Managing Soil Deterioration and Erosion under Oil Palm

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ABSTRACT

Planting oil palm on steepland can cause severe soil degradation as erosion carries away fertile topsoil and nutrients, especially at the early stage of field development. Hence, good agronomic practices are essential to sustain the soil properties associated with oil palm productivity. This article is a review of soil conservation practices that can minimise soil degradation under oil palm planted on sloping land. The common agronomic practices include terracing, silt pits, mulches (empty fruit bunches and pruned fronds) and establishment of leguminous cover crops, all of which will help to reduce run-off and soil erosion. The purpose of implementing these techniques is to manage soil degradation in order to achieve site yield potential while safeguarding the environment right from the early stage of plantation development. Preserving riparian zones is also essential as they serve as natural filters for surface run-off from the plantation areas and hence minimise the amount of sediments and in doing so preserve the quality of water entering the watercourses.

INTRODUCTION

Oil palm is the most important plantation crop in Malaysia, exploiting about 5.74 million hectares of cultivated area and producing more than 17.32 million tonnes of palm oil in 2016 (MPOB, 2017). The Malaysian palm oil industry continues to perform well, contributing significantly to the national economy. Nevertheless, Malaysia has almost run out of land suitable for planting oil palm and this has led to the conversion of marginal areas, including hilly and sloping lands, into oil palm plantations. High rainfall can cause soil erosion in these marginal areas, resulting in nutrient as well as water losses through run-off. This will in turn decrease soil fertility and will adversely affect oil palm growth and productivity. Therefore, proper soil conservation practices are needed to prevent land degradation and promote sustainable land management.

A reliable oil palm production system depends on good agronomic practices resulting in soil and water conservation. Such practices include erosion control practices, planting leguminous cover crops and using mulching materials. Erosion risks vary with climate and rainfall patterns, soil type, slope gradient, ground cover, drainage, road pattern and crop management. Terracing hilly areas, constructing drains and preserving water catchment areas, as well as using silt pits are often the recommended soil conservation practices to reduce soil erosion on sloping lands (Mohsen et al., 2014). Soil and nutrient loss via surface run-off can also be reduced by using oil palm residues such as empty fruit bunches (EFB) and pruned fronds which are usually utilised as mulches to promote nutrient recycling. They contain essential plant nutrients that can be recycled into the soil during their decomposition, and they provide organic

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matter as well to improve soil fertility properties (Khalid et al., 2000).

Soil and water conservation is intended to reduce soil degradation which subsequently minimises environmental pollution. Conservation practices should be implemented immediately after land clearing to protect bare areas. Soil particles in the topsoil disperse from the impact of rain, and this results in run-off and erosion, which occur when the rate of rainfall exceeds the infiltration rate of water into the soil. Occasionally, topsoil losses reduce soil fertility as well as affect other soil properties that are vital for plant growth (Mohsen et al., 2014).

Conversion of a forest into an oil palm plantation is expected to cause changes in the whole ecosystem which will directly affect the hydrological cycle as shown in Figure 1 (Henson, 1999). Activities during oil palm plantation establishment such as clearing of forested areas, construction of roads and drainage networks, fertiliser and agrochemical use, as well as wastewater released from the mill and worker quarters are expected to increase water flow and raise nutrient and sediment delivery to streams, causing deterioration in water quality (ECD, 2000). Water reaching the ground may either infiltrate into the soil or flow directly into the stream through surface run-off, depending on soil infiltrability and rainfall intensity.

**SOIL EROSION UNDER OIL PALM**

The decreasing availability of suitable agricultural land in Malaysia has led to expansion of oil palm plantations into marginal lands such as steepland. Soil erosion then becomes a concern, with the loss of fertilisers and poor soil water storage, subsequently resulting in nutrient deficiency (Ferwerda, 1977), pollution of fresh and groundwater as well as other environmental problems. Soil erosion under oil palm (Figure 2) is very much associated with slope gradient, with erosion rate increasing with greater steepness. Soils at the harvesting paths are compacted due to frequent use by harvesters and fresh fruit bunch (FFB) evacuation machineries. Kee and Chew (1996) reported that in Malaysia surface run-off is highest during the wet season. The amount of nutrients lost in run-off water is directly dependent on the magnitude and intensity of rainfall following fertiliser application. Nutrient loss *via* eroded sediments is directly related to the eroded soil. Topsoil loss by erosion indicates a serious reduction in soil chemical properties or

![Figure 1. The hydrological cycle in an oil palm plantation (Henson, 1999).](image-url)
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nutrient content (Lal, 1997; Ruppenthal et al., 1997; Zobisch et al., 1995). As high soil loss and run-off coincide with high rainfall, correct timing of fertiliser application is critical to minimise excessive losses in surface run-off. Urea fertiliser losses can exceed 30%, not considering loss through volatilization, if applied during unfavorable weather conditions, and more so when applied in concentrated bands (Chan and Chew, 1984).

Several studies done earlier found differing erosion values among sites, depending on slope gradient and soil variability. For instance, in the second to fourth years after planting oil palm on Munchong soil series with newly established leguminous ground covers, the erosion rates were 8.8, 24.0, 35.4 and 50.0 t ha\(^{-1}\) yr\(^{-1}\) on slopes of 2, 5, 9 and 15\(^{\circ}\), respectively (DID, 1989). However, bare soil on Munchong series of less than 5\(^{\circ}\) slope, had an erosion rate of 12.5 t ha\(^{-1}\) yr\(^{-1}\) (PORIM, 1990). On Rengam soil series with a moderate slope of 3 to 5\(^{\circ}\), Lim (1990) found erosion rates of 16.3, 19.7 and 28.0 t ha\(^{-1}\) yr\(^{-1}\), for the respective mulching treatments of: two times the normal amount of frond mulching, normal frond mulching, and bare soil (where all pruned fronds were removed from the field). Lim (1990) reported that soil erosion under mature oil palm planted on sloping lands with gradients of 6% to 8% was more than 25 t ha\(^{-1}\) yr\(^{-1}\). However, lower values of 1.5 to 7.1 t ha\(^{-1}\) yr\(^{-1}\) soil erosion were reported on sloping oil palm plantations (Kee and Chew, 1996), while soil erosion values of 7 to 21 t ha\(^{-1}\) yr\(^{-1}\) from other oil palm plantations were reported by Chew et al., (1999). Hartemink (2006) reported that soil erosion under oil palm plantations was between 13 and 78 t ha\(^{-1}\) yr\(^{-1}\) for Oxisols and from 1 to 28 t ha\(^{-1}\) yr\(^{-1}\) for Ultisols. Both are major soil orders planted with oil palm in Malaysia.

Soil erosion reduces oil palm production not only by decreasing soil fertility and organic matter but also by reducing soil water infiltration, soil water content and soil water-holding capacity that would consequently cause less available soil water content. Soil erosion in young oil palm planted areas is usually negligible because of the cover crop protecting the soil and this is not attributable to the palms themselves (Hartemink, 2006; Maene et al., 1979).

**SOIL AND WATER CONSERVATION PRACTICES**

Steepland cultivation causes severe soil erosion which carries away fertile topsoil and nutrients from applied fertilisers, especially at the early stage of field development. Due to steep gradient and high rainfall in Malaysia, sloping lands face great risks of soil erosion which results in serious soil degradation. Reduction in soil fertility will adversely affect oil palm nutrition, growth and yield. Proper soil and water conservation practices are needed to maintain and improve the soil’s physical and chemical properties which are linked to soil fertility and productivity for oil palm growth on sloping lands. Soil erosion, nutrient and water deficits in oil palm plantations can be minimised through agronomic practices such as employing measures for soil and water conservation and mulches. These practices can increase oil palm productivity immediately apparent through improved bunch weight and oil content (Donough et al., 2006; Goh et al., 1994).

The purpose of soil and water conservation is to prevent soil degradation and environmental pollution, which are vital to sustain long-term productivity. Appropriate timing in implementing soil conservation measures is also important as the highest risk of erosion usually occurs at specific periods such as during planting or replanting, especially in the monsoon season. Besides soil conservation, water management is also a crucial aspect of oil palm cultivation because a deficit or excess of water can cause stress to the oil palm, which is highly detrimental to crop yields. Water management is more critical on undulating, hilly, or inland soils because growers need to conserve soil moisture while minimising soil erosion and nutrient losses. Soil and water conservation practices (e.g. terracing and silt pits) and organic mulches (using empty fruit bunches, pruned fronds and Eco-mats) are the most common methods, practised over several decades in Malaysia (Mohsen et al., 2014).

**Terracing**

Contour terraces and platforms are usually constructed in steeper and undulating areas (Figure 3). Slope assessments should be made before any terracing and lining work is considered. Terraces are constructed with the purpose of reducing run-
off and soil erosion across the slopes (Morgan, 2005; Troeh et al., 2004). In order to reduce erosion, terraces with an adequate back slope and stop bunds should be built at regular intervals along the planting terrace. Lim et al. (1994) suggested that soil and water conservation measures be established on slopes of 3° or more. Depending on the soil type, Goh (1995) suggested that highly erodible soils steeper than 6° should be terraced, especially if the area experiences high and frequent intense rains of more than 25 mm hr⁻¹. On milder slopes, conservation terraces should be sufficient.

Soil erosion and run-off in some areas can be very severe, even with terraces. Besides conserving soil and water, terraces (Figure 4) also facilitate harvesting and crop evacuation as well as maintenance operations. The type of terraces to be constructed depends on the slope gradient. Single terraces are the traditional type, with various widths ranging from 3.5 to 4.5 m; and these are constructed in terrains with a slope of more than 20°. Terrace width must also be chosen to cater for mechanisation. Conservation terraces are constructed in terrain between 5° and 10° slope. When terracing, a back slope that is adequate (from 10% to 15% gradient) is employed to minimise surface run-off and allow for effective moisture conservation. Terraces with a 2.5 m-wide base and a 15° back slope are constructed where all infield operations are done manually. In contrast, terraces with a 4 to 6 m-wide base and a 10° back slope are constructed to support mechanisation. The cut is deeper at about 20° slope to control erosion as well as to conserve water. Stop bunds are constructed to prevent lateral erosion. Another type of terrace which allows for mechanisation but has not been widely used is the double terrace where the terraces are constructed in two tiers in areas having between 10 and 20° slope. The top terrace is the planting row while the bottom terrace is for movement of machines. The total width of the double terrace is the same as that of a single terrace. Besides allowing for mechanisation, this technique is also excellent for erosion control because there are two tiers of terraces to restrain the flow of water.

Contour bunds of varying configurations can be constructed on slopes of <6°, whereas planting platforms are constructed in areas with slightly steeper slopes (6-20°). Platforms are sometimes referred to as ‘individual terraces’ but are not interconnected. They are aligned along the contour to facilitate effective establishment, maintenance and harvesting of the palms, to facilitate mechanisation, to improve soil as well as water conservation, to minimise erosion, and to reduce surface run-off and nutrient losses. The platform area should be at least 12 m², with a 3.5 m-wide base and a 15° back slope. Full contour terracing is essential in steep areas with a slope of >20°. Terraces or platforms should be completed in time to allow for settling and repair of any landslides before planting. Areas where the slope exceeds 40° (or 80% gradient) should not be planted; hence, no lining or terracing is allowed.

Despite the advantages of terraces, their construction results in soil compaction while the topsoil layer is removed, hence reducing soil fertility (Hamdan et al., 2000). Soil physical properties can also be affected due to disruption to its hydraulic properties, aggregate stability and water-holding capacity (Ramos et al., 2007).

Silt Pits

In some areas, soil erosion and run-off may be very severe even with the construction of conservation and planting terraces. In such areas, silt pits (Figure 5) should be dug in addition to the terraces to reduce the path of water flow, so as to increase water infiltration into the soil and maximise moisture conservation. Silt pits are one of the recommended methods for soil and water conservation in Malaysia (Teh et al., 2011). The pits are spaced at 20 to 30 m intervals, depending on the degree of slope and the severity of erosion. Silt pits are close-ended trenches dug (<1 m deep) between
the oil palm planted rows, particularly on steep slopes, to reduce the slope length. The pits serve to trap soil and water sediments from surface run-off which contains nutrients, and to redistribute the water and nutrients to be fully utilised by the palms (Bohluli et al., 2012).

A study done by Murtilaksono et al. (2007) showed that silt pits were able to effectively defer soil dryness by 3.5 months, and contour ridges by 2.5 months, compared with the control (no conservation practices). Atmaja and Hendra (2007) evaluated the effectiveness of ridge terraces and silt pits in conserving soil moisture content in oil palm plantations. They found that soil water content was highest in areas with silt pits, followed by areas with ridge terraces and the control (no conservation practices). Higher moisture content indicates that with silt pit construction, the soil will be able to store water better. They concluded that silt pits will be able to fulfil the oil palm’s water demand and significantly increase production. Soon and Hoong (2002) recorded the highest run-off of 30.83% in plots with pruned fronds stacked down the slope, followed by 17.88% run-off in plots with contour stacked fronds, and the lowest run-off of 10.68% in those plots with a conservation practice, i.e. utilising contour stacked fronds plus silt pits.

Mulches

Oil palm by-products such as pruned fronds, empty fruit bunches (EFB), palm oil mill effluent (POME), shells, mesocarp fibre, and Eco-mat are either obtained in the field or are wastes from palm oil milling processes. EFB have been applied as a mulch because of their high nutrient content and ability to conserve water (Figure 6). Their application under oil palm was found to be beneficial to palm performance. The beneficial effect of EFB on oil palm growth and productivity as well as improvement in soil properties have been studied by many workers (Gurmit et al., 1989; Chan and Goh, 1978). The expected benefits of mulching with EFB include improvement in soil structure due to better aeration, increased water-holding capacity, improved soil pH and nutrient status, increased cation exchange capacity, better root growth, increased microbial activities and reduction in surface wash, leaching and soil surface temperature, all of which can help improve oil palm growth and productivity. EFB minimise erosion and run-off from bare soil around the palms and reduce soil moisture evaporation, especially during the dry months (Lim and Messchalck, 1979).

Singh et al. (1999) estimated that one tonne of EFB can contribute an equivalent of 7.0 kg of urea, 2.8 kg of rock phosphate, 19.3 kg of muriate of potash and 4.4 kg of kieserite. Depending on the soil attributes, several rates of EFB application have been recommended. Zin and Tarmizi (1983) recommended that 30-50 and 50-100 t ha⁻¹ yr⁻¹ of EFB be applied. However, Loong et al. (1987), Jantaraniyom et al. (2001) and Etta et al. (2007) suggested suitable rates of 37, 35 and 40-60 t ha⁻¹ yr⁻¹, respectively. Nevertheless, application of EFB is only practical for plantations that are near palm oil mills due to storage problems and high transportation costs (Teh et al., 2011). Production of Eco-mat was
inspired by the difficulties in applying the bulky EFB in the field. EFB is compressed forming the Eco-mat, a carpet-like material (Yeo, 2007). The product is lighter in weight, easier to handle during application, incurs cheaper transportation cost as well as reduces storage space. Eco-mat is made from 100% natural oil palm fibre and is biodegradable, and is therefore an environmental-friendly product. It has been shown to improve soil organic matter, soil nutrient contents and nutrient uptake by plants, soil structure and moisture retention capacity; it also reduces soil erosion and fertiliser loss. However, the benefits of EFB or Eco-mat mulching will taper off over time as the materials decompose. It is probably ineffective in conserving soil moisture after about 240 days from application. Thus, re-mulching is necessary every 200 days or so to ensure effective soil moisture conservation (Arif et al., 2003).

Another oil palm crop waste, pruned oil palm fronds are also commonly used as mulch in oil palm plantations. Pruned frond stacking (Figure 7) is carried out to minimise the velocity of surface run-off down hill slopes, and to conserve water through mulching. Pruned fronds are normally stacked along the palm avenues across the slope, placed in an L-shaped pattern along contours, or placed across the terrace width at regular intervals. A simple agronomic practice like contour frond stacking can reduce soil erosion to less than 5 t ha\(^{-1}\) yr\(^{-1}\) and run-off by 13% (Soon and Hoong, 2002).

Moradi et al. (2012) reported that EFB and pruned palm fronds had higher nutrient concentration and water than Eco-mat; this is due to the loss of nutrients and water during the manufacturing process of turning EFB fibre into Eco-mat. However, there were no significant differences in decomposition and nutrient release rates between EFB and Eco-mat, or between the Eco-mat and oil palm fronds during their decomposition.

Leguminous Cover Crops (LCC)

Leguminous cover crops should be established on slopes immediately after land clearing and land preparation for planting or replanting. In oil palm plantations, the establishment of LCC (Figure 8) gives a significantly and economically higher yield compared with palms with natural covers. Common LCC are Calapogonium mucunoides, Pueraria javanica, Calapogonium caeruleum and Mucuna bracteata. M. bracteata has been found to be the best leguminous cover plant as it smothers noxious weeds well and deters insects as well as cattle. It also has superior drought and shade tolerance, has deep roots, and produces significant quantities of litter that decomposes slowly to increase the fertility of surface soil.

LCC have long been used in the tropics to protect the soil from erosion, especially on steep land, as well as to enrich its organic content. LCC also prevent growth of noxious weeds and reduce pest breeding sites. Where water for crop production is in short supply, LCC can be used as a mulch to conserve water by shading and cooling the soil surface. Besides the beneficial effects on soil fertility (through decomposition of organic matter, recycling of soil nutrients and nitrogen fixation), soil physical properties (soil structure, water infiltration
and water-holding capacity) and microbiological activities are also improved (Chan et al., 1977).

A study on LCC by Khalid et al. (2000) found that total dry matter of legumes and weeds was 5370 and 1930 kg ha⁻¹, respectively. Nutrient contents of the legumes were quite high, contributing 113 kg N, 11 kg P, 106 kg K, 28 kg Ca and 9 kg Mg ha⁻¹. The nutrients in the legume cover and weeds represent a transient pool that will be recycled in the plantation. Besides LCC, shade-tolerant herbaceous species (Figure 9) such as moss, soft grasses and ferns are encouraged as ground cover under mature palms in place of competitive weeds. Soil movement is also inhibited due to the interception of rainfall by LCC, thus reducing run-off and hindering erosion by decreasing surface velocity. These can also improve water infiltration as well as reduce soil temperature during the dry season (Turner and Gillbanks, 2003).

Figure 9. Soft vegetation.

Riparian Zones

The impact of development of oil palm plantations in terms of ecology disturbance, soil erosion and water pollution can be minimised by the establishment of riparian zones (Figure 10) or buffer areas. In general, riparian zones can be defined as vegetative areas or green zones that separate planted areas from watercourses nearby such as streams, rivers and lakes. The plants that naturally inhabit this unique habitat perform several important functions. Riparian zones in oil palm plantations provide ecological, environmental and economic benefits. The purpose of maintaining riparian zones is for these zones to serve as natural filters for surface run-off from the plantation areas and hence minimise the amount of sediments as this will preserve the quality of water entering the watercourses. They also provide a natural mitigation system for run-off and erosion, groundwater containing sediments and contaminants or pollutants, resulting in reduced run-off velocity and facilitating dissolved nutrients to be taken up by the vegetation. These zones of natural vegetation with their extensive root system are effective for stabilising stream banks, as well as protecting them from erosion. Furthermore, riparian zones within the plantation area will minimise destruction of riparian habitats of fauna, thus preventing their extinction. In addition the riparian zones also help protect the hydrological environment (Zainudin et al., 2013). The elimination of these zones creates numerous problems, resulting in the partial or complete destruction of the immediate stream habitat, as well as destruction of the vitality of areas further downstream.

Recommendations on riparian zone width vary widely, depending on the purpose of the riparian zone and on the land use beyond the riparian zone. The Department of Irrigation and Drainage (DID, 2010) specifies the width of river reserves to a maximum of 50 m, based on the width of the river, mainly for bank stabilisation. However, riparian zones as biodiversity habitats or for water quality improvement require greater widths in general (MNRE, 2009).

Figure 10. Riparian zone.

Legislations for Steepland Cultivation

Currently, the palm oil industry adheres to more than 15 laws and regulations, including the legislations for steepland cultivation. There are several legislations and guidelines which prohibit the development of oil palm plantation on steep terrain, namely:

Oil palm plantation development is a Prescribed Activity, which requires EIA approval prior to project commencement (ECD, 2000). One of the strategies towards achieving the site yield potential is to conserve the environment by applying some of the advanced technologies for managing soils, water and nutrients so that there will be less soil deterioration and erosion. MSPO, RSPO and COP provide guidelines for appropriate soil conservation measures to prevent or minimise soil erosion as well as siltation of drains and waterways.

**CONCLUSION**

Soil degradation under oil palm is relatively high when planted on slopes that are more than 20°; hence, planting oil palm on severely sloping land should be avoided. Managing soil degradation can be achieved successfully by applying good agronomic practices including construction of terraces and silt pits, correct placement of pruned fronds, mulching with EFB and planting of leguminous cover crops. Furthermore, establishment of riparian zones is important in protecting watercourses from being polluted by the degraded soil.

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