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Consumptive Water Use Assessment and Life Cycle Assessment-based Water Footprint for Palm Oil

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ABSTRACT

Water scarcity and climate change are serious issues facing our planet. This study evaluates the impacts caused by water consumption of oil palm, from seedling until the production of crude palm oil, based on a full tlife cycle assessment. The consumptive water use evaluation for direct water was based on the local water stress index (WSI). The system boundary included the oil palm nursery, plantation (with land use change from oil palm to oil palm, and from logged-over forest to oil palm) and palm oil mill (in a biogas capture scenario). The findings show that direct water used by the palms and for processes is low. This is valid as most oil palm plantations are not irrigated but rather rain-fed, coupled with Malaysia's climate that is characterised by high rainfall, leading to a very low WSI for the country. The main potential impacts within the system boundary are dominated by land conversion, production and use of fertilisers and pesticides. These findings contradict the general perception of any agriculture system, i.e. the notion assuming that water used during crop cultivation will have a major potential impact. It is recommended that oil palm plantations implement Good Agricultural Practices that help address the key elements of land and water management, as well as fertiliser and integrated pest management to obtain a favourable water footprint.

ABSTRAK

Kekurangan air dan perubahan iklim merupakan isu serius yang dihadapi oleh planet kita. Kajian ini mengkaji impak yang disebabkan oleh penggunaan air oleh pokok sawit, daripada peringkat anak benih sehingga pengeluaran minyak sawit mentah, berasaskan penilaian kitar hayat lengkap. Kajian penggunaan air secara langsung adalah berdasarkan indeks tekanan air tempatan (WSI). Sempadan kajian termasuk tapak semaian sawit, perladangan (dengan perubahan penggunaan tanah daripada sawit kepada sawit, dan daripada pembalakan hutan kepada sawit) dan kilang minyak sawit (dengan senario penangkapan biogas). Hasil kajian menunjukkan penggunan air yang digunakan secara lansung oleh pokok dan pemprosesan adalah rendah. Ini disebabkan kebanyakan ladang sawit tidak menggunakan sistem pengairan sebaliknya ladang hanya bergantung kepada air hujan, kerana cuaca Malaysia dicirikan dengan taburan hujan yang tinggi dan menghasilkan WSI yang sangat rendah untuk negara ini. Impak utama dalam sempadan kajian dipengaruhi oleh penukaran tanah, pengeluaran dan penggunaan baja dan racun perosak. Penemuan ini bercanggah dengan persepsi umum tentang sistem pertanian yang mempunyai tanggapan bahawa air yang digunakan untuk penanaman tanaman memberi impak besar. Adalah disyorkan ladang sawit patut melaksanakan amalan pertanian baik bagi membantu menangani unsur-unsur utama pengurusan tanah dan air selain pengurusan baja dan pengurusan serangga bersepadu, untuk mendapatkan kadar penggunaan air yang berpatutan.

Keywords: water footprint, life cycle assessment, crude palm oil, FFB, oil palm seedlings.

INTRODUCTION

The Malaysian oil palm industry celebrated its 100th year of commercial cultivation of oil palm in 2017 (Zunaira and Hanim, 2017). To date, Malaysia has a total planted oil palm area of 5.81 million ha (MPOB, 2018), and ranks as the second largest palm oil producer globally, bringing in large export revenues for the country annually. In 2017 alone, crude palm oil (CPO) production was 19.92 million tonnes, while revenue from the export of palm products was worth RM 77.85 billion (MPOB, 2018). Currently, the world is facing two serious issues, namely climate change and water scarcity. When the demand for water surpasses its supply, then a region is said to be experiencing water scarcity (Harhay, 2011). Just like the carbon footprint, water scarcity issues have given rise to the quantification of water consumption through a water footprint (WF) for products which are carried out through the Life Cycle Assessment (LCA) approach. Water Use in Life Cycle Assessment (WULCA) (2014)

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defines LCA as a method to evaluate the potential environmental impacts of a product or process for the whole life cycle. A component of LCA is WF which quantifies impacts related to water consumption and disposal, based on the availability of water in a region (WULCA, 2014).

This national study used data from over 240 palm oil mills (POMs). The study assessed the amount of water that is used by the industry, and the impact from this use. It evaluated the sources of the impact – whether it is from the crop cultivation stage or from the process stage, of from other parts of the supply chain.

Generally, oil palm is planted at a density of 136 to 148 palms ha^{-1} (Hashim *et al*., 2010). The total oil palm cultivated area of 5.81 million ha results to 790.16 million to 859.88 million palms of varying ages in the country. Identification of areas most suitable for planting oil palm and the quantification of water consumption by these palms are very important. It is anticipated that the findings of this study will enable better decision-making in determining areas that are suitable for oil palm planting as well as in formulating better water management practices in the plantations. The findings can also inform policy makers and stakeholders of the hotspots where the potential impact on water consumption exists along the supply chain of the system boundary. This study also intends to evaluate the impacts associated with the use of water by oil palm trees and the industry and if necessary suggest mitigation measures.

METHODOLOGY

Variations exist in the findings from various WF studies (Jeswani and Azapagic, 2011). LCA was carried out by the ReCiPe LCA method to identify potential impacts, and using the software SimaPro version 8.0.4. The mid-point ReCiPe was used. The ReCiPe method is one of the harmonised indicator approaches available for life cycle impact assessment (LCIA) (Goedkoop *et al*., 2009). A full LCIA determines the potential impacts for WF. The method by Ridoutt and Pfister (2013) was conducted to obtain a stand-alone number for consumptive water use (CWU). CWU calculates direct water use according to localiser and water stress index (WSI). This approach provides a more local realistic evaluation because water varies from area to area.
One of the most commonly used measures of water scarcity is the 'Falkenmark indicator' or WSI. The range of WSI is from 0 to 1, where 0 = no stress and 1 = extreme stress.

This measure defines water scarcity in terms of total availability of water to the population of a region, measuring scarcity as the amount of renewable freshwater that is available for each person a year (UNESCO, 2012). If the amount of renewable water available per person in a country is < 1700 m^3 yr^{-1}, that country is said to be experiencing water stress (UNESCO, 2012).

CWU relates to the removal of water from a water body, and is calculated based on Equation (1).-

$$CWU\ (H_2Oe) = \sum_i \frac{CWU_i \times WSI_{local}}{WSI_{global}} \qquad \text{Equation (1)}$$

where CWU_i = direct water use; WSI_{local} = local WSI; WSI_{global} = global WSI (Ridoutt and Pfister, 2013).

The CWU calculations are based on WSI of a country. WSI of Malaysia is assumed to be 0.05, as the mid-point WSI of Malaysia which is below 0.1. Global WSI as stated in Ridoutt and Pfister (2013) is 0.602.

Water applied into the system boundary for processes, such as boiler water or water for irrigation, pesticide application, *etc*., is considered direct water. Water used to produce the products used in the system boundary but not produced within the boundary, such as diesel, fertilisers and pesticides, is considered indirect water. Both direct and indirect water are accounted for in this study.

System Boundary

The system boundary for this study is shown in *Figure.1.* The nursery stage is the first stage of the system boundary where the germinated seeds are planted in polybags. These oil palm seedlings are irrigated with sprinklers and applied with fertilisers and herbicides. After 10-12 months, the healthy oil palm seedlings are then transplanted to the oil palm plantations, where they grow into palms. The oil palm plantations in the study are not irrigated, but are rain-fed. The only water input at the plantations is for pesticide application. The oil palm start to bear fresh fruit bunches (FFB) at three years of age. The ripe FFB are harvested and transported to the third stage of the supply chain which is the palm oil mill (POM). The economic life cycle of an oil palm is 25 years, after which the palms are cut down to be replanted with new seedlings. The scenario of continuing land use change (LUC) of oil palm to oil palm as well as that of the earlier LUC of oil palm from logged-over forest (LOF) were examined at the plantations. Data for LOF and LUC were obtained from Lasco (2002) and Syahrinudin (2005), respectively.

The oil palm plantations in Peninsular Malaysia have continued LUC scenario because one life cycle

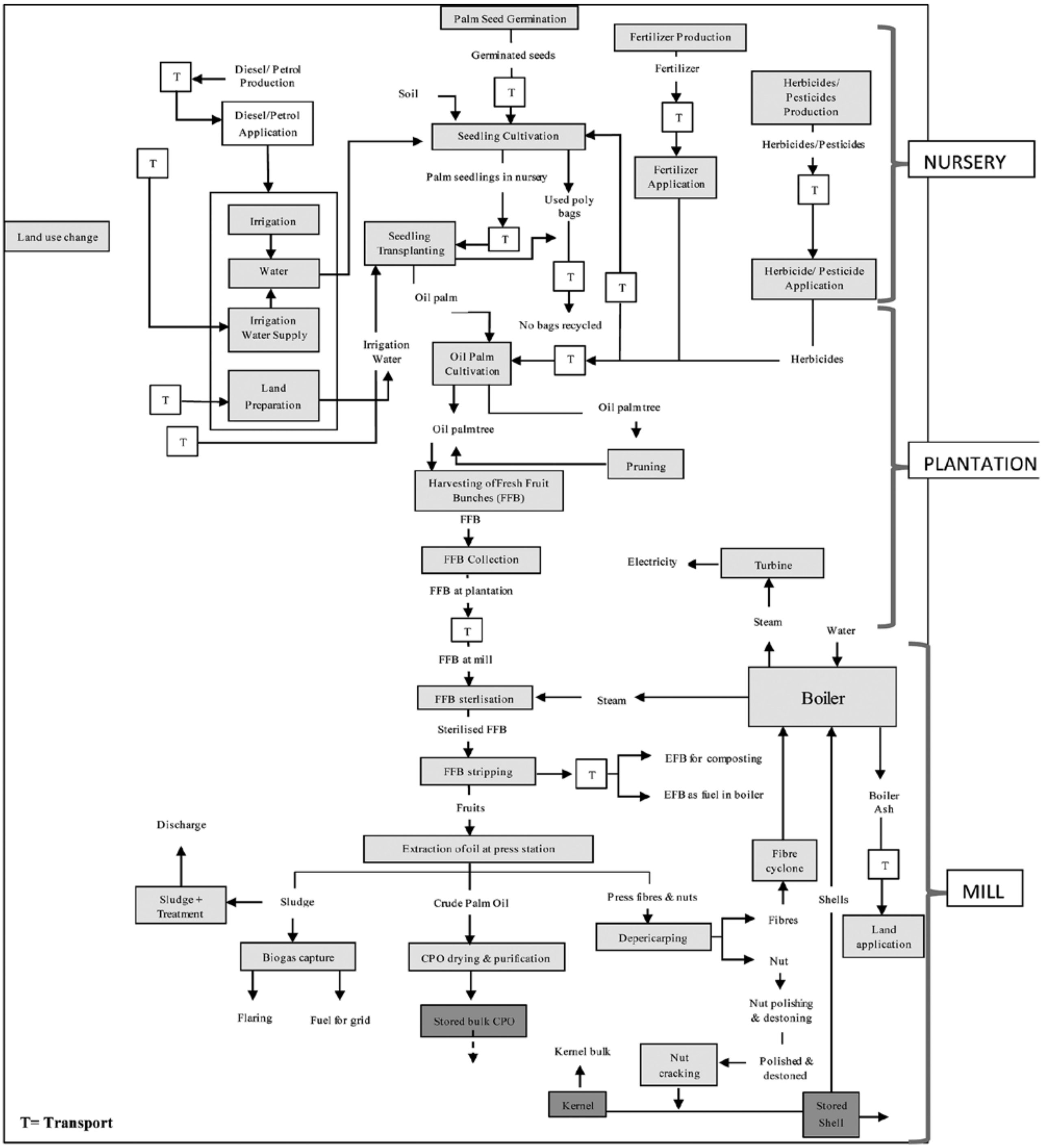

Figure 1. System boundary.

of the oil palm is 25 years. As these areas had been planted with oil palm at least 50-100 years ago, they are undergoing their second or third cycle of replanting. In Sabah and Sarawak, the allotted agriculture land for new plantations is from LOF. This assessment only covered oil palm plantations on mineral soils and did not include plantations on peat soil.

The milling process in POMs involves sterilisation, stripping of the fruitlets, digestion and mechanical pressing. Water consumption is from the boiler water for the production of steam. A turbine is run by this steam to generate electricity to power the whole POM. Some POMs practise dilution and so water is added. There is also some water used for general washing and cleaning.

Water Footprint Findings

Sprinklers are used to water the seedlings in the nurseries. However, at the plantations there is no irrigation. Water is only used for pesticide applications, which amount to 3.56 $m^3\ t^{-1}$ FFB (Hashim *et al*., 2014).

Direct water consumption at POM is 5.5 m^3 t^{-1} CPO, sourced from the boiler requirements, processing (dilution) and cleaning. The direct water input for the whole system boundary is 24.10 m^3 as shown in *Figure 2*.

Applying Equation (1), CWU(H_2Oe) = (24.10 m^3*0.05)/0.602 = 2.00 m^3 H_2Oe t^{-1}CPO. This shows that the impact of direct water use is very low.

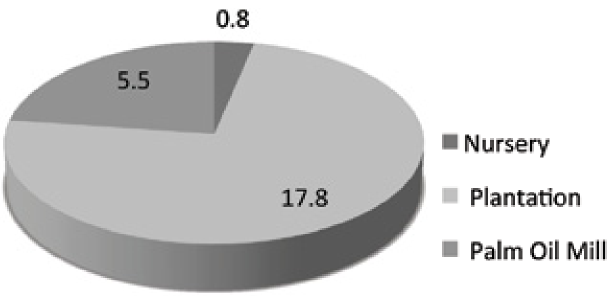

Figure 2. Direct water consumption at the various stages (m^3 t^{-1}CPO).

Life Cycle Impact Assessment

Figures 3 and *4* show the LCIA (weighted) results for the production of one tonne CPO for the LOF to oil palm and oil palm to oil palm LUC scenarios, respectively.

The major potential impact for the LOF to oil pam LUC scenario is caused at the plantation phase under the climate change human health impact category due to land conversion, production and application of fertilisers and pesticides. However, the residual biogas from palm oil mill effluent

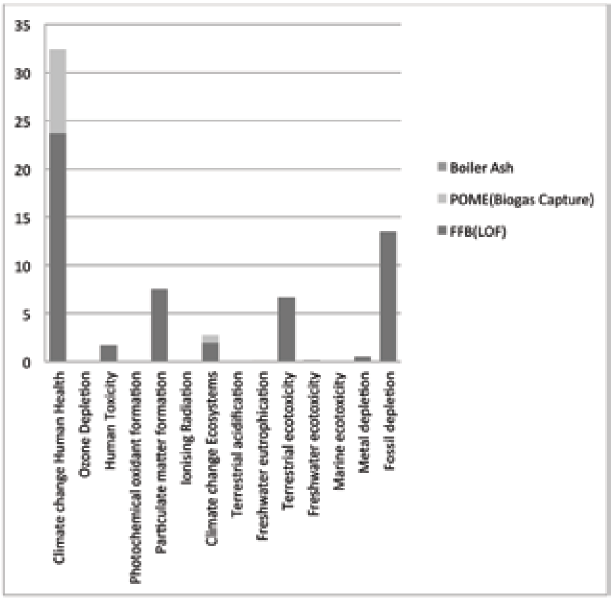

Figure 3. Weighted life cycle impact assessment for 1 t crude palm oil where land use change is from logged-over forest to oil palm.

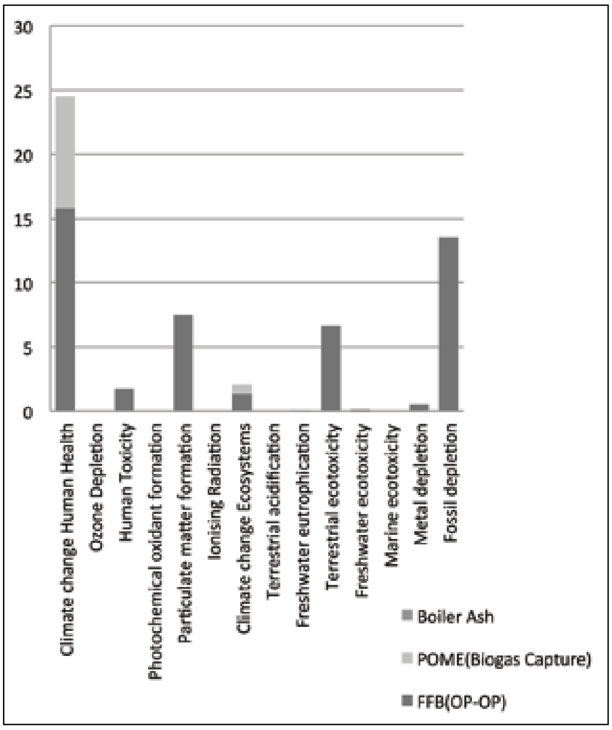

Figure 4. Weighted life cycle impact assessment for 1 t crude palm oil where land use change is from oil palm to oil palm.

(POME) at POM (estimated at 90% capture efficiency) contributes minimally towards this category. This is followed by the fossil fuel depletion impact category, again caused by the plantation phase, due to the production and transportation of fertilisers and pesticides. For the oil palm to oil palm LUC scenario (*Figure 4*), the intensity of the climate change human health impact category is reduced due to the absence of land transformation.

For WF based on LCIA, the first scenario is the continued LUC (from oil palm to oil palm) in the plantations with biogas capture at POMs. The impact from direct water use is shown in *Table 1* and the indirect water use impact is shown in *Table 2*.

The second scenario is LOF to oil palm LUC in the plantations with biogas capture at POMs (*Tables 3* and *4*).

TABLE 1. WEIGHTED POINTS FOR 1 T CRUDE PALM OIL FROM DIRECT USE OF WATER (LAND USE CHANGE FROM OIL PALM TO OIL PALM)

Impact category	Weighted points (Pt)
Freshwater eutrophication	0.0259
Freshwater ecotoxicity	0.1170
Marine ecotoxicity	0.0014
Total	0.1443

TABLE 2. WEIGHTED POINTS FOR 1 T CRUDE PALM OIL FROM INDIRECT USE OF WATER (LAND USE CHANGE FROM OIL PALM TO OIL PALM)

Impact category	Weighted points (Pt)
Climate change human health	28.1000
Ozone depletion	0.0035
Human toxicity	1.7500
Photochemical oxidant formation	0.0034
Particulate matter formation	8.8400
Ionising radiation	0.0053
Total	38.7022

TABLE 3. WEIGHTED POINTS FOR 1 T CRUDE PALM OIL FROM DIRECT USE OF WATER (LAND USE CHANGE FROM LOGGED-OVER FOREST TO OIL PALM)

Impact category	Weighted points (Pt)
Freshwater eutrophication	0.0259
Freshwater ecotoxicity	0.1170
Marine ecotoxicity	0.0014
Total	0.1443

TABLE 4. WEIGHTED POINTS FOR 1 T CRUDE PALM OIL FROM INDIRECT USE OF WATER (LAND USE CHANGE FROM LOGGED-OVER FOREST TO OIL PALM)

Impact category	Weighted points (Pt)
Climate change human health	36.0000
Ozone depletion	0.0035
Human toxicity	1.7500
Photochemical oxidant formation	0.0034
Particulate matter formation	8.8400
Ionising radiation	0.0053
Total	46.6022

WF based on LCIA for 1 t CPO produced from the two scenarios is shown in *Figure 5*.

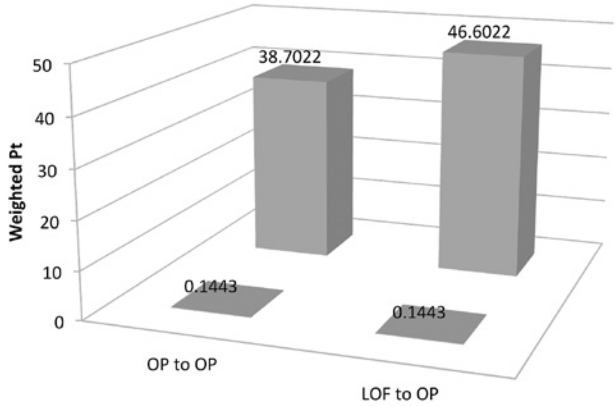

Figure 5. Life cycle impact assessment-based weighted water footprint for the production of 1 t crude palm oil.

WF of the LOF scenario is about 20% larger than the continued LUC scenario due to the land conversion from logged-over forest in the former. Surprisingly, WF impacts from indirect water are more dominant. This is due to the water consumed to produce and utilise energy, fertilisers, pesticides and POME treatment.

In general, an agricultural product needs a lot of water during its cultivation stage, thus the same concerns apply to oil palm. However, when the impact of the water consumption by the oil palms was assessed, it turned out to be small. Further investigations support the findings because oil palm plantations are rain-fed and not irrigated. This is possible because of the strategic location of Malaysia near the equator, making the climate hot and humid all year long, with an average temperature of 27°C and rainfall of > 2500 mm yr^{-1} (Nur Amira, 2015). This makes Malaysia a water-abundant country, and resulting in WSI < 0.1 (Pfister *et al.*, 2009). The UN World Water Development Report (United Nations, 2015) shows that Malaysia is in a region that has abundant (15,000 to 50,000 m^3) access to renewable water per person. Thus, Malaysia is way above the specification in the WSI definition where the minimum requirement is 1700 m^3 $person^{-1}$.

This is crucial as water used in a place which is water-abundant does not have the same impacts as water used in a place that is experiencing water scarcity (Ridoutt and Poulton, 2009). Another reason can be the high yields achieved by oil palm at 21 t FFB ha^{-1} yr^{-1}. Indirect water use dominates the climate change impact category and particulate matter formation category which are linked to gaseous emissions. These emissions arise from fertiliser and pesticide applications in the nursery and in the field.

An important contributor to yield is adequate fertilisation. However, fertilisers also commonly contribute to the highest operational cost in a well-run plantation in Malaysia. As fertilisers are meant for enhancing growth (Bulagric, 2016), they play an essential part in the profitability of oil palm (Goh *et al*., 2010). This may be why the impacts from production and application of fertilisers dominate, coming after the impact from land conversion. Studies have shown that yields in the agriculture sector will be reduced in the range of 35%-85% (depending on crop type, soil, technology and climate) if there are no chemical fertilisers to apply (ICCA, 2009). This is undesirable as then more land will have to be converted to farming to meet food demand, and this will in turn increase CO_2 emissions. Thus, it is vital to strike a balance between yield and fertilisation.

To minimise the dominating impacts from the field, management of the whole plantation is crucial. In the last twenty years, the Green Revolution has made way for sustainable agriculture, enabling crops to be produced without affecting the environment as well as the surrounding ecosystems. The basis for initiatives in sustainable agriculture was provided in the Third National Agricultural Policy (1998-2010) of Malaysia. As climate change and water scarcity become increasingly important, sustainable agriculture will be able to contribute to both climate mitigation and adaptation. Good Agricultural Practices (GAP) ensure the sustainability of plantation operations. The key elements of GAP are land and water management, as well as fertiliser and integrated pest management (IPM) (Tradewinds, 2017). It is best for plantations to practise GAP. GAP addresses the management of the whole plantation system to obtain the best outcome, both in yield and reduced economic and environmental burdens.

CONCLUSION

Where agricultural products are involved, the perception is that the crop cultivation stage will be the most water-intensive. However, due to the availability of water in the equatorial region, oil palm is not irrigated. So, the water used at this stage has minimal impacts. The findings reiterate the importance of planting oil palm in water-abundant regions with low WSI. The findings however may change for plantations located in other regions with different WSI and having to practise irrigation. One of the best ways to manage the water requirements in plantations without irrigation is to practise GAP.

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