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# Crop Evapotranspiration and Crop Water Requirement for Oil Palm in Peninsular Malaysia

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**Abstract**
The estimation of potential evapotranspiration constitutes an important part in the estimation of crop water requirement. Many methods exist and all of these are indirect methods using equations that relate climatic data with evapotranspiration. A comparison of the three methods to estimate crop evapotranspiration being the method of Department Irrigation and Drainage, Doorenbos and Pruitt and Penman-Monteith. Results showed that the method of Doorenbos and Pruitt provides a fairer estimation of potential evapotranspiration, crop evapotranspiration and crop water requirement for oil palm cultivation in Peninsular Malaysia
**Keywords**: Potential evapotranspiration, oil palm, Peninsular Malaysia

## 1. Introduction

Prediction methods for crop-water requirements are used due to the difficulty of obtaining accurate field measurements. The methods need to be applied under climatic and agronomic conditions different from those under which they were originally developed. Testing the accuracy of the methods under a new set of conditions is laborious, time consuming and costly and yet crop water requirement data are frequently needed for project planning. Calculation of crop evapotranspiration ($ET_{crop}$) includes the effect of climate on crop water requirement and is given by the reference crop evapotranspiration or known as potential evapotranspiration. The objective of this paper is to compare the methods of estimating crop evapotranspiration and to determine crop water requirement be used for land evaluation for oil palm cultivation.

## 2. Materials and Methods

Peninsular Malaysia is located within the equatorial zone between latitudes $1^0$ 5' and $6^0$ 45'N and longitudes $99^0$ and $104^0$ 20'E with South China Sea lies to the east while Straits of Malacca to the west of the peninsula. Peninsular Malaysia has an area of 13.2 million hectares. Its greatest length is about 735 km and the maximum width is about 320 km. Eight meteorological stations in Peninsular Malaysia were selected for the study (Figure 1). They are Alor Star (Kedah), Ipoh (Perak), Subang (Selangor), Malacca (Malacca), Kluang (Johore), Senai (Johore), Kuantan (Pahang) and Kuala Krai (Kelantan). These towns are also focal points which large hectareages of oil palm are cultivated. The climatic data from Malaysian Meteorological Services Department between 2004 to 2013 of the above stations were used in this study. Only one example of the climatic data of these stations is presented as shown in Table 1 as it involved the same calculation.

The crop evapotranspiration for oil palm was estimated according to the method of Doorenbos and Pruitt(1977). Water availability was estimated according to the relationship between crop evapotranspiration and water availability (Sys *et. al*., 1991)

$$WA = \frac{(ET_c - D)}{ET_c} 100$$

Where,
WA = water availability in %
$ET_c$ = crop evapotranspiration
D = water deficit comparing $ET_c$ and effective rainfall, taking into account to storage capacity of the soil. The effective rainfall is considered as the rainfall useful for meeting crop-water requirement

The methods of Drainage and Irrigation Department (1977), Doorenbos and Pruitt (1977) and Penman and Monteith (Smith,1991) were used to calculate potential evaporation (reference crop evapotranspiration) from the climatic data.


Figure 1: The location of Meteorological stations chosen for the study

 

Table 1: Climatic Data for Alor Star ( Average over 10 years)

| Criteria \ Months | J | F | M | A | M | J | J | A | S | O | N | D | Annual mean | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean temp.($^0$C) | 26.8 | 27.5 | 27.7 | 27.3 | 27.8 | 27.6 | 27.0 | 26.8 | 26.7 | 26.5 | 26.3 | 26.3 | 27.0 | |
| Mean daily max.temp ($^0$C) | 33.0 | 34.2 | 34.4 | 33.6 | 32.3 | 32.0 | 31.7 | 31.4 | 31.2 | 31.3 | 31.3 | 31.3 | 32.3 | |
| Mean daily min. temp ($^0$C) | 22.2 | 22.5 | 23.1 | 24.1 | 24.5 | 24.2 | 23.8 | 23.5 | 23.6 | 23.5 | 24.0 | 22.7 | 23.5 | |
| Mean rainfall (mm) | 10.5 | 45.0 | 123.5 | 171.3 | 225.3 | 126.6 | 195.7 | 181.5 | 248.2 | 257.1 | 163.0 | 111.6 | | 1859.0 |
| Rain days | 3.0 | 4.0 | 10.0 | 15.0 | 19.0 | 12.0 | 17.0 | 19.0 | 20.0 | 22.0 | 22.0 | 17.0 | | |
| Rainfall intensity | 3.5 | 11.2 | 12.3 | 11.4 | 11.8 | 10.5 | 11.5 | 9.5 | 12.4 | 11.7 | 9.6 | 16.0 | | |
| Sunshine (hrs month$^{-1}$) | 273.0 | 257.6 | 263.5 | 255.0 | 232.5 | 213.0 | 210.8 | 193.5 | 171.0 | 168.0 | 183.0 | 217.0 | | 2640.0 |
| Mean relative humidity (%) | 73.4 | 72.6 | 78.0 | 82.4 | 85.1 | 86.0 | 86.0 | 87.1 | 85.6 | 87.0 | 85.5 | 81.8 | 82.5 | |
| Length of dry season (month year$^{-1}$) | | | | | | | | | | | | | | 1.0 |

Table 2: Potential Evapotranspiration Values (mm month$^{-1}$) Estimated by the Method of Drainage and Irrigation Department, Doorenbos and Pruitt and Penman-Monteith

| Stations/PET | Alor Star | | | Ipoh | | | Subang | | | Malacca | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Months | DID | D | PM | DID | D | PM | DID | D | PM | DID | D | D$^1$ | PM |
| J | 141.7 | 212.6 | 156.0 | 121.8 | 150.3 | 116.6 | 199.0 | 150.0 | 111.3 | 125.2 | 168.0 | 193.7 | 118.1 |
| F | 139.4 | 197.4 | 151.2 | 117.0 | 123.5 | 122.1 | 120.1 | 164.0 | 114.0 | 121.5 | 170.5 | 196.8 | 123.2 |
| M | 117.8 | 200.8 | 163.1 | 138.6 | 181.0 | 132.1 | 139.0 | 171.4 | 126.5 | 138.0 | 177.6 | 200.3 | 130.5 |
| A | 149.0 | 184.0 | 152.4 | 104.4 | 167.7 | 126.3 | 133.5 | 160.0 | 118.5 | 136.2 | 163.5 | 176.4 | 123.3 |
| M | 119.6 | 169.6 | 141.0 | 125.5 | 155.0 | 117.8 | 126.6 | 151.0 | 117.0 | 124.1 | 151.6 | 161.8 | 116.0 |
| J | 138.6 | 150.0 | 131.0 | 127.0 | 148.0 | 113.4 | 123.6 | 144.5 | 110.0 | 120.0 | 143.5 | 147.0 | 107.7 |
| J | 112.8 | 161.8 | 130.8 | 126.2 | 157.0 | 120.0 | 126.2 | 140.4 | 117.0 | 120.1 | 144.8 | 153.0 | 108.0 |
| A | 166.2 | 157.2 | 128.6 | 124.3 | 149.0 | 117.0 | 123.7 | 134.0 | 113.5 | 119.7 | 141.7 | 153.1 | 106.0 |
| S | 127.5 | 144.3 | 120.6 | 121.5 | 139.2 | 109.2 | 124.2 | 138.0 | 110.0 | 110.1 | 139.5 | 147.6 | 105.3 |
| O | 119.0 | 136.4 | 120.7 | 116.9 | 138.3 | 104.5 | 122.4 | 136.7 | 112.8 | 124.6 | 149.4 | 158.1 | 116.6 |
| N | 100.0 | 138.3 | 117.3 | 110.7 | 125.0 | 100.0 | 114.3 | 128.1 | 101.0 | 111.0 | 132.0 | 142.5 | 94.5 |
| D | 124.0 | 150.7 | 134.8 | 111.6 | 134.0 | 105.4 | 108.2 | 130.0 | 99.2 | 113.5 | 151.6 | 168.5 | 101.4 |
| Total | 1555.5 | 2003.1 | 1647.5 | 1445.2 | 1705.0 | 1383.4 | 1480.8 | 1748.1 | 1352.5 | 1462.9 | 1835.5 | 1998.0 | 1350.6 |

DID – Drainage and Irrigation Department (1977), D - Doorenbos and Pruitt (1977); day/night wind ratio =1,D1 - Doorenbos and Pruitt (1977);day/night wind ratio = 3, PM=Penman-Monteith (Smith,1991)

 

Table 2: (cont'd)

| Stations/PET | Keluang | | | Senai | | | Kuantan | | | | Kuala Krai | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Months | DID | D | DPM | DID | D | DPM | DID | D | $D^1$ | PM | DID | D | DPM |
| J | 117.5 | 157.5 | 113.8 | 118.7 | 156.0 | 110.6 | 122.8 | 137.0 | 157.2 | 104.5 | 99.5 | 124.0 | 93.0 |
| F | 110.9 | 151.5 | 121.0 | 118.2 | 143.0 | 112.2 | 117.3 | 150.0 | 166.6 | 109.5 | 110.6 | 143.0 | 96.6 |
| M | 129.6 | 156.0 | 125.5 | 134.0 | 148.0 | 105.1 | 133.6 | 163.7 | 183.8 | 123.1 | 143.5 | 161.5 | 120.6 |
| A | 127.8 | 150.3 | 119.7 | 122.4 | 138.6 | 104.4 | 120.6 | 161.7 | 177.0 | 124.5 | 124.0 | 166.2 | 123.3 |
| M | 113.8 | 139.0 | 119.8 | 114.1 | 125.0 | 92.4 | 128.3 | 149.4 | 167.1 | 121.0 | 127.7 | 154.4 | 119.3 |
| J | 115.2 | 133.6 | 107.4 | 119.3 | 120.6 | 87.3 | 125.0 | 150.3 | 158.7 | 115.0 | 126.5 | 145.0 | 110.0 |
| J | 113.8 | 131.0 | 126.0 | 112.8 | 131.0 | 91.8 | 123.4 | 150.0 | 164.6 | 118.1 | 116.0 | 143.0 | 111.1 |
| A | 113.7 | 132.7 | 112.2 | 113.1 | 127.4 | 90.0 | 126.0 | 130.5 | 143.0 | 119.7 | 118.7 | 148.2 | 114.0 |
| S | 115.8 | 128.4 | 107.7 | 73.2 | 128.0 | 93.0 | 123.3 | 140.7 | 153.0 | 169.0 | 116.4 | 136.5 | 107.0 |
| O | 116.6 | 137.0 | 112.2 | 113.1 | 121.0 | 97.3 | 115.6 | 135.2 | 145.7 | 110.4 | 110.7 | 116.2 | 101.7 |
| N | 106.2 | 114.6 | 98.1 | 108.0 | 121.5 | 90.0 | 97.0 | 106.5 | 113.0 | 84.0 | 91.0 | 92.4 | 81.0 |
| D | 104.8 | 131.7 | 103.0 | 107.0 | 123.1 | 90.0 | 97.1 | 108.0 | 118.4 | 88.3 | 88.0 | 100.1 | 66.0 |
| Total | 1385.8 | 1663.3 | 1336.3 | 1353.9 | 1583.2 | 1164.1 | 1430.0 | 1683.0 | 1848.1 | 1387.1 | 1370.7 | 1630.5 | 1244.5 |

**DID – Drainage and Irrigation Department (1977), D - Doorenbos and Pruitt (1977); day/night wind ratio =1,D1 - Doorenbos and Pruitt (1977);day/night wind ratio=3,PM=Penman-Monteith(Smith,199 3. Results and Discussion**

**Crop Evapotranspiration for Oil Palm**

The crop evapotranspiration for oil palm was estimated according to the method of Doorenbos and Pruitt (1977). The effect of the crop characteristics on crop water requirements is given by the crop coefficient ($K_c$) which represents the relationship between potential evapotranspiration (PET) and crop evapotranspiration ($ET_{crop}$). Doorenbos and Pruitt (1977) reported that the crop coefficient ($K_c$) relates to the evapotranspiration of a disease-free crop grown in large fields under optimal soil, water and fertility conditions and achieving full production potential under the given growing environment. Doorenbos and Pruitt (1977) further reported that the $K_c$ value of tomato and sunflower both very sensitive to moisture stress is 1.05 when the mean minimum relative humidity of the air is more than 70% and the mean wind speed is 0 to 5 $ms^{-1}$. The $K_c$ value of more hardy crops like millet and sorghum is 1.0. The $K_c$ of cocoa, a sensitive crop to drought is 0.9 to 1.0 for close tree spacing without cover crop and shade trees while with shade trees and undergrowth, the $K_c$ value is 1.1 to 1.15.

Water availability was calculated according to the water holding capacities of the soil to be 75 and 200 mm $150^{-1}$ cm soil. Soong (1979) reported the moisture characteristics of the soils in Peninsular Malaysia where most of the soils have available water between 100 and 200 mm $m^{-1}$. In general, the average water-holding capacity of most soils in Peninsular Malaysia is 150 mm $m^{-1}$ or 225 mm $150^{-1}$ cm. Soong (1979) further reported that the lowest water-holding capacity of the soil is Holyrood series soil, a sandy loam with available water content of 52 mm $m^{-1}$ or 78 mm $150^{-1}$ cm.

Table 3: Rainfall, Crop Evapotranspiration, Effective Rainfall, Water Deficit and Water Availability at Alor Star

| Variable \ Months | J | F | M | A | M | J | J | A | S | O | N | D | Total | Water avail (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall (mm) | 10.5 | 45.0 | 123.5 | 171.3 | 25.3 | 126.6 | 195.7 | 181.5 | 248.2 | 257.1 | 163.0 | 111.6 | 1859.3 | |
| ETc (mm) | 212.6 | 197.4 | 200.8 | 184.0 | 169.6 | 150.0 | 161.8 | 157.2 | 144.3 | 136.4 | 138.3 | 150.7 | 2003.1 | |
| Effective rainfall (mm) at storage 75 mm | 10.0 | 40.0 | 100.0 | 136.0 | 157.0 | 91.0 | 138.0 | 122.0 | 165.0 | 170.0 | 110.0 | 81.0 | | |
| Effective rainfall (mm) at storage 200 mm | 10.8 | 43.2 | 108.0 | 147.0 | 169.0 | 97.0 | 149.0 | 132.0 | 178.0 | 183.0 | 119.0 | 87.0 | | |
| Water deficit / surplus (mm) at storage 75 mm | -202.0 | -157.0 | -101.0 | -48.0 | -13.0 | -60.0 | -24.0 | -35.0 | 21.0 | 34.0 | -28.0 | -70.0 | -683.0 | 66.0 |
| Water deficit / surplus (mm) at storage 200 mm | -202.0 | -154.0 | -93.0 | -37.0 | -1.0 | -53.0 | -13.0 | -25.0 | 34.0 | 47.0 | -19.0 | -64.0 | -580.0 | 71.0 |
| Rainfall/ETc | 0.05 | 0.23 | 0.61 | 0.93 | 1.33 | 0.84 | 1.21 | 1.15 | 1.72 | 1.88 | 1.18 | 0.74 | | |

Table 4 shows the crop evapotranspiration and water availability for oil palm in the different regions in Peninsular Malaysia.

 

Table 4: Crop Evapotranspiration and Water Availability for Oil Palm in theDifferent Regions in Peninsular Malaysia

| Stations | Crop Evapotranspiration (mm year $^{-1}$) | Water Availability (%) at Soil Water Storage | |
|---|---|---|---|
| | | 75 mm | 200 mm |
| Alor Star | 2003 | 66 | 71 |
| Ipoh | 1765 | 93 | 100 |
| Subang | 1748 | 100 | 100 |
| Malacca (coastal) | 1998 | 72 | 77 |
| Malacca (non-coastal) | 1835 | 76 | 82 |
| Kluang | 1663 | 89 | 96 |
| Senai | 1583 | 98 | 100 |
| Kuantan (coastal) | 1848 | 85 | 92 |
| Kuantan (non-coastal) | 1683 | 91 | 99 |
| Kuala Krai | 1630 | 75 | 83 |

The crop evapotranspiration of mature oil palm has a range from 1, 583 to 2, 003 mm year $^{-1}$. The highest crop evapotranspiration is observed for areas around Alor Star and the lowest is for areas around Senai. The water availability for oil palm in the different regions follows similar trends as the crop evapotranspiration rates. The results showed that the water availability is less on soils with lower water storage when compared to soils with higher water storage capacity (Table 4).

**Crop-Water Requirement of Oil Palm**

The crop coefficient ($K_c$) of mature oil palm is estimated to be 1.0 and $PET_D$ is also equivalent to the crop evapotranspiration for oil palm. The consumptive use of water by mature oil palm calculated by different methods of determining potential evapotranspiration and crop evapotranspiration are as shown in Table 5.

Table 5: Consumptive Use of Water by Oil Palm in Different Regions in Peninsular Malaysia

| | Crop Evapotranspiration (mm year $^{-1}$) | | |
|---|---|---|---|
| Stations | DID | D | PM |
| Alor Star | 1555 | 2003 | 1647 |
| Ipoh | 1445 | 1765 | 1383 |
| Subang | 1481 | 1748 | 1352 |
| Malacca (coastal) | 1463 | 1998 | 1351 |
| Malacca (non-coastal) | 1463 | 1835 | 1351 |
| Kluang | 1386 | 1663 | 1336 |
| Senai | 1354 | 1583 | 1164 |
| Kuantan (coastal) | 1430 | 1848 | 1387 |
| Kuantan (non-coastal) | 1430 | 1683 | 1387 |
| Kuala Krai | 1373 | 1630 | 1244 |

DID – Drainage and Irrigation Department (1977), D - Doorenbos and Pruitt (1977), PM - Penman-Monteith (Smith, 1991)

The consumptive use of water by mature oil palm is 1430 mm at Kuantan and 1463 at Malacca when estimated by method of Drainage and Irrigation Department (1977) while that estimated by the method of Doorembos and Pruitt (1977) is 1683 mm at Kuantan and 1835mm at Malacca considering the non-coastal areas.

Brunig (1970) reported that the mean annual evapotranspiration from tall mixed dipterocarp of 45 m calculated by the Thornthwaite method was 1, 728 mm. Brunig (1970) considered that the evapotranspiration for tall trees with irregular surface was at least 1, 700 mm and could be near 2, 000 mm year $^{-1}$.

Scarf (1976) in the study of forest evapotranspiration in several places in Peninsular Malaysia reported that the actual evapotranspiration at Charok Padang (Perak) was 1, 773mm, Lenggong (Perak) 1, 715 mm, Tanjung Rambutan (Perak) 1, 794 mm and Air Hitam, Bahau (Negeri Sembilan) was 1, 682 mm.

Lemon (1963) reported that there is an increase of roughness with the height of the plants. At higher elevations, the retardation of wind by surface friction is lower. Decon (1969) reported that wind speeds are reduced by 50% at a height of 0.5 m and by 25% at a height of 5 m. Larger volumes of roughness and wind speeds result in a larger evaporation of tall trees like oil palm. The larger values of the crop evapotranspiration for mature oil palm as calculated by the method of Doorenbos and Pruitt (1977) provided a good estimation of the actual evapotranspiration for oil palm.

It is concluded, therefore that the crop evapotranspiration values estimated by the method of Doorenbos and Pruitt (1977) gives a fair estimation of the actual evapotranspiration of mature oil palm while the method of Drainage and Irrigation Department (1977) and Penman-Monteith (Smith, 1991) probably underestimated the values. The method of Doorenbos and Pruitt (1977) has therefore been adopted to estimate the crop evapotranspiration for mature oil palm.

## Conclusion

Potential evapotranspiration constitutes an important part in the estimation of crop water requirement. Three methods were used to calculate potential evapotranspiration and climatic data from eight meteorological stations in Peninsular Malaysia were used in the study. It is therefore recommended the method of Doorenbos and Pruitt (1977) to be used for estimating potential evapotranspiration and crop evapotranspiration and the method of Sys *et al*. (1991) is recommended to determine water availability for oil palm.

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