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Simulated potential and water-limited yields of cocoa under different agro-ecological zones in Peninsular Malaysia

(Simulasi hasil koko pada keadaan potensi dan air terhad di zon agro-ekologi yang berbeza di Semenanjung Malaysia)

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Key words: model simulation, potential and water-limited yields, cocoa, agro-ecological zones

Abstract

The yield of cocoa under potential and water-limited production levels in different agro-ecological zones was simulated using cocoa model CASE2. For both production levels, the yield was simulated using five years of climatic data (1991–1995) and plant data of three-year-old plant. The results showed that the average potential yield for the selected areas was about 3.5 t/ha/year. Under water-limited production, the average yield was approximately 4% lower than potential yield except for Sitiawan and Jerangau with reduction of 16% and 20% respectively. Basically, the differences between these two production levels were due to weather conditions and soil characteristics at any particular location, by which weather seemed to be the predominant factor. The yield difference between potential and water-limited production on different soil series were comparatively small, especially with respect to Munchong, Bungor and Rengam series. There was also evidence that the performance on Bungor series and Rengam series were generally higher compared with other soil series.

Introduction

Despite a decline in production due to unfavourable prices, climatic variability, the prevalence of the cocoa pod borer (Azhar et al. 2002) and farmers continued shifting to other crops, cocoa is still a major crop in Malaysia after rubber and oil palm. The total area under cocoa cultivation declined from 168,219 ha in 1996 to 45,000 ha in 2004 (Anon. 1997, 2005). In tandem with the reduction in cocoa hectarage, production of cocoa beans also declined over the years. For example, production of cocoa beans dropped to 45,000 t in 2004 (from 120,000 t in 1996), and in 2005 the production was estimated to decrease further to 30,000 t (Anon. 2005). In Peninsular Malaysia, cocoa growing areas are scattered in a wide range of climatic conditions and soil series which is reflected in yield levels and trends (Thong et al. 1990; Ramadasan et al. 1991; Mohamad Zabawi 1993).

Earlier studies on the length of the dry month established showed that there are four general moisture zones in Peninsular Malaysia (Nieuwolt et al. 1982). These are: (a) regions with a clear and regular dry season – Zone 1, (b) regions with short dry season – Zone 2, (c) regions with two

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shorter dry season – Zone 3, and (d) regions without regular dry season – Zone 4. The establishment of these agro-ecological zones has proved very useful to agricultural planners for matching individual crops with suitable areas in order to achieve maximum yield. For example, suitable areas for cocoa cultivation can be derived by matching the environmental requirements for optimal growth with actual climatic and soil characteristics at particular area (Mohd Zaki et al. 1985; Ramadasan et al. 1991; Mohamad Zabawi 1993).

In recent years, mathematical modelling and simulation techniques have been developed to provide a comprehensive and quantitative description of agricultural production systems. Over the past years, a cocoa growth model based on universal plant and crop physiological reactions has been developed and tested (Gerritsma 1994). This simulation model provides a powerful tool to obtain a quantitative estimate of the growth and productivity of cocoa under different production situations i.e. potential and water-limited. In fact, the value of this approach has already been successfully demonstrated in an earlier study on representative areas in major cocoa-growing areas including BAL Estates in Sabah (Gerritsma and Wessel 1996). The objective of this study was to assess the performance of cocoa production under different agro-ecological zones by estimating potential and water-limited yields using system techniques (simulation model).

Materials and methods

Simulation model

The basic prototype cocoa production model, CASE2 (Gerritsma 1994) was employed. CASE2 consists of three modules i.e. crop module, soil water balance module and evapotranspiration module. In this simulation study, only crop module was implemented to simulate growth and production for potential and water-limited growing conditions, and was evaluated on a daily basis.

Sites

Prime growing areas of cocoa (*Figure 1*) were selected from two different agro-ecological zones i.e. Tangkak (Zone 4), Merlimau, Sitiawan and Jerangau (Zone 2). Yield data (1991–1995) were collected from each location.

Plant, weather and soil data

To operate the crop model, weather data, plant parameters and soil water retention characteristic are required. Six weather variables are critically important in operating the model; these are solar radiation, minimum and maximum temperature, rainfall, wind speed and vapour pressure. All the data were compiled from the Malaysian Meteorological Services reports from 1991 to 1995. The data were obtained directly from the location itself. If incomplete or unavailable, data from the nearest meteorological station were used. The plant parameters were obtained from Thong and Ng (1978) as they are the most representative data for Malaysian cocoa, while soil water retention characteristic at saturation, field capacity and wilting point

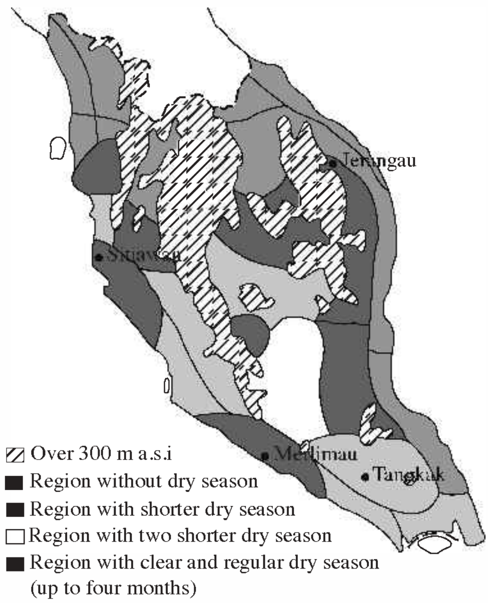

Figure 1. Location of the study areas

were compiled from previous soil survey reports (Anon. 1971; Wong 1971, 1986).

Yield simulation

Yield simulation was conducted at two different production levels i.e. potential and water-limited. Potential production situation was limited to conditions defined only by the availability of solar radiation and air temperature. Whereas the water-limited production level, apart from solar radiation and temperature, the shortage or abundance of water was also considered. In both scenarios, it was assumed that planting materials were uniform and the plants were grown under perfect conditions with no nutrient stress and free from pests and diseases. These assumptions were also used for validation of the model by Gerritsma (1994).

Results

Climatic characteristics

Climatic factors such as rainfall, temperature, solar radiation, relative humidity and wind are important factors in cocoa cultivation. The climatic characteristics of the study areas are summarized in *Figure 2*. Among these factors, the rainfall regimes could be considered as the most important single factor which influenced the area (in which cocoa can be grown) as well as the yield. Rainfall distribution characteristics at the representative locations might be more meaningful if each rainfall region was further subdivided on the basis of duration of the dry period (*Table 1*). In Merlimau, Sitiawan and Jerangau (Zone 2) the dry period occurs for 2 months from February to March, January to February, and June to July, respectively. On the other hand, in Tangkak (Zone 4), there are no dry months but moisture stress due to irregular rainfall occurs for three months.

Soil characteristics

In this study, soil chemical properties such as soil fertility status were not taken into account. Of the characteristics, only water-holding capacity was considered and the results were presented in *Table 2*. Generally, soils with clayey texture could retain more water compared to soils with sandy texture. The soil series in the study areas are mainly clayey, koalinite with good water retention (Anon. 1971). However, Munchong series seems to be more capable of water retention compared to the other soil series, but the difference is relatively small.

Simulated potential and water-limited yields

Results of the simulation under two different production levels i.e. potential and water-limited, are presented in *Figure 3*. In both simulation scenarios, the simulated results were to precocious in comparison with actual yield at similar age of cocoa plant. The simulated yield for the potential growing condition scenario was higher than the water-limited scenario, and there were differences in yield between agroclimatic zones and soil series. Basically, the differences are due to the climatic conditions and soil characteristics at any particular area. Between these two factors, climate seems to be the predominant factor which influences yield variation.

By comparing the potential yield at different agro-ecological zones (*Figure 3*), regardless of the soil series, the average yield of cocoa was 3.5 t/ha/year, with the yield in Zone 2 (Merlimau, Sitiawan and Jerangau) was 3% higher than in Zone 4 (Tangkak). These yield differences are attributable to the differences in weather profile. Generally, Tangkak (Zone 4), could produce better yield due to optimal agro-ecological conditions, especially in terms of rainfall, absence of dry months, low wind speed and sufficient radiation. However, under potential production, only temperature and radiation were taken into account. Therefore, the areas in Zone 2, which received plenty of radiation and optimum range of desired temperature produced higher yield compared to area in Zone 4. Meanwhile, in terms of soil performance,

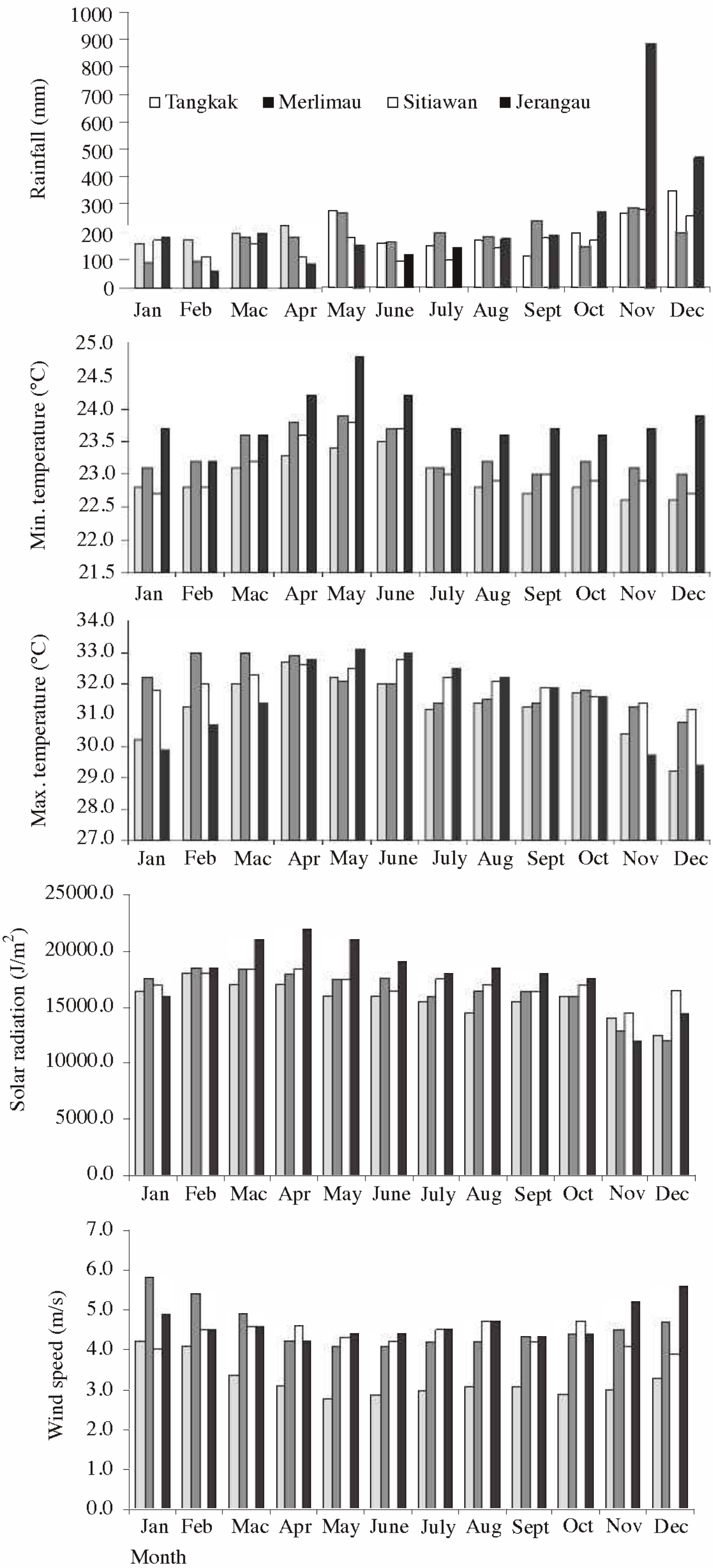

Figure 2. Monthly average of rainfall, minimum and maximum temperatures, solar radiation and wind speed in the study areas

Table 1. Dry and wet periods of representative regions.

Region	J	F	M	A	M	J	J	A	S	O	N	D
Tangkak	x	x	x									
Sitiawan						d	d					
Merlimau	d	d										
Jerangau		d	d						w	w		

x = Moisture deficit; d = Dry month; w = Wet month
Source: Nieuwolt et al. (1982)

Table 2. Water retention characteristics of selected soil series at different depths

Soil series	Pressure (bar)	Moisture content (v/v)			
		0–15 cm	15–30 cm	30–60 cm	60–100 cm
Bungor	0.001	0.424	0.497	0.489	0.575
	0.33	0.319	0.344	0.355	0.399
	15	0.279	0.271	0.252	0.332
Rengam	0.001	0.554	0.528	0.546	0.526
	0.33	0.361	0.362	0.376	0.366
	15	0.283	0.301	0.304	0.301
Durian	0.001	0.465	0.474	0.540	0.601
	0.33	0.325	0.354	0.405	0.457
	15	0.280	0.333	0.381	0.415
Munchong	0.001	0.624	0.624	0.610	0.713
	0.33	0.476	0.476	0.489	0.522
	15	0.409	0.409	0.422	0.469
Sogomana	0.001	0.537	0.621	0.501	0.501
	0.33	0.431	0.484	0.403	0.403
	15	0.345	0.393	0.273	0.273
Jerangau	0.001	0.639	0.719	0.829	0.832
	0.33	0.344	0.384	0.423	0.422
	15	0.244	0.278	0.321	0.321

there is also evidence that the performance on Bungor series and Rengam series are generally higher compared with other soil series.

The differences of yield on different soil series and agro-ecological zones were also reflected in the simulation results at water-limited production level. Under water-limited production (*Figure 3*), only soil water retention capacity, which was related to the amount of rainfall received, has been considered as a limiting factor, regardless of the chemical and physical characteristics. As such, the yield in Tangkak and Merlimau were not affected much under this production level due to the fact that these two areas received higher and uniformly distributed rainfall compared to Sitiawan and Jerangau. In Sitiawan and Jerangau, the yield reduction due to water stress was about 16% and 20% respectively.

On the other hand, besides reduction in yield due to water stress, under water-limited production, two main behaviours of cocoa plant could be observed i.e. yield trend in relation to rainfall and carry forward effect (*Figure 4*). The yield in Merlimau exactly followed the trend of rainfall which was reduced with the reduction of rainfall. However, in Sitiawan at certain years, the yield was stable although the rainfall was lower. This explained that the cumulative water storage in the soil can reduce the effect of water stress and the carry forward behaviour of perennial trees.

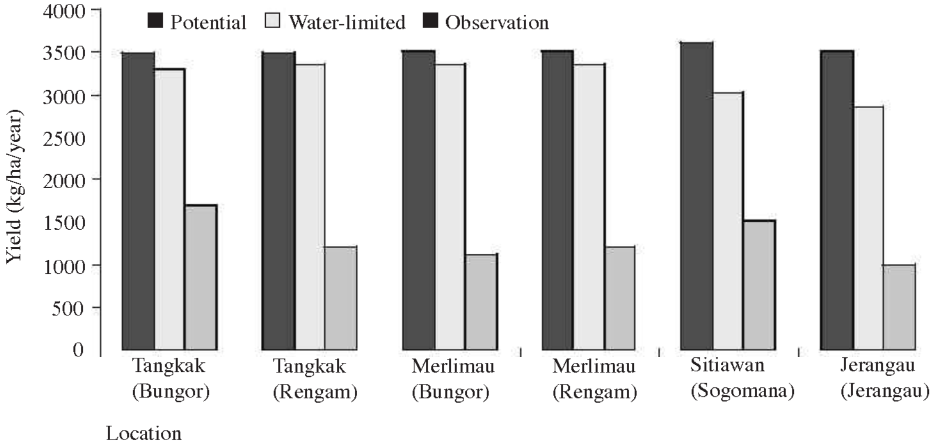

Figure 3. Average simulated potential and water-limited yield of cocoa in the study areas on different soil series as compared to actual field observations

Discussion

Currently, cocoa has been cultivated on a wide range of soils and climatic conditions in Peninsular Malaysia, ranging from areas of highly suitable to marginal (Mohd Zaki et al. 1985). Therefore, considerable differences in yield were to be expected. In this study, there were small differences between potential and water-limited production, attributable to a single factor i.e. water, and the values were far above actual yields. This is understandable since there are possibly definite limitations posed by management inputs, soil nutrient status and plant genetic variation. It is noteworthy that observed yields in the study areas were less than that observed for Tawau area (Ramadasan et al. 1991), while those for potential and water-limited were comparable based on simulations performed by Gerritsma (1994). The correspondence of simulated potential yields and water limited yields is a strong indication that water limitations play an important role in yield formation of cocoa.

The variations of cocoa yields from year to year and between regions are affected more by rainfall than any other climatic factors (Gerritsma and Wessel 1996). Cocoa trees are very sensitive to soil-water deficiency particularly when they are competing with other plants, shade trees or casual weeds, a situation which frequently occurs in plantation. It is generally accepted that total annual rainfall in cocoa-growing areas exceeds annual water loss by evapotranspiration. The rainfall normally lies between 1,250–3,000 mm per year and preferably between 1,500–2,000 mm (Mohd Zaki et al. 1985;

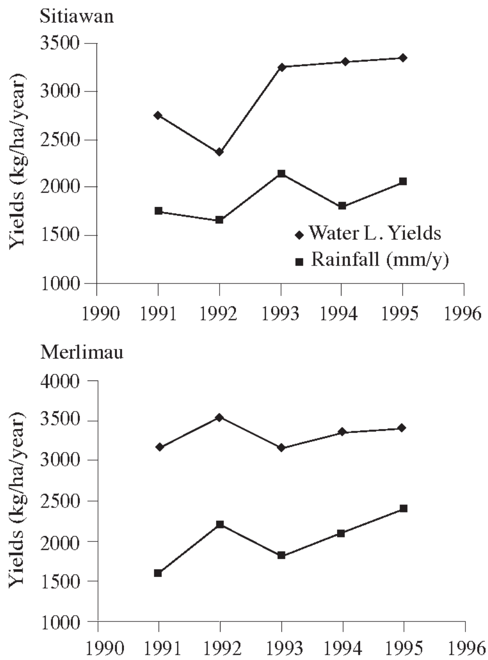

Figure 4. Simulated water-limited yield and rainfall at Sitiawan and Merlimau

Ramadasan et al. 1991). Dry conditions due to inadequate rainfall and appreciable moisture deficit, will depress yield probably by promoting cherelle wilt and reducing pod number and, to some extent, reducing the bean size (Wood and Lass 1985; Mohamad Zabawi 1993).

Rainfall distribution in Peninsular Malaysia varies greatly from region to region (Nieuwolt 1982) and is the main factor responsible for differences in cropping pattern and yield trends. Cocoa needs even distribution of rainfall throughout the year when planting and growth can be continuos over many months. On the other hand, excessive rainfall can also be detrimental to cocoa production. Cocoa yield decreases under conditions of soil water logging and/ or flooding which increases plant chlorosis, poor fruit set, cherelle wilt and diseases infection (Wood and Lass 1985; Thong et al. 1990).

In Peninsular Malaysia, cocoa can be grown on a wide range of soils, provided they have satisfactory physical and chemical properties. Soil properties, particularly physical, must be considered in connection with the amount and distribution of rainfall. Good cocoa soil can be characterized as soil with good moisture retention, well-drained and well-aerated (Alvim 1977). With good soil physical characteristics, the adverse effect of local climate, such as a dry period can be ameliorated. Therefore, in Peninsular Malaysia, the best cocoa soils usually have good physical properties like soil depth, sandy clay and clay loam to loam texture, free drainage and good structure coupled with pronounced water-holding capacity (Wong 1971, 1986). This has been shown in this study and previously by Thong et al. (1990) and Mohamad Zabawi (1993). Contribution of soil physical properties to cocoa growth and production was estimated to be about 70% of soil characteristics (Mohd Zaki et al. 1985; Ramadasan et al. 1991).

The importance of soil physical properties is related to root growth and capacity to retain water for plants during the moisture stress period. In this study, the water-retention characteristics of the selected soils were generally very favourable for cocoa performance. So that, there is no problem of soil moisture deficit especially during the short dry period.

Conclusion

Generally, for Malaysia, the major factors which influence cocoa yield potential are the presence or absence of dry month, its length and soil characteristics. According to this preliminary analysis, it was obvious that the climate especially drought and soil properties played an important role in determining the productivity of cocoa. It also shows that the development of quantitative method of assessment i.e. CASE2 model can be useful for prediction of cocoa yield under potential and water limited conditions on different soils and climate. However, apart from the need for further validation of the model in Malaysia condition, its sensitivity to changes in various physiological parameters need further investigation to identify the factors explaining the yield gap between the production levels. There is also a need to test the model for specific cocoa clones and to introduce soil chemical relation into the model.

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Abstrak

Hasil koko pada keadaan potensi dan air terhad di zon agro-ekologi yang berbeza telah disimulasi menggunakan model koko CASE2. Bagi kedua-dua aras pengeluaran, hasil koko telah disimulasi menggunakan data cuaca bagi tempoh 5 tahun (1991–1995) dan data tanaman koko yang berusia 3 tahun. Hasil simulasi menunjukkan purata hasil potensi koko bagi beberapa kawasan terpilih sebanyak 3.5 t/ha/tahun. Pengeluaran hasil pada keadaan air terhad ialah 4% lebih rendah daripada hasil potensi kecuali bagi kawasan Sitiawan dan Jerangau dengan hasil berkurangan masing-masing sebanyak 16% dan 20%. Perbezaan hasil bagi dua keadaan pengeluaran ini adalah disebabkan oleh faktor cuaca dan tanah bagi kawasan tersebut, dengan cuaca merupakan faktor utama. Sementara itu, perbezaan hasil bagi kedua-dua keadaan ini di atas tanah yang berbeza adalah kecil terutamanya bagi tanah siri Muncong, Bungor dan Rengam. Keputusan juga menunjukkan pengeluaran di tanah siri Rengam dan Bungor adalah tinggi dibandingkan dengan siri tanah yang lain.

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