sawit menggunakan sedikit air tanah. Perlu ada upaya khusus mengurangi jejak air abu-abu berasal dari pupuk, pestisida dan herbisida yang besarnya 15.15 $m^3$, 4.77 $m^3$, 3.07 $m^3$ ton$^{-1}$ TBS; diantaranya melalui penerapan teknik budidaya presisi.

Kata kunci: CPO, Elaeis guineensis, jejak air, budidaya presisi, produksi berkelanjutan

## INTRODUCTION

Global area for oil palm (*Elaeis guineensis* Jacq.) production has increased markedly from 10 to 17 million ha over the last decade; and the fields predominantly located in tropical countries as a home of the rest of tropical rainforest, water sanctuary, biodiversity and carbon reserved (Pirker *et al*., 2016; Srinivas and Koh, 2016). Therefore, water, pollution and genetic biodiversity managements of large plantation such as oil palm plantation become global concern (Moreno-Peñaranda *et al*., 2015; Siregar *et al*., 2015; Saswattecha *et al*., 2016).

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By 2016, oil palm field in Indonesia covered area of 11.4 million ha comprised of 5.9 million ha operated by private, 4.7 million ha by small holders and 0.8 million ha by state own companies, with annual crude palm oil (CPO) production of 17.4, 11.3 and 2.2 million metric ton, respectively (Dirjenbun, 2016). Thus, it is important to evaluate water utilization by oil palm plantations in Indonesia as a global leader on oil palm production.

Some studies show that oil palm field conserves less nutrients and water than other tree fields (Taufiq *et al*., 2013; Guillaume *et al*., 2016; Tarigan *et al*., 2016). According to Taufiq *et al*. (2013), discharge water to river by oil palm field is 30 to 40% lower than that of forest condition. Thus, issues on local water quality and related problem arises inline with increasing size of the palm plantations (Larsen *et al*., 2014; Euler *et al*., 2016; Merten *et al*., 2016). However, water issues from oil palm plantation is not simply evaluated due to complex interaction of edaphic, climatic and agronomic practices (Hoekstra and Chapagain, 2007).

Water footprint (WF) is one of rigorous method to evaluate water utilization by crops (Hoekstra and Chapagain, 2007). In this contex, water used by crop is simplified as virtual water relative total yield that is applicable to all crops (Aivazidou *et al*., 2016; Lovarelli *et al*., 2016). Many WF assesments have been made on the oil palm (Bulsink *et al*., 2009; Mekonnen and Hoekstra, 2011; Zulkifli *et al*., 2014; Suttayakul *et al*., 2016) that mostly used field basis calculation. WF evaluation based on tree stand was limited. Tree-based WF needs to be evaluated because WF value is sensitive to volume of water consumption, climate and agricultural practice (Hoekstra and Chapagain, 2007), productivity and region (Bulsink *et al*., 2009), variety and efficiency on oil extraction (Suttayakul *et al*., 2016).

Sumatera is home of well-established oil palm plantations in Indonesia. It contributes about 64% on basis of area or 69% on basis of the crude oil in the country in which North Sumatera manages area more than one million hectares (Dirjenbun, 2016). Therefore, the objective in the study was to assess water footprint in well-established oil palm plantation in North Sumatera in order to develop better water management.

## MATERIALS AND METHODS

### Study Site

Research was conducted on PTPN IV North Sumatera (125 m above sea level), Indonesia from February to June 2016. Immature (*TBM*) and mature trees (*TM*), and milling factory were assessed in Dolok Ilir Estate, while nursery was at Bah Jambi Estate. The Dolok Ilir Estate had podzolic soil (typic hapludult), and topography mostly flat (82%). Rainfall ranged from 1,570 to 2,416 mm (average 1,940 mm). The estate dedicated 557 ha for *TBM* and 5864 ha for *TM* and 928 ha for other facilities. Plant density was 143 tree ha$^{-1}$ of *Tenera* variety (*Dura* x *Pisifera*). Data were gathered from interviews, reports and publications. In case the field

data was not available in the field, information was obtained from public institutions such as RSPO (www.rspo.org).

### Water Footprint Calculation

WF in oil palm field (m$^3$ water tonne$^{-1}$ fresh fruit bunchs-FBB, WF$_{FFB}$) was summarized from nursery (WF$_N$), immature (WF$_{TBM}$), and mature (WF$_{TM}$) stages, as follow: WF$_{FFB}$ = WF$_{NP}$ + WF$_{TBM}$ + WF$_{TM}$. WF in palm oil milling (m$^3$ water tonne$^{-1}$ crude palm oil-CPO, WF$_{OE}$) was calculated based on CPO extraction. Thus, total WF CPO = WF$_{FFB}$ + WF$_{OE}$.

The water was classified as green, blue and grey water (Hoekstra *et al*., 2011), WF$_{CPO}$ = WF$_{green}$ + WF$_{blue}$ + WF$_{grey}$. The green WF$_{FFB}$ referred to the volume of rainwater consumed for FFB production including transpiration of oil palm tree stand, below vegetation and weed-free area, and harvested biomass (Table 1). Green WF was calculated by dividing the green water use (m$^3$ ha$^{-1}$) by the crop yield (*Y*, tonne ha$^{-1}$). Blue WF referred to the volume of surface and ground water consumed including water for irrigation to FFB production, CPO extraction and domestic labor; it was calculated by dividing the blue water use (m$^3$ ha$^{-1}$) by the crop yield (*Y*, tonne ha$^{-1}$). Due to no irrigation was applied in the study site, water for irrigation was setted as zero; thus Blue WF for oil palm was calculated from difference between water of palm consumption and rainfall. Rainfall interception of palm tree was calculated according to Tanjung (2013) for *TBM* to *TM-3*, and according to Pasaribu *et al*. (2012) for *TM-4* to *TM-20*, i.e., 11.6% and 21.2%, respectively.

Grey WF is volume of freshwater that is required to dilute the load of pollutants based on natural background concentrations and existing ambient water quality standards (Hoekstra *et al*., 2011; Franke *et al*., 2013). The grey WF was calculated based on application of agrochemicals rate (tonne ha$^{-1}$) times the leaching-run-off fraction (α) divided by the maximum acceptable concentration (*Cmax*, tonne m$^{-3}$) minus the natural concentration (*Cnat*, tonne m$^{-3}$) and then divided by the crop yield (*Y*, tonne ha$^{-1}$); α for pesticide and herbicide was 0.01 (Franke *et al*., 2013). Leaching-run-off fraction (α) for N, P, K, Mg, Ca and B were obtained from mature oil palm plantation, i.e., 0.11, 0.03, 0.05, 0.06, 0.05, and 0.21, respectively (Comte *et al*., 2012). *Cnat* was setted as zero. *Cmax* value was obtained from United State Environmental Protection Agency (US EPA, www.epa.gov), Ong *et al*. (2009), Franke *et al*. (2013), Mekonnen and Hoekstra (2015), and Ministry of Health New Zealand (www.health.govt.nz). In case *Cmax* value differ among reports, the lowest allowable concentration was used.

Direct WF referred to the water that directly involved at FFB production (Table 1) or CPO extraction (Table 2). Indirect WF refers to the water consumption and pollution that indirectly associated with the production of the FFB or CPO extraction. In present study, the indirect water for production of agrochemicals, diesel lifting, and field tools and materials (Halimah *et al*., 2014) were excluded from WF calculation.

*Limitation of the Study*

WF of seed production was calculated based on assumption that a FFB produced 1,300 high quality seeds. Blue water of cover crop (LCC) seedling was calculated based on assumption that one hectare of oil palm field required 600 seedling bags of *Mucuna bracteata*; and each LCC seedling consumed 100 mL daily for 45 days in the nursery.

A two-stage-nursery of oil palm was used, i.e., 3 months in pre-nursery and 9 months in main-nursery with daily watering was 0.3 L and 2.0 L per bag, respectively. For one hectare of palm stand, it required 165 plants at pre-nursery and 150 plants at main-nursery by considering abnormal and dead seedlings. Grey water in the nurseries was considered zero. In established plantation like Dolok Ilir, land clearing was none and trees replanting used herbicide injection. WF for land preparation was concluded from 4 weeks field evaporation, 2 mm per day. Palm life cycle was determined 24 years composed of 1, 3, and 20 years in nurseries, *TBM* and *TM*, respectively. Average annual FFB production was determined 19.9 tonne ha⁻¹.

Field evapotranspiration rate (ET) followed equation: PT+GV+FW+DF; where PT-palm transpiration, GV-ground vegetation transpiration of LCC and (or) weeds, FW-evaporation weed-free area, and DF-evaporation of fronds dumping site, dead inter-row (called *gawangan mati*). $ET_{PT}$ was assumed 0.2 to 1.3 mm per day dependent on plant age followed the model of Röll *et al* (2015). It assumed that a palm tree occupied an area of 12.56 m². In brief, individual tree water consumption ($ET_{PT}$) were 12.5, 25.0, and 50.0 liter per day for *TBM-1* to *3*, and 60.0, 75.0, 82.5, 92.5, 100.0, and 110.0 liter per day for *TM-1* to *6*. $ET_{PT}$ was 125.0 liter per day for *TM-7* to *20*. Total PT $=\sum_{n=1}^{20}(ETn \times 365 \times 143)$; value 365 was days in a year and 143 was tree population ha⁻¹. ET *gawangan mati* that covered 1800 m² ha⁻¹ was setted zero. ET ground vegetation was estimated from 100% LCC for *TBM* to *TM-2*, 50% LCC and 50% *Axonopus compressus* for *TM-3* to *TM-4*, and 100% *A. compressus* for *TM-5* to *TM-20*. Crop coefficient (Kc) of *A. compressus* was determined as 0.3 (Connellan, 2013). *M. bracteata* growth was assumed decline about 50% at *TM-3* and fully suppressed in *TM-5*. Water efficiency of *M. bracteata* was estimated from legumes (Biederbeck and Bauman, 1994), i.e., 11 kg ha⁻¹ mm⁻¹; *M. bracteata* biomass produced half of 11.02 ton dry mass ha⁻¹ (Chee, 2007).

Weed-free areas of circle below trees (*piringan*, 4 m in diameter), collecting road (*jalan pikul*, 1.5 m x 600 m), and fruit collecting point (*tempat pengumpulan hasil*, 3 m x 4 m) were considered. Weed-free circle was maintained in both *TM* and *TBM*, while *jalan pikul* and fruit collecting point were exclusive in *TM* fields. Weed-free area was 1796 m² ha⁻¹ for *TBM* and 2708 m² ha⁻¹ for *TM*; and the evaporation rate was determined 1,200 mm per year (Nuryanto and Rizal, 2013).

Labor WF was evaluated based on labor index (*ITK*) times 365 days per year for 24 years times average water consumption, i.e., 0.1761 m³ per day. *ITK* considered 839 permanent labor devided by cropped area (6,421 ha) equal

to 0.13. Manhour of seasonal labor was accumulated and devided by eight working hours per day. Labor in factory was 5.25 mandays per hour. Water for public facilities was obtained from installed water meter device.

Water for agrochemical applications were recorded; and water for nutrient dillution was calculated based on active ingredient(s) or nutrient(s). Application rate of pesticide, herbicide and empty fruit bunch (EFB) was obtained from RSPO (www.rspo.org), and rate of fertilizer was from Silitonga (2015). Nutrient content of EFB followed Abdullah and Sulaiman (2013). Nutrient balance of N, P, K, Mg, Ca and B were calculated based on application rate considering the nutrient-fixed by biomass of tree, ground cover vegetation and FFB (Abdullah and Sulaiman Pahan, 2013; Mekonnen and Hoekstra, 2015; Brueck and Lammel, 2016). Ground cover biomass was calculated based on *A. compressus* and LCC (Chee, 2007; Purwantari *et al.*, 2015) as in transpiration measurement. Nutrients contribution from dry fronds and tree litter were excluded from analysis.

CPO milling factory was generated by biomass utilized water from Bah Bolon River; had capacity 54 tons FFB resulted 12.96 tonne CPO hour⁻¹ (oil extraction rate 24%). The milling released effluent with 90% water.

## RESULTS AND DISCUSSION

WF for FFB production was 510.69 m³ tonne⁻¹ (Table 1), while WF for CPO production was 517.79 m³ tonne⁻¹. The WF values were different from those reported by previous authors. WF for FFB production is reported as much as 853 m³ tonne⁻¹ (Bulsink *et al.*, 2009), 1,063 m³ tonne⁻¹ (Suttayakul *et al.*, 2016), and 1,166 m³ tonne⁻¹ (Zulkufli *et al.*, 2014), while for CPO production is 4,971 m³ tonne⁻¹ (Mekonnen and Hoekstra, 2011) and 5,083 m³ tonne⁻¹ (Suttayakul *et al.*, 2016). According to Mungkalasiri *et al.* (2015), WF oil palm depends on productivity, climate, management and model used for calculation. Present study shows that WF calculation based on existing tree stand is lower than those by general modelling such as by Bulsink *et al.* (2009), Mekonnen and Hoekstra (2011), and Suttayakul *et al.* (2016). Present study demonstrated that WF calculation based on tree stand transpiration, ground vegetation and weed-free area abled to enhance the accuracy on WF estimates.

Direct water foot print contributed 65.99% and 65.53% of total WF in FFB and CPO productions, respectively. The indirect water footprint contributed low on FFB and CPO productions (Figure 1). FFB production required direct water 334.68 m³ tonne⁻¹ and indirect water 176.01 m³ tonne⁻¹. High WF in CPO production was due to WF from FFB production. CPO extraction consumed direct water of 7.10 m³ tonne⁻¹ or 1.38% of total WF (Table 2).

In Dolok Ilir milling factory, water quantity for CPO extraction has complied with goverment regulation, i.e., 1.2 to 1.5 m³ tonne⁻¹ FFB. Based on water meter record, average water consumption was 1.29 m³ tonne⁻¹ FFB, at which 1.16 m³ for FFB milling and 0.13 m³ for cleaning factory. Milling factory operated 1 unit boiler, 3 units screw press, 5 units sludge separator, and 1 unit hydrocyclone, equal to

Table 1. Direct and indirect water footprint (WF, m$^3$) per one tonne fresh fruit bunchs (FFB) of oil palm in Dolok Ilir estate, North Sumatera

| Component of water usaged | Direct WF (m$^3$ tonne$^{-1}$) | | | Indirect WF (m$^3$ tonne$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Green | Blue | Grey | Green | Blue | Grey |
| Labor on seedling and mature | - | - | - | - | 0.89 | - |
| Seed production | - | - | - | 0.001 | - | - |
| Seedling legume | - | - | - | 0.01 | - | - |
| Land preparation | - | - | - | 1.52 | - | - |
| Transpiration oil palm | 309.17 | 2.01 | - | - | - | - |
| Transpiration ground vegetation | - | - | - | 132.89 | - | - |
| Evaporation weed-free area | - | - | - | 18.46 | - | - |
| Rainfall interception | - | - | - | 21.71 | - | - |
| Irigation water in nursery | - | 0.20 | - | - | - | - |
| Agrochemicals application | 0.03 | - | - | - | - | - |
| Pesticides assimilation | - | - | 4.77 | - | - | - |
| Herbicides assimilation | - | - | 3.07 | - | - | - |
| Fertilizers assimilation | - | - | 15.15 | - | - | - |
| Total biomass oil palm | 0.28 | - | - | - | - | - |
| Biomass ground vegetation | - | - | - | 0.27 | - | - |
| Public facilites | - | - | - | - | 0.55 | - |
| Total | 309.48 | 2.31 | 22.99 | 174.86 | 1.44 | 0 |

' – ' denotes no value

water consumption of 35.0, 30.0, 17.5 and 0.5 m$^3$ hour$^{-1}$, respectively.

FFB production consumed 484.05 m$^3$ green WF, 3.65 m$^3$ blue WF and 22.99 m$^3$ grey WF equal to 94.78%, 0.71% and 4.52%, respectively (Figure 2). Suttayakul *et al.* (2016) stated that green, blue, and grey waters contributes 68%,
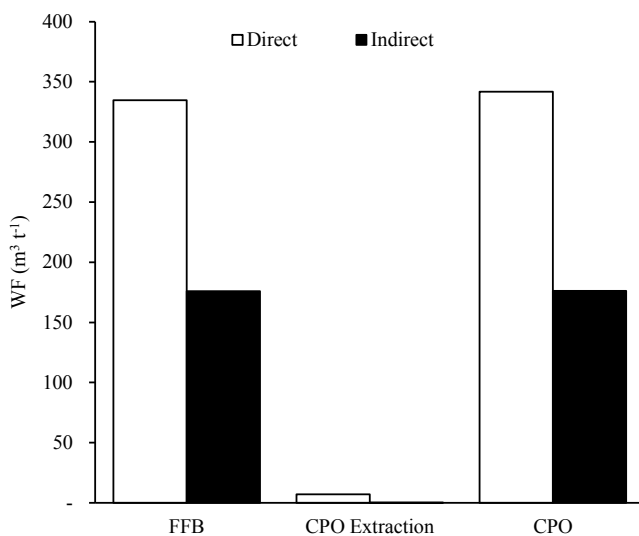


Figure 1. Direct and indirect water footprint (WF) of fresh fruit bunchs production (FFB), crude palm oil extraction (CPO Extraction) and CPO production (CPO) in Dolok Ilir Estate, North Sumatera

18%, and 14% to total WF, respectively. High value of green water indicates that the site is suitable for oil palm production in water perspective. Every year, there is a month between February and June with rainfall less than 60 mm. During particular period, oil palm trees utilized ground water (blue WF) for growing. Low blue water requirement in present study than that in Thailand (Suttayakul *et al.*, 2016), indicates that oil palm production in North Sumatera is more sustain on reference to ground water conservation.

No green water was used for CPO extraction (Figure 2). Oil extraction utilized blue water for milling at rate 4.86 m$^3$ tonne$^{-1}$ CPO and 0.54 m$^3$ tonne$^{-1}$ CPO for cleaning factory (Table 2). Thirty percent of WF in CPO extraction was grey water from milling effluent. It needs further evaluation on CPO extraction because grey water from water treatment, water coolant, electric generation and milling effluent that sink to waterbody had not incorporated yet in present study. High proportion of blue water at milling factory, resulted in higher blue WF of CPO production (Figure 2).

Grey WF in FFB production of present study is lower than study in Malaysia by Zulkifli *et al.* (2014), although the annual FFB production is nearly equal, i.e., 20.7 tonne ha$^{-1}$ in Malaysia vs. 19.9 tonne ha$^{-1}$ in North Sumatera. Out of 22.99 m$^3$ grey WF in every tonne of FFB production, 65.90% was used to assimilate fertilizers, 20.75% to assimilate pesticides and 13.35% to assimilate herbicides. Large amount of water was used for assimilating magnesium and boron, i.e., 46.44% and 22.89%, respectively, followed by nitrogen (14.16%), calcium (10.38%), phosphorus (4.64%),

Table 2. Direct and indirect water footprint (WF, m³) per one tonne crude palm oil (CPO) extraction in Dolok Ilir milling factory, North Sumatera

| Water usaged | Direct WF (m³ tonne⁻¹) | | | Indirect WF (m³ tonne⁻¹) | | |
|---|---|---|---|---|---|---|
| | Green | Blue | Grey | Green | Blue | Grey |
| Labor | - | - | - | - | 0.01 | - |
| Milling factory | - | 4.9 | - | - | - | - |
| Effluent | - | - | 2.13 | - | - | - |
| Total | 0 | 4.9 | 2.13 | 0 | 0.01 | 0 |

' – ' denotes no value

and potassium (1.08%) (Figure 3A). Water for assimilating herbicides was 3.07 m³ tonne⁻¹ FFB, at which 67.80% WF was used for assimilating paraquate dichloride, followed by fluroxypyr (16.38%), isoprophylamina glyphosate (14.60%), and metil metsulfuron (1.23%) (Figure 3B). Water to assimilate pesticide was 4.77 m³ tonne⁻¹ FFB at which 54.79% WF was used for assimilating acephate, followed by deltametrine (40.81%), dimehypo (2.11%), carbosulfan (1.51%), and cypermethrine (0.79%) (Figure 3C).

Grey WF is determined by management of fertilizers, pesticide and herbicides (Franke *et al.*, 2013). High grey WF for agrochemicals dilution might be one of indications of luxury application. Based on calculation, excess of nitrogen in the form of amonium or nitrite, irrespectively, was at rate of 12.39 g per day followed by potassium at rate of 7.62 g per day and boron at rate of 6.88 g day⁻¹. High annual N and K fluxes to waterbody has been noted by Comte *et al.* (2012) in Jambi plantation at rate 1.53 to 8.24 kg $NO_3$-N ha⁻¹ and 5.4 to 37.9 kg $K^+$ ha⁻¹, respectively.

The palm oil industry is a major water polluter in Southeast Asia because uses large amounts of fertilizers (Muyibi *et al.*, 2008), and discharge POME (Wu *et al.*,

2010) to aquatic ecosystems; a challenge for Indonesian (de Jong *et al.*, 2015; Comte *et al.*, 2015). According to Saswattecha *et al.* (2015) five most activities in palm oil field that contribute negative impact onto environmental are: burning fibers in boilers, use of fertilizers, wastewater treatment and empty-fruit-bunch disposal, gasoline in weed cutters and glyphosate for control of weed.

Although in palm field the fertilizer inputs could be different from time to time depend on plant age, environmental issues, price, as well as local regulation (Hoekstra and Chapagain, 2007), to reduce fertilizer application in palm field is not easy. Intensive cultivation could lead to intensive soil degradation under oil palms. According to Guillaume *et al.* (2016) 10% of soils under oil palms had very low C content (<1%). Thus, field improvement could be made to reduce nutrient leaching. In rubber plantation, Rusli and Heryana (2015) revealed that silt pit (*rorak*) construction enables to conserve N-P-K nutritions from sinking to waterbody. Furthermore, Tarigan *et al.* (2016) demonstrated that application of frond pile management, and its combination with silt pit construction reduce run-off water by 10% and 31% in palm field, respectively. Utilization of ground cover *Nephrolepis biserrata* as a cover crop in combination with ridge terracing reduces the rate of water loss by percolation and run-off by 36% and 80%, respectively according to Ariyanti *et al.* (2016). Comte *et al.* (2012) demonstrated that although oil plantation receives high fertilizer application, nutrient losses especially $Mg^+$ into the waterbody is equal fluxes from forest if EFB is applied as mulch. These facts exhibite that better field management reduce grey WF in the oil palm field.

In WF evaluation, over or underestimate value might occurs due to agronomic factors such as palm genotype, age, culture techniques and record data availability. In Dolok Ilir, the palm genotypes composed of Marihat, Lonsum and Socfindo. Palupi and Dedywiryanto (2008) stated that oil palm genotype determines water use. Variation in plant density and number of existing frond among plantations was eviden. Number of standing tree reduced by about 37% at *TM-5*, and by about 50% at *TM-13* from original planting 143 plants ha⁻¹ in Dolok Ilir due to *Ganoderma sp.* infection. Overcounting standing crop consequently underestimates coverage of ground cover vegetations and weed-free areas, leading to lower WF values. According to Gromikora *et al.*
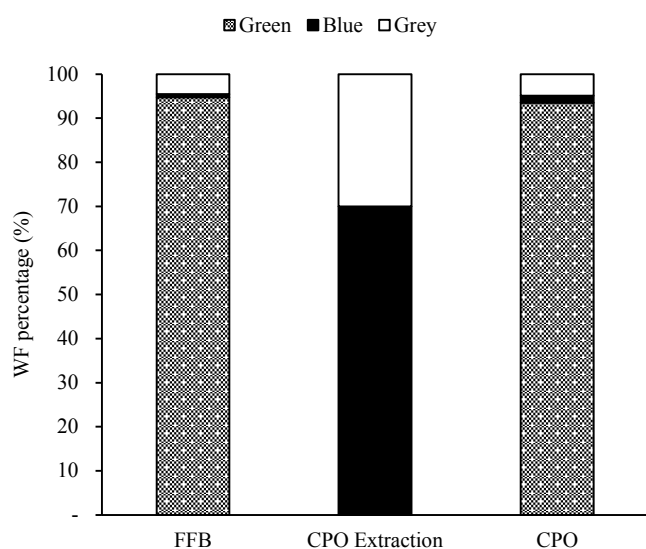


Figure 2. Proportion of green, blue and grey water footprint (WF) of fresh fruit bunchs production (FFB), crude palm oil extraction (CPO Extraction) and CPO production (CPO) in Dolok Ilir Estate, North Sumatera
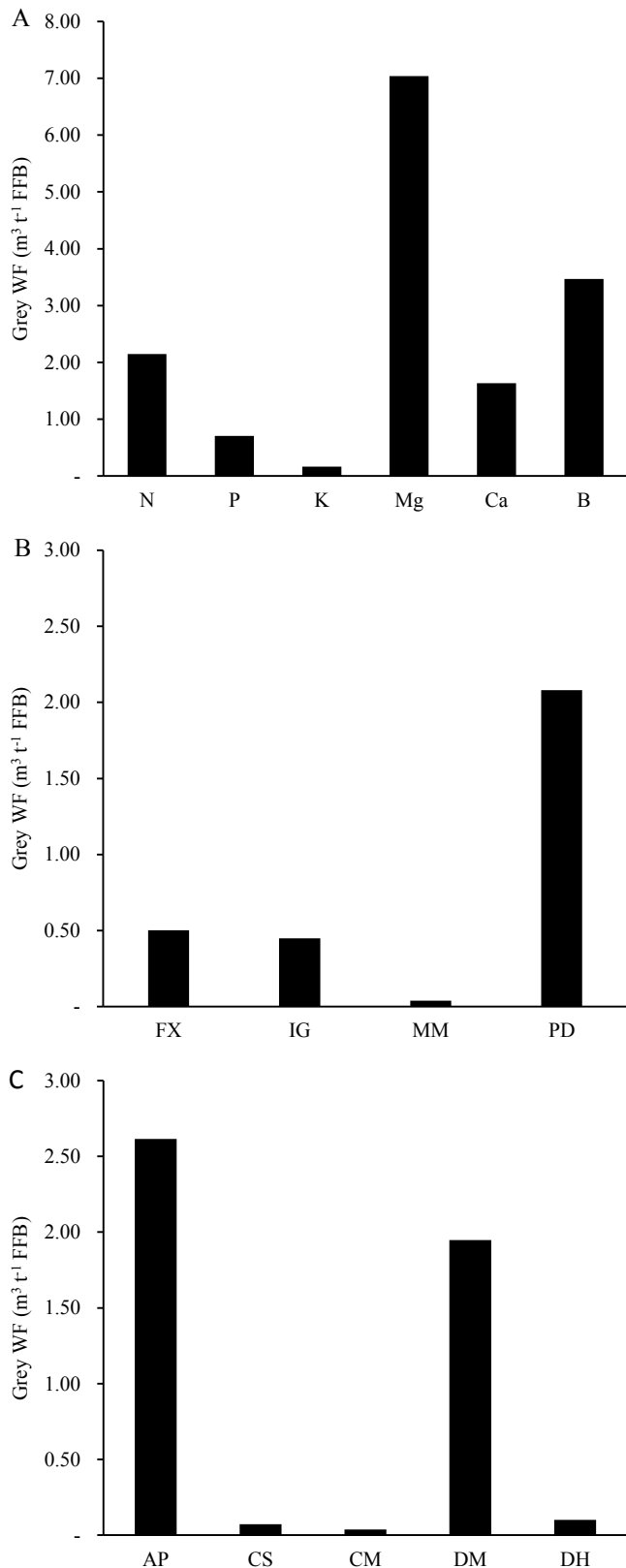
Figure 3. Grey water footprint (WF) of fresh fruit bunch (FFB) production for assimilation of fertilizers (A), herbicides (B) and pesticides (C) in Dolok Ilir Estate, North Sumatera. FX-fluroxypyr, IG-isopropylamina glyphosate, MM-metil metsulfuron, PD-paraquat dichloride, AP-acephate, CS-carbosulfan, CM-cypermethrine, DM-deltametrine and DH-dimehypo

(2014), number of existing frond per tree determines level of production. In the field, number of frond per tree ranged from 37 to 52 depend on tree age and fruit load. Moreover, mishandling of herbicide application at rate 15 to 20% was found during study, causes miscalculation on acreage of weed-free areas.

Recently, adoption of new cover crops such as *Mucuna bracteata*, *Neprolepsis bisserata*, and *Asystasia sp.*, and some forages crops in palm field is increasing (Prof. Sudirman Yahya, agronomist, personal communication 2016). According to Saswattecha *et al.* (2016) application of EFB and cover crops as mulch improve oil palm sustainability. According to Ariyanti *et al.* (2016) planting *Nephrolepis biserrata* Kuntze as ground cover vegetation of oil palm field improves soil water during dry season. However, application of these new cover crops needs further evaluation especially on its contribution to green and blue WF consumption.

Finally, in advance oil palm management (Afriyanti *et al.*, 2016; Saswattecha *et al.*, 2016), effort to reduce transpiration rate of weed-free area and ground vegetations should be implemented in order to address water and environmental issue (Moreno-Peñaranda *et al.*, 2015). Instead of some difficulties to obtain the accurate climatic and agrochemical data, WF evaluation enable to describe the basic need on water management. In the future, field improvement should be made to alter pollution to waterbody from the agrochemical inputs as indicating by grey WF, such as through implementing precission farming.

## CONCLUSION

Water footprint in oil plantation was 510.69 $m^3$ tonne$^{-1}$ FFB and 517.79 $m^3$ tonne$^{-1}$ CPO. Every tonne FFB required 484.05 $m^3$ (94.78%), 3.65 $m^3$ (0.71%) and 22.99 $m^3$ (4.50%) of green, blue and grey WF, respectively. In CPO production, additional blue and grey water on to FFB at rate 8.62 and 25.12 $m^3$ tonne$^{-1}$ or 1.66% and 4.85%, respectively, was required. Green water in CPO production (93.48%) mostly derived from FFB production. Large green and grey WF for FFB and CPO production denoted the importance to manage water resources. It implies that precission farming is mandatory in the plantation in order to sustain palm oil production.

## ACKNOWLEDGEMENT

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