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MODEL PENGARUH KETERSEDIAAN AIR TERHADAP PERTUMBUHAN DAN HASIL KELAPA SAWIT

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ABSTRAK

*Kajian ini bertujuan untuk mengembangkan suatu model guna memprediksi dan menganalisis fluktuasi bulanan hasil kelapa sawit (*Elaeis guineensis *Jacq.). Pengembangan model menekankan pada faktor penyebab fluktuasi hasil. Faktor tersebut adalah variasi ketersediaan air, yang dipengaruhi oleh distribusi curah hujan. Pendekatan yang digunakan untuk pengembangan model tersebut dilakukan dengan dua cara, yaitu (1) mengintroduksi aspek neraca air ke dalam model, sehingga model memiliki 2 submodel, yaitu submodel pertumbuhan dan perkembangan tanaman, dan submodel neraca air, (2) melakukan pengumpulan data melalui pengamatan lapang selama satu tahun (Maret 1996 – Maret 1997) untuk membangun dan menguji model tersebut. Data dikumpulkan dari plot pengujian percobaan pemuliaan No. BJ-26-S, yang ditanam pada 1990 di kebun Bah Jambi, PT.Perkebunan Nusantara IV, Simalungun, Sumatera Utara. Pengembangan model divalidasi dengan data pengamatan pertumbuhan organ vegetatif dan generatif, laju emisi pelepah daun, hasil tandan, dan komponen-komponen neraca air yang meliputi evapotranspirasi dan kadar air tanah. Pengembangan model menunjukkan kevalidan model, dan introduksi submodel neraca air meningkatkan kepekaan model terhadap variasi ketersediaan air, yang akhirnya dapat meningkatkan ketepatan prediksi hasil tandan buah hingga 15 %. Model tersebut dapat digunakan untuk menganalisis pengaruh kekeringan terhadap hasil tandan melalui perlakuan skenario kekeringan. Hasil skenario menunjukkan bahwa kekeringan selama 3 dan 6 bulan berturut-turut menyebabkan penurunan hasil 8-9 % dan 21-33% pada tahun berikutnya. Pengaruh kekeringan mulai terlihat pada 3 bulan pertama setelah awal kekeringan dan kemudian meningkat hingga mencapai puncaknya pada 9 – 13 bulan setelah awal kekeringan. Tiga belas bulan setelah awal kekeringan, tanaman menunjukkan pemulihan kondisi dan kemudian pengaruhnya relatif kecil setelah 36 bulan.*

Kata kunci: *Elaeis guineensis*, model tanaman , pengembangan model, prediksi, fluktuasi hasil, ketersediaan air, kekeringan, perlakuan skenario

PENDAHULUAN

Sebaran curah hujan menyebabkan hasil kelapa sawit berfluktuasi (10). Fluktuasi hasil tersebut mempengaruhi sebaran panen yang sulit untuk diprediksi. Prediksi sangat diperlukan dalam pengelolaan budidaya kelapa sawit, seperti pengelolaan produksi, transportasi dan tenaga kerja. Kegiatan memprediksi hasil dapat dilakukan dengan menggunakan pendekatan analisis kuantitatif terhadap sistem produksi tanaman kelapa sawit.

Model simulasi tanaman adalah salah satu pendekatan kuantitatif untuk menganalisis sistem tanaman pada berbagai tingkat kompleksitas (2), yang dapat menerangkan dampak masukan sistem, seperti faktor lingkungan terhadap hasil tanaman.

Pada saat ini telah dikembangkan suatu model simulasi kelapa sawit yang ditujukan untuk memprediksi potensi hasil, dengan asumsi tidak terdapat faktor pembatas pada lingkungan tanam. Pada kenyataannya, iklim musiman, terutama pada wilayah tropis menyebabkan hasil yang berfluktuasi, sehingga diperlukan pengembangan model dengan mempertimbangkan faktor iklim tersebut.

Penelitian ini bertujuan mengembangkan suatu model untuk memprediksi hasil tanaman kelapa sawit dengan mempertimbangkan radiasi surya dan ketersediaan air sebagai faktor pembatas.

BAHAN DAN METODE

Pendekatan yang digunakan untuk mengembangkan model adalah (1) membangun struktur model yang meliputi submodel pertumbuhan dan fenologi, dan submodel neraca air, (2) melakukan pengamatan lapang untuk mengumpulkan data yang digunakan dalam penurunan parameter dan validasi model.

Pengamatan lapang dilakukan pada Maret 1996 – Maret 1997 (satu tahun) di plot pengujian percobaan pemuliaan, No. BJ-26-S, tahun tanam 1990, kebun Bah Jambi, PT. Perkebunan Nusantara IV, Simalungun, Sumatera Utara (2°59' LU 99°13'). Pengamatan lapang dibagi dalam tiga aspek yaitu fotosintesis, pertumbuhan dan fenologi, dan neraca air. Pengembangan model divalidasi terhadap data pertumbuhan organ vegetatif, generatif, dan komponen neraca air (evapotranspirasi dan kadar air tanah) menggunakan metode pembandingan uji-t dengan jenjang kepercayaan 1 dan 5 % (9).

Laju fotosintesis diukur *in situ* dengan menggunakan penganalisis portabel (IRGA), tipe LCA-4 (Analytical Development Co., UK) mengikuti metode Caemmerer dan Farquhar (1). Pertumbuhan dan fenologi diukur non-destruktif (3). Untuk aspek neraca air, pengukuran kadar air tanah mengikuti metode gravimetris, dan pengukuran evapotranspirasi menggunakan metode lysimeter untuk laju evaporasi tanah dan menggunakan metode Dufrene, Dubous, Rey, Quencez, and Saugier (4) untuk laju transpirasi tanaman. Aplikasi model dilakukan setelah model divalidasi. Pada penelitian ini aplikasi model ditujukan untuk menganalisis dampak kekeringan terhadap hasil tandan buah melalui perlakuan skenario.

HASIL DAN PEMBAHASAN

Struktur model

Pengembangan model ditekankan pada introduksi faktor ketersediaan air ke dalam model yang telah dikembangkan sebelumnya oleh Gerritsma dan Goudriaan (5), dan Van Kraalingen *et al.* (11). Model yang dikembangkan memiliki dua submodel yaitu submodel pertumbuhan dan fenologi serta submodel neraca air.

Submodel pertumbuhan dan fenologi

Submodel ini mensimulasi proses-proses yang berhubungan dengan keseimbangan biomassa selama periode pertumbuhan. Proses pertumbuhan dapat dilihat pada diagram Forrester untuk submodel pertumbuhan dan fenologi (Lampiran 1a).

Asimilat kotor (A, kg CH_2O ha^{-1} $hari^{-1}$) sebagai sumber perolehan biomassa yang dihasilkan dari proses fotosintesis yang memerlukan radiasi surya (QO, MJ ha^{-1} $hari^{-1}$) sebagai sumber energi. Di samping radiasi surya, aktivitas fotosintesis juga ditentukan oleh faktor-faktor lainnya yaitu intersepsi radiasi surya oleh kanopi (ι), ketersediaan air (fw), dan parameter efisiensi penggunaan radiasi surya (ε, kg CH_2O MJ^{-1}), sehingga produksi asimilat kotor dapat diformulasikan mengikuti persamaan (1)

$$A = \varepsilon (1 - \tau)\, Qo\, fw \quad (1a)$$

dengan,

$$\tau = e^{-k\,LAI} \quad (1b)$$

$$fw = \Gamma a/\Gamma m;\ \Gamma a = f(Ta);\ \Gamma m = f(Qo) \quad (1c)$$

k : koefisien pemadaman
LAI : indeks luas daun
Γa : konduktans stomatik aktual (mm $hari^{-1}$)
Γm : konduktans stomatik maksimum (mm $hari^{-1}$)
Ta : transpirasi aktual (mm $hari^{-1}$)

Asimilat kotor (A), kemudian didistribusikan ke dalam tiap organ (buah, daun, batang, dan akar) berdasarkan faktor partisinya (η). Sebagian dari asimilat digunakan untuk respirasi pertumbuhan dan pemeliharaan sehingga mengurangi kebutuhan untuk pertumbuhan organ tanaman. Simbol proses respirasi untuk organ buah, daun, batang, dan akar berturut-turut adalah Rf, Rl, Rs, dan Rr. Pertumbuhan tiap organ tanaman dihitung berdasarkan persamaan (2).

$$dW_x = \eta_x (A - Rm) - Rg_x \quad (2a)$$

$$= (1 - kg_x)\ \eta_x(A - kmWQ_{10}) \quad (2b)$$

dengan,

$$Q_{10} = 2^{(T-255)/10} \quad (2c)$$

dW_x : pertumbuhan tiap organ (kg ha^{-1} $hari^{-1}$)
η_x : partisi asimilat untuk pertumbuhan organ
A : asimilat kotor (kg CH_2O ha $hari^{-1}$)
Rm : respirasi perawatan (kg CH_2O ha^{-1} $hari^{-1}$)
Rg_x : respirasi pertumbuhan (kg CH_2O ha^{-1} $hari^{-1}$)
km : koefisien respirasi perawatan
W : bobot kering biomassa tanaman (kg ha^{-1})
kg_x : koefisien respirasi pertumbuhan
Q_{10} : kuosien suhu
T : suhu udara (°C)

Pada submodel pertumbuhan dan fenologi, hasil tandan dihitung dari kedudukan pelepah dan pertumbuhan tandan buah, sehingga laju emisi pelepah dan jumlah pelepah harus dideterminasi. Submodel ini juga mendeterminasi biomassa tegakan, sehingga pemangkasan pelepah dan laju senesen akar dimasukkan ke dalam submodel pertumbuhan dan fenologi. Indeks luas daun (LAI) dihitung sebagai fungsi biomassa tegakan dan parameter luas daun spesifik (sla).

Submodel neraca air

Submodel neraca air terdiri dari komponen kadar lengas tanah (θ), infiltrasi air (Is), transpirasi tanaman (Ta), evaporasi tanah (Ea), dan perkolasi (Pc). Interaksi di antara komponen-komponen tersebut dapat dilihat pada Persamaan (3) dan Lampiran 1b.

Lapisan tanah bagian atas (1)

$$\theta_t(1) = \theta_{t-1}(1) + Is_t - Pc_t(1) - Ta_t(1) - Ea_t(1) \quad (3a)$$

Lapisan tanah bagian bawah (2)

$$\theta_t(2) = \theta_{t-1}(2) + Pc_t(1) - Pc_t(1) - Ta_t(1) \quad (3b)$$

Sebagian curah hujan diintersepsi oleh kanopi (Ic) ketika mencapai permukaan puncak kanopi dan sisanya mencapai permukaan tanah melalui kanopi dan aliran batang. Air yang diintersepsi kemudian dievaporasikan kembali ke atmosfir, sedang yang mencapai permukaan tanah akan terinfiltrasi ke dalam tanah sebagai air infiltrasi.

Pada submodel ini diasumsikan bahwa tidak terdapat aliran permukaan, sehingga model tersebut ditujukan untuk aplikasi pada permukaan tanah yang datar.

Air infiltrasi masuk ke lapisan tanah yang lebih dalam jika kadar air tanah pada lapisan tersebut telah melebihi kadar air pada kapasitas lapang (fc). Kelebihan air pada tiap lapis tanah dikenal sebagai air perkolasi (Pc). Air perkolasi pada lapisan tanah yang terdalam akan hilang sebagai air drainase.

Kadar air tanah (θ) pada tiap lapis tanah di atas titik layu permanen (wp) akan diabsorpsi akar, yang kemudian digunakan dalam proses fisiologis dan transpirasi tanaman melalui permukaan daun. Kebutuhan air untuk proses fisiologis relatif sedikit, yaitu sekitar 1 % dari yang ditranspirasikan, sehingga dapat diabaikan.

Air yang diasorbsi akar pada tiap lapis tanah dapat dihitung dari nilai transpirasi maksimum (TM), kondisi atmosfir (evapotranspirasi potensial, ETP), dan indeks luas daun (LAI). Transpirasi maksimum terjadi jika tidak ada keterbatasan air tanah. Jumlah air yang diabsorpsi akar pada keseluruhan lapisan disebut sebagai air transpirasi aktual (Ta).

Pada lapisan tanah atas, air tanah dapat hilang melalui proses evaporasi dari permukaan tanah ke atmosfir. Evaporasi tanah (Ea) dihitung berdasarkan metode dua fase (8). Evaporasi maksimum (Em) pada fase pertama terjadi ketika tidak ada keterbatasan air tanah, sedangkan fase kedua terjkadi jika laju evaporasi menurun secara eksponensial.

Baik transpirasi maupun evaporasi diturunkan dari peubah eksternal (lingkungan), yaitu radiasi surya, suhu udara, kelembaban udara, dan kecepatan angin. Peubah eksternal yang mengendalikan evapotranspirasi melalui evapotranspirasi potensial (ETP), dihitung melalui formula Penman (6).

Masukan model

Data masukan yang dibutuhkan model adalah peubah iklim harian dan inisialisasi kondisi tanaman dan tanah. Peubah iklim meliputi curah hujan (mm $hari^{-1}$), suhu (°C), lama penyinaran (jam $hari^{-1}$), kelembaban relatif (%), dan kecepatan angin (km $hari^{-1}$). Sedangkan nilai inisialisasi meliputi bobot kering biomassa tegakan tiap organ (kg ha^{-1}), indeks luas daun, kadar air tanah pada kapasitas lapang dan titik layu permanen tiap lapisan tanah (%).

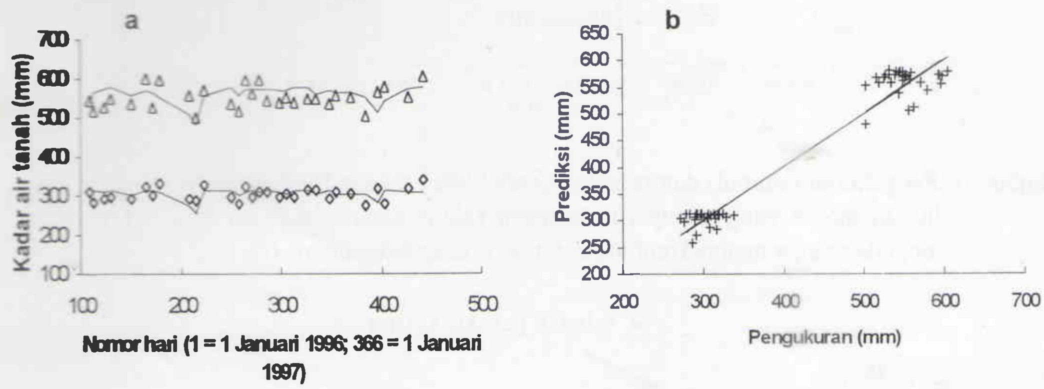
Validasi dan kepekaan model

Penggunaan model membutuhkan nilai-nilai parameter, yang merupakan hasil penurunan dari pengamatan lapang. Parameter pada setiap submodel dan nilainya disajikan pada Lampiran 2a.

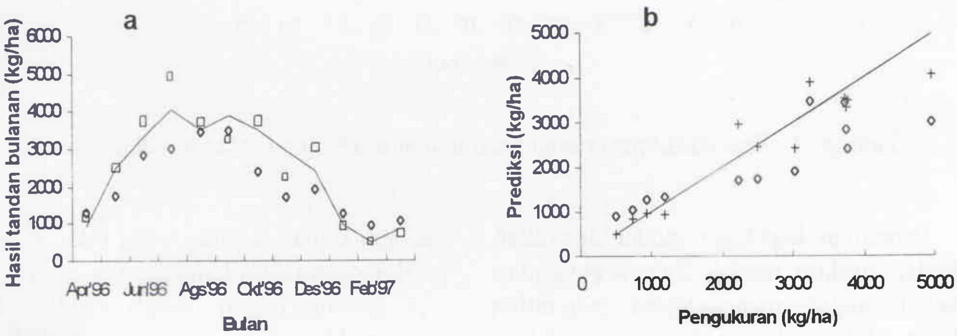
Validasi model bertujuan untuk mengevaluasi keberhasilan pembangunan dan penurunan parameter model. Validasi dilakukan dengan cara membandingkan antara keluaran model dengan hasil pengukuran lapang.

Tampilan model neraca air, yang terdiri dari kadar air tanah pada kedalaman 0 – 100 dan 0 – 180 cm menunjukkan ketepatan prediksi yang baik (Gambar 1). Hal tersebut juga terjadi pada komponen neraca air lainnya (Lampiran 2b). Kecuali pertumbuhan organ daun, hasil prediksi peubah dalam submodel pertumbuhan dan fenologi menunjukkan ketepatan yang baik (Lampiran 2b). Tampilan prediksi hasil bulanan disajikan pada Gambar 2, yang menunjukkan bahwa terdapat dua periode ekstrim hasil tandan bulanan, yaitu periode hasil tandan buah yang tinggi terjadi pada Oktober dan periode hasil rendah terjadi pada Februari-April. Penampilan tersebut merupakan gambaran representatif fluktuasi hasil bulanan di Sumatera Utara.

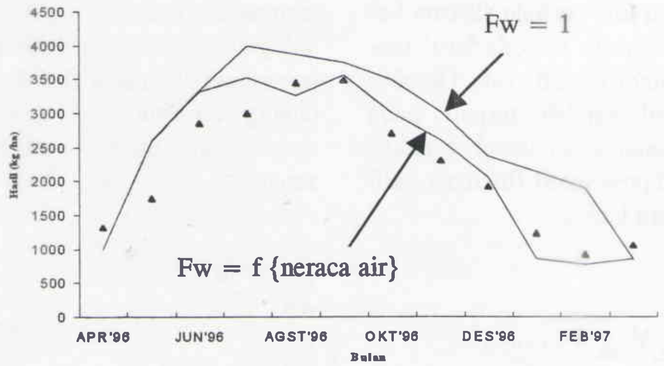
Umumnya, penampilan model mampu memprediksi peubah aspek pertumbuhan fenologi, dan neraca air dengan baik, sehingga penurunan parameter dari hasil pengamatan lapang tersebut layak digunakan untuk membangun model pertumbuhan kelapa sawit.



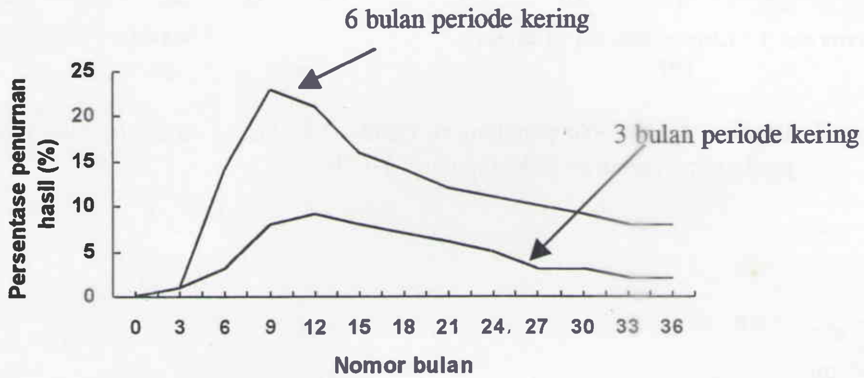
Gambar 1. Prediksi (garis) dan pengukuran (simbol) kadar air tanah (a) dan ploting data prediksi-pengukuran terhadap garis 1:1 (b)



Gambar 2. Prediksi (garis) dan pengukuran (simbol) hasil tandan buah segar bulanan (a) dan ploting data prediksi-pengukuran terhadap garis 1:1 (b)



Gambar 3. Pengukuran (simbol) dan prediksi (garis) hasil tandan buah bulanan sebagai keluaran model yang mempertimbangkan faktor ketersediaan air (fw = f{neraca air}) dan tanpa mempertimbangkan faktor ketersediaan air (fw =1)



Gambar 4. Persentase penurunan hasil akibat kekeringan selama 3 dan 6 bulan

Pengujian kepekaan model dilakukan terhadap struktur model. Tujuan pengujian tersebut adalah mengevaluasi pengintroduksian faktor ketersediaan air dalam pengembangan model. Pengujian dilakukan dengan cara membandingkan antara keluaran model yang mempertimbangkan faktor ketersediaan air (fw = f { neraca air}) dengan keluaran model yang tidak mempertimbangkan faktor ketersediaan air (fw = 1).

Pembandingan hasil tandan buah menunjukkan bahwa keluaran model yang tidak mempertimbangkan faktor ketersediaan air cenderung lebih tinggi dibanding dengan keluaran model yang mempertimbangkan faktor ketersediaan air. Hasil pembandingan dari keluaran kedua model tersebut dengan hasil pengukuran lapang menunjukkan bahwa pengembangan model meningkatkan ketepatan prediksi hasil tandan bulanan (Gambar 3).

Model yang tidak mempertimbangkan faktor ketersediaan air menghasilkan keluaran model 19 % lebih tinggi dibanding pengukuran langsung, sedangkan pengembangan model yang mempertimbangkan faktor ketersediaan air menghasilkan keluaran model hanya 4 % lebih tinggi dari pengukuran langsung. Hal ini menunjukkan bahwa pengembangan model dengan mempertimbangkan faktor ketersediaan air dapat meningkatkan ketepatan prediksi sekitar 15 %. Hasil analisis tersebut didasarkan pada data yang dikumpulkan dari wilayah penelitian yang beriklim basah, sehingga diperkirakan model tersebut akan lebih peka jika diaplikasikan di wilayah yang memiliki perbedaan musim kering dan penghujan yang jelas.

Analisis pengaruh kekeringan terhadap hasil tandan buah

Analisis dilakukan dengan menggunakan skenario perlakuan kekeringan. Perlakuan kekeringan meliputi (1) tiga bulan periode kering yang berkelanjutan, (2) enam bulan periode kering yang berkelanjutan. Perlakuan tersebut mengasumsikan bahwa jumlah curah hujan pada periode kering tidak melebihi 60 mm per bulan.

Kedua perlakuan tersebut menunjukkan bahwa pengaruh kekeringan mulai terlihat pada 3 bulan pertama setelah awal kekeringan, dan kemudian meningkat sampai puncaknya pada 13 bulan kemudian yang menurunkan hasil 8 – 9 % pada periode kekeringan 3 bulan dan 21 – 23 % pada periode kekeringan 6 bulan. Tiga belas bulan setelah kekeringan, tanaman menunjukkan pemulihan dan pengaruhnya relatif kecil pada 36 bulan setelah awal kekeringan (Gambar 4). Penurunan kadar air tanah yang disebabkan periode kering menyebabkan penurunan perolehan asimilat untuk pertumbuhan tandan buah, sehingga hasil menurun. Pengaruh tersebut mulai tampak pada 3 bulan setelah awal kekeringan. Hal tersebut berhubungan dengan perkembangan tandan buah yang membutuhkan pasokan asimilat yang tinggi untuk fase pengisian minyak yang terjadi sejak 3 bulan sebelum buah matang fisiologis (7). Pengaruh kekeringan terhadap perkembangan tandan buah dimulai sejak awal antesis hingga matang fisiologis yang membutuhkan waktu 6 – 7 bulan. Apabila terjadi periode kekeringan selama 6 bulan, maka pengaruhnya dapat terjadi selama 12 bulan.

KESIMPULAN

Model tanaman kelapa sawit yang dikembangkan adalah suatu model fisiologis yang menekankan pada faktor penyebab fluktuasi hasil, yang berasumsi bahwa fluktuasi tersebut disebabkan variasi ketersediaan air yang berhubungan dengan distribusi curah hujan. Model menunjukkan kevalidan, dan introduksi submodel neraca air meningkatkan kepekaan model terhadap variasi ketersediaan air, sehingga meningkatkan ketepatan prediksi hasil tandan buah hingga 15 %. Oleh karena itu, pengembangan model layak digunakan untuk menganalisis pengaruh kekeringan terhadap hasil melalui skenario perlakuan.

Hasil skenario menunjukkan bahwa kekeringan 3 dan 6 bulan menyebabkan hasil menurun berturut-turut sebesar 8 – 9 %

dan 21 – 23 % berturut-turut. Pengaruh kekeringan mulai tampak pada 3 bulan pertama setelah awal kekeringan, kemudian meningkat pada 9 – 13 bulan kemudian. Tiga belas bulan setelah awal kekeringan, tanaman menunjukkan pemulihan dan pengaruhnya relatif kecil setelah 36 bulan kemudian.

Penurunan parameter dalam model ini dilakukan pada kondisi yang terbatas (hanya pada satu bahan dan umur tanaman), sehingga membutuhkan penurunan parameter pada kondisi yang lebih luas. Di samping itu, model ini membutuhkan verifikasi pada wilayah yang memiliki tipe iklim yang lebih kering.

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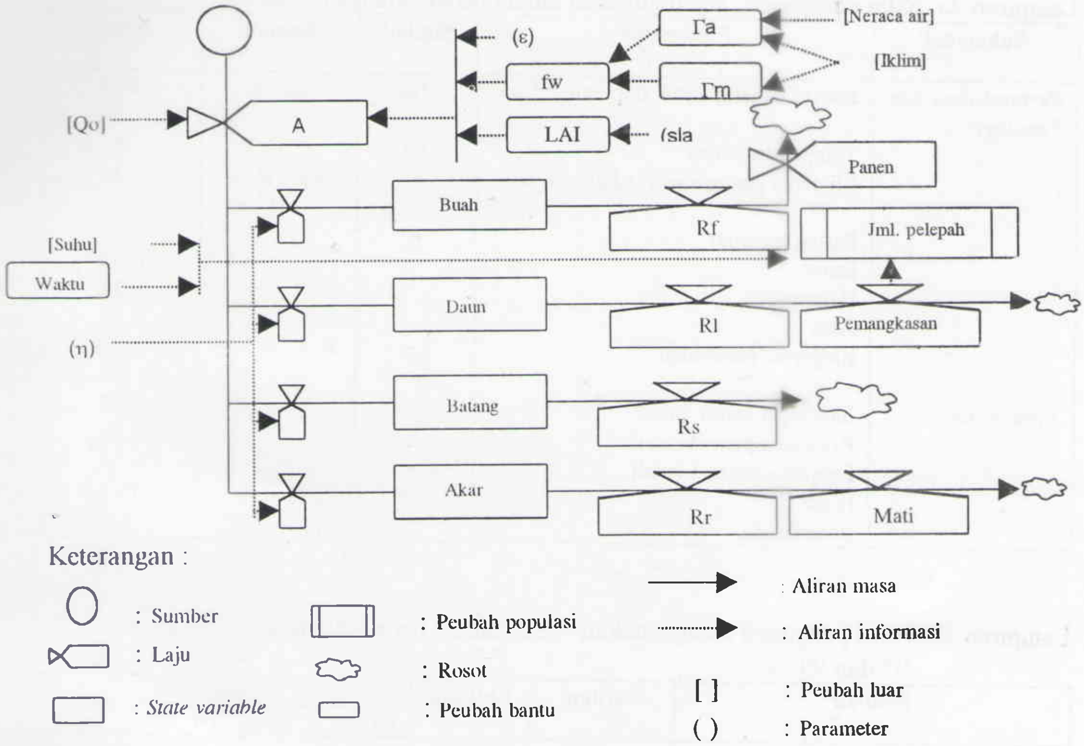
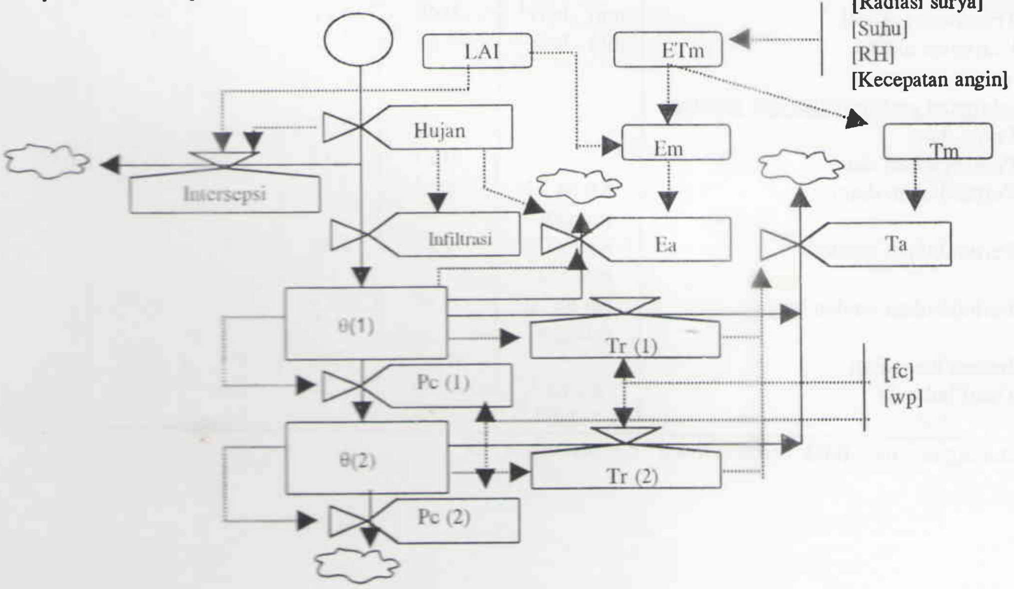
Lampiran 1a. Diagram Forrester pertumbuhan dan fenologi kelapa sawit



Lampiran 1b. Diagram Forrester neraca air kelapa sawit



Lampiran 2a. Nilai parameter yang digunakan dalam pengembangan **model**

Submodel	**Parameter**	**Simbol**	**Satuan**	**Nilai**
Pertumbuhan dan Fenologi	Satuan bahang untuk tiap emisi daun	Hue	Hari °C	159,7
	Temperatur dasar	To	°C	15
	Efisiensi penggunaan radiasi surya	ε	Kg CH_2O MJ^{-1}	$3{,}1\ 10^{-3}$
	Partisi asimilat	η	-	
	Daun		-	0,64
	Batang		-	0,24
	Akar		-	0,12
	Respirasi perawatan	Km	-	0,005
Neraca air	Intersepsi curah hujan	-	-	0,87
	Koefisien pemadaman	k	-	0,32
	Evapotranspirasi tanah			
	(Fase I)	U	mm	11,1
	(fase II)	β	mm $hari^{-1.5}$	2,7

Lampiran 2b. Hasil pengujian menggunakan t-test student pada jenjang kepercayaaan 95 dan 99 %

Peubah	**Satuan**	**t-hitung**	**t-tabel**			
			t_005	Beda	t_001	Beda
Submodel neraca air						
Kadar air tanah 0 – 100 cm	mm	0,53	2,04	ns	2,76	ns
Kadar air tanah 0 – 180 cm	mm	1,43	2,04	ns	2.76	ns
Transpirasi aktual	mm $hari^{-1}$	-0,48	2,12	ns	2,92	ns
Evaporasi aktual	mm $hari^{-1}$	-0,67	2,02	ns	2,70	ns
Submodel pertumbuhan dan fenologi						
Emisi daun	-	-0,21	2,13	ns	2,94	ns
Pemangkasan daun	-	-0,27	2,13	ns	2,94	ns
Pertumbuhan daun	Kg ha^{-1} 2 $minggu^{-1}$	-2,63	2,10	*	2,89	ns
Pertumbuhan batang	Kg ha^{-1} 2 $minggu^{-1}$	-1,23	2,10	ns	2,89	ns
Pertumbuhan tandan buah	Kg ha^{-1} 2 $minggu^{-1}$	-1,87	2,10	ns	2,89	ns
Indeks luas daun	-	1,69	2,10	ns	2,89	ns
Hasil bulanan	Kg ha^{-1} $bulan^{-1}$	-0,72	2,20	ns	3,10	ns

Keterangan : ns = tidak berbeda nyata ; * = berbeda nyata

Model of water availability effect on the growth and yield of oil palm

Iman Yani Harahap and Sjafrul Latif

Abstract

The study was aimed to develop an oil palm crop model to predict and analyze monthly yield fluctuation. The model stressed on the factor causes yield fluctuation. This factor was the variation on soil water available, affected by rainfall distribution. The approaches used to develop that model were, firstly, by introducing soil water balance submodel, which simulate water available into previous model, to develop growth, phenology, and water balance submodels. Secondly, by conducting field observation for one year (March 1996 - March 1997) to collect data for constructing and validating the developed model. Data were collected from Indonesian Oil Palm Research Institute (IOPRI) breeding trial plot, No. BJ-26-S, planted in 1990, at Bah Jambi estate, PT. Perkebunan Nusantara IV, Simalungun, Sumatera Utara. The developed simulation model was validated against the data of vegetative and generative organ biomass, number of frond emission, fruit bunch yield, and water balance components including evapotranspiration and soil water content. The model showed good agreement with the observation data and the introduction of water balance submodel into developed model increased sensitivity of model to variation of soil water available, which increase the precision of prediction on monthly fruit bunch yield fluctuation by 15 percent. Therefore, it could be used to analyze the influence of drought on yield in drought treatment scenario. The scenario showed that 3 and 6 month dry period would decrease yield on the next year as much as 8 - 9 % and 21 - 23 %, respectively. The immediate influence of drought could be seen in the first 3 months, and then arise to reach its peak in 9 - 13 months later. At thirteen months after arought, the trees showed recovering and then the influence of drought was relatively small after 36 months.

Key words : oil palm, crop model, developed model, predict, yield fluctuation, soil water available, drought, treatment scenario

Introduction

Rainfall distribution causes the fluctuation of oil palm yield (10). The fluctuation causes difficulties in predicting harvest distribution. Prediction of harvest distribution is necessary in oil palm cultivation, in order to manage the production, transportation, and labour. Yield prediction could be made by using quantitative analysis approach on the production system of oil palm.

Crop simulation model is one of quantitative approaches to analyze the croping system at several complexity levels (2), and therefore, it could explain the effect of input system which is environmental factor to yield.

In recent year, the simulation model on oil palm has been developed which assume that there is no limiting factor on crop environment, and the model was purposed to predict the yield potential. In fact, seasonal climate, especially in tropical regions, can cause yield fluctuation, therefore developing model which consider the seasonal climate factor is required.

This research was aimed to develop a crop modeling of oil palm on growth and yield of oil palm by considering the solar radiation and water available as driving factors.

Materials and Methods

The approaches used in order to develop the model were (1) by constructing the model which is include the growth, phenology and water balance submodels, (2) by collecting field data for deriving and validating the model.

Field observation was conducted for one year, between March 1996 and March 1997, at Indonesian Oil Palm Research Institute (IOPRI) breeding trial, plot No. BJ-26-S, planted in 1990, at Bah Jambi estate, PTP Nusantara IV, Simalungun, North Sumatera (2°59' N - 99°13'). Field observations were separated into three aspects, including photosynthetic activity, growth, phenology and water balance. The model was validated against the data of vegetative, generative organ biomass, and water balance components (such as evapotranspiration and soil water content). Data were statistically analyzed by using t-test at 1 and 5 % confidence levels (9).

Photosynthetic activity rate was measured *in situ* using portable analyzer (IRGA), type LCA-4 (Analytical Development Co., UK) referring to Caemmer and Farquhar method (1). Growth rate and phenology non-destructively measurement was done referring to Corley *et al.* (3). In water balance aspects, soil water content was measured using gravimetric method, and evapotranspiration was measured using microlysimeter for evaporation and crop transpiration were determined by Dufrene *et al.* method (4). The application of model was done after the model was validated to analyze drought effect on yield by scenario treatment.

Results and Discussion

Structure of the model

The development of model was stressed on the introduction of water available factor into previous model, which was developed by Gerritsma and Goudriaan (5) and by Van Kraalingen et al. (11). The model developed here had two submodels, *growth and phenology* and *water balance* submodels.

Growth and phenology submodel

This submodel simulates the processes, which is relating to biomass balancing during the growth period. The growth process could be seen in Forrester diagram for growth and phenology submodels (Appendix 1a).

Gross assimilate (A, kg CH_2O ha^{-1} day^{-1}), as a source of biomass was obtained from photosynthetic activity that require solar radiation (Qo, MJ ha^{-1} day^{-1}) as source of energy. Beside the solar radiation, photosynthetic activity, also determined by other factors such as radiant interception by canopy (τ), water availability (fw), and parameter of light use efficiency (ε, kg CH_2O MJ^{-1}), so the production of gross assimilate could be formulated by equation below (1).

$$A = \varepsilon (1 - \tau) Qo\, fw \quad (1a)$$

with,

$$\tau = e^{-k\, LAI} \quad (1b)$$

$$fw = \Gamma a / \Gamma m;\ \Gamma a = f(Ta);\ \Gamma m = f(Qo) \quad (1c)$$

k : extinction coefficient
LAI : leaf area index
Γa : stomatic conductance actual (mm day^{-1})
Γm : maximum stomatic conductance (mm day^{-1})
Ta : actual transpiration (mm day^{-1})

Gross assimilate (A) was then distributed into each organ (fruit, leaf, stem, and root) according to their partition factor (η). A part of assimilate will be used for growth and maintenance respiration's, and therefore, it will be decreasing for organ growth. The symbol of respiration process for fruit, leaf, stem, and root were Rf, Rl, Rs, and Rr, respectively. The growth of each organ was calculated based on the following equation (2).

$$dW_x = \eta_x (A - Rm) - Rg_x \quad (2a)$$

$$= (1 - kg_x)\ \eta_x (A - kmWQ_{10}) \quad (2b)$$

with,

$$Q_{10} = 2^{(T-255)/10} \quad (2c)$$

dW_x : growth each organs (kg ha^{-1} day^{-1})
η_x : assimilate partition which allocated to each organs
A : gross assimilate (kg CH_2O ha day^{-1})
Rm : maintenance respiration (kg CH_2O ha^{-1} day^{-1})
Rg_x : growth respiration for each organ
Km : coefficient of maintenance respiration
W : dry weight of crop biomass (kg ha^{-1})
kg_x : coefficient of growth respiration
Q_{10} : temperature quotient
T : air temperature (°C)

For growth and phenology submodels, yield was calculated from frond position and fruit bunch growth, therefore emission rate of frond and frond position will determine the yield. This submodel also determines the standing biomass, so that frond pruning and root death rate will be entered into the component of growth and phenology submodels. Leaf area index (LAI), was calculated as function of standing biomass and specific leaf area parameter (sla).

Water balance submodel

Water balance submodel consists of the following component, i.e. soil water content (θ), water infiltration (Is), crop transpiration (Ta), soil evaporation (Ea), and percolation (Pc). Interaction among these components could bee seen in equation (3) and in Appendix 1b.

Upper soil layer (1)

$$\theta_t(1) = \theta_{t-1}(1) + Is_t - Pc_t(1) - Ta_t(1) - Ea_t(1) \quad (3a)$$

Lower soil layer (2)

$$\theta_t(2) = \theta_{t-1}(2) + Pc_t(1) - Pc_t(1) - Ta_t(1) \quad (3b)$$

A part of rainfall was intercepted by canopy (Ic) when reaching the top of canopy and the other will go to soil surface by free fall from the canopy and through stem flow. The intercepted rainfall will be re evaporated to atmosphere and the remaining water in the soil surface will be infiltrated into the soil. In this submodel, it was assumed that there was no run-off or water run-on. Therefore, its application was proposed to the flat surface soils.

Infiltration water entered the deeper layer of soil if water content in this layer is lesser than the water content at field capacity (fc). The exceed water on each soil layer was known as percolation water (Pc). Percolation water on the deepest soil layer will lose as drainage water.

Water content (θ) in each soil layer which is higher than the wilting point (wp) will be absorbed by root, then it was used in physiological process and transpired through passing leaf surface. The water needed for physiological process was relatively too small compared to transpiration, less than 1 %, and therefore, it could be ignored in water balance submodel.

The water, which was absorbed by root in each soil layer, was calculated from its maximum transpiration value (Tm), atmospheric condition (evapotranspiration potential, ETP), and leaf area index (LAI). Maximum transpiration occurred when there was no limitation on soil water content. Amount of water absorbed by root at whole layer was called as actual transpiration (Ta).

At upper soil layer, there was water lost by evaporation from soil surface to atmosphere. The soil evaporation (Ea) was calculated based on two-phase methods (8). Maximum evaporation (Em) at first phase occurred when there was no limitation on soil water content, whereas the second phase occurred when evaporation rates immediately decreasing exponentially with time.

Both transpiration and evaporation were derived by external variable (environment), including solar radiation, air temperature, air humidity and wind speed. The exogenous variable driving evapotranspiration by evapotranspiration potential (ETP), will be calculated by Penman formula (6).

Input model

Input data required in the model were daily climate variables and initialization of crop and soil condition. The climate variable including rainfall (mm day^{-1}), air temperature (°C), sunshine duration (hour day^{-1}), relative humidity (%), and wind speed (km day^{-1}). Whereas the initialization values including standing biomass dry weight of each organ (kg ha^{-1}), leaf area index, soil water content of each layer at field capacity and wilting point (%).

Validation and sensitivity model

The use of model requires parameters, which are derived from the result of field observation. The parameters of each submodel and their value were shown in Appendix 2a.

Validity of model proposed to evaluate the successful of constructing and deriving of parameters model. Validity was done by comparing between output model and field measurement.

Performance of water balance model, which were consist of soil water content on 0 - 100 and 0 - 180 cm deeps (Figure 1) showed a good precise on prediction of soil water content and all of water balance components. Except growth of leaf, the prediction showed a good precise on all of growth and phenology variables (Appendix 2b).

Performance of monthly yield prediction presented in Figure 2. Model performance showed that there were two extremes period of monthly yield. The first was high yield period, which occurred in October and the second one was low yield period in February- April. This performance was generally representing the monthly yield fluctuation in North Sumatera.

In general, the model performance was able to predict the variable of growth, phenology, and water balance aspects, and therefore, the parameters were derived from field observation can be used to develop a model of oil palm growth.

The sensitivity test of model was done on model structure. The aim of this testing

was to evaluate the effectivity of the introduction of water available factor in order to develop the model. The testing was done by comparing the output of model which consider the water available factor
(fw = f {water balance}) with the model without considering that factor (fw = 1).

The comparison showed that fruit bunch yield as the output of model without considering the water availability (fw = 1) tended to be higher than the output of another model (fw = f {water balance}). The output comparison of both models with field measurement showed that the development of model could increase the precision of prediction on monthly yield fluctuation (Figure 3).

The output of model without considering the water available factor was 19 % higher compared to the direct measurement, whereas the output of model considering the water available factor just 4 % higher compared to direct measurement.
Therefore, the development of such model could increase the precision of prediction by 15 %. This analysis was based on the data collected from field location having wet climate type.

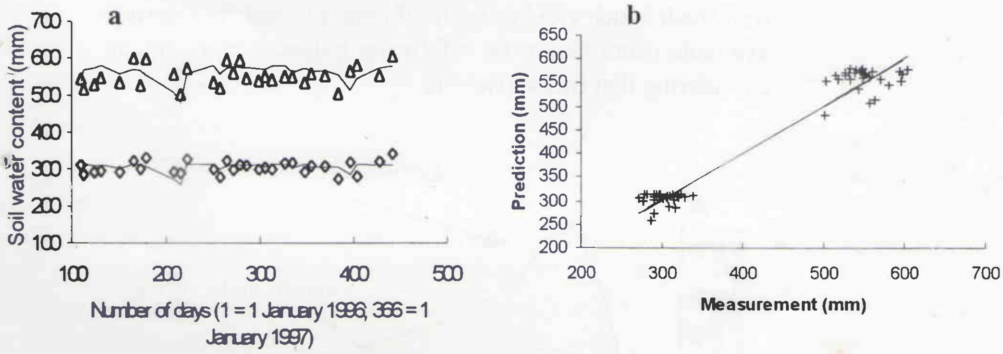


Figure 1. Prediction (lines) and measurement (symbol) of soil water content (a) and plotting data of prediction-measurement on line 1:1 (b)

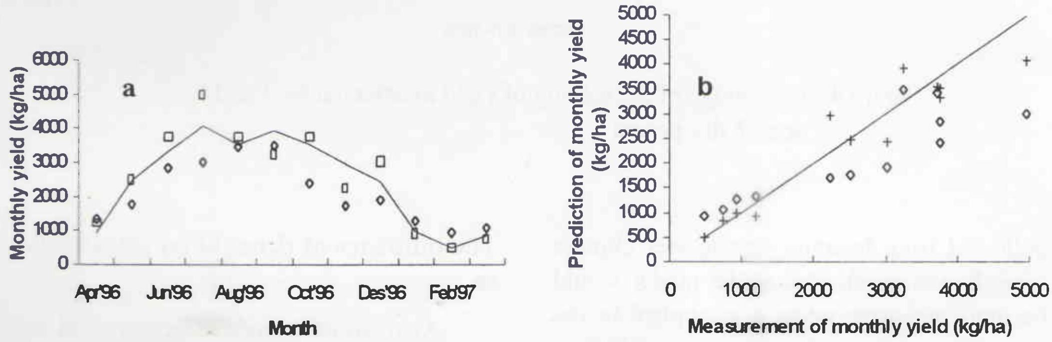


Figure 2. Prediction (line) and measurement (symbol) of monthly fruit fresh bunch yield (a) and plotting data of prediction-measurement on line 1:1 (b)

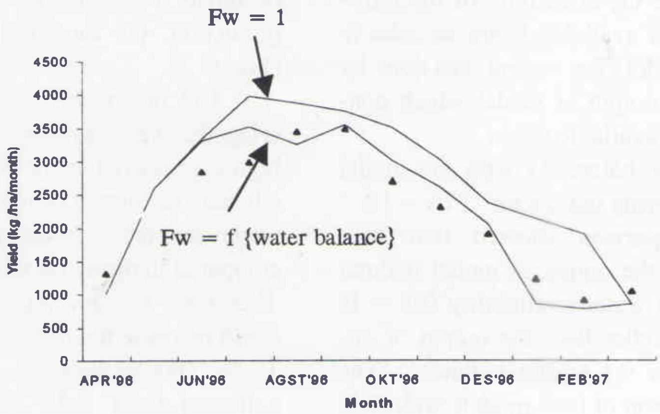


Figure 3. Prediction (lines) and measurement (symbol) of monthly fruit fresh bunch yield as result of output model considering available water factor, fw = f {water balance} and without considering that factor (fw = 1)

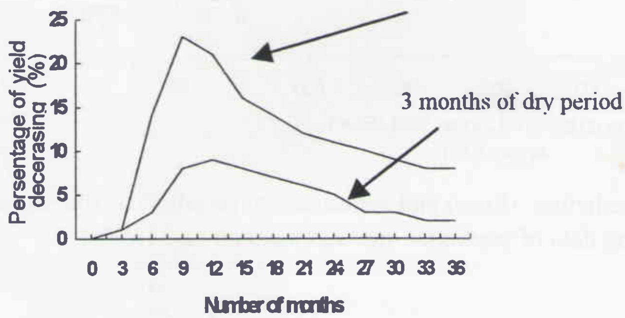


Figure 4. Persentage of decreasing of yield as affected by 3 and 6 month dry period

collected from location having wet climate type. It was assumed that the model would be more sensitive when it is applied to the area having dry and rainy season which is sharply difference.

The influence of drought on yield analysis

Analysis of drought effect on yield will be based on the scenario of drought treatment. The drought treatments were 3 months and 6 months continuously. These treatments were assumed as the amount of rainfall was less than 60 mm at each dry month period.

Both of scenario treatments showed that the immediate influence of drought could be seen in the first 3 month, and then reached its peak in 13 month later which decreased as much as 8 – 9 % and 21 – 23 % for 3 and 6 months dry period, respectively. Thirteen months after drought, the trees recovered their growth and the influence of drought was relatively small 36 months later (Figure 4).

The lowering of soil water content affected by dry period caused the decreasing of assimilate gain for growth of fruit bunch and finally decreased the yield. The immediate influence of drought occurred at 3 month later. It related to the phase of fruit bunch development, when fruit bunch required a highly assimilate supply for synthesizing of oil 3 months prior to ripening (7). The influence of drought on yield occurred as long as 12 months since the beginning of dry period. It may relate to fruit bunch development period, since fruit ripening completely happened within 6 - 7 month after anthesis. If dry period occur as long as 6 month, its totally effect will be as long as 12-13 months since the beginning of drought.

Conclusion

The presented crop model is a physiological model stressing on the factors cause the yield fluctuation. It was assumed that the factors were the variation of soil water available, which was affected by rainfall distribution. The model showed good correlation with observation data. The introduction of water balance submodel into the developed model could increase its sensitivity. The variation of soil water available, could increase the precision of prediction on fruit bunch yield by 15 %. Therefore, it could be use to analyze the influence of drought on yield in drought treatment scenario.

The scenario showed that 3 and 6 month dry period would decrease the yield one year later, as much as 8 – 9 % and 21 – 23 %, respectively. The immediate influence of drought could be seen in the first 3 months, and reached its peak in 9 – 13 month later. The trees recovered after thirteen months of drought, however, the influence of drought was relatively small after 36 months later.

Deriving of parameters in this model was done at limited environment (just on one material and age of planting), it is therefore, required a wider environment condition to represent the parameters. In addition, the development of this present model needs verification on the area with more dry climate type.

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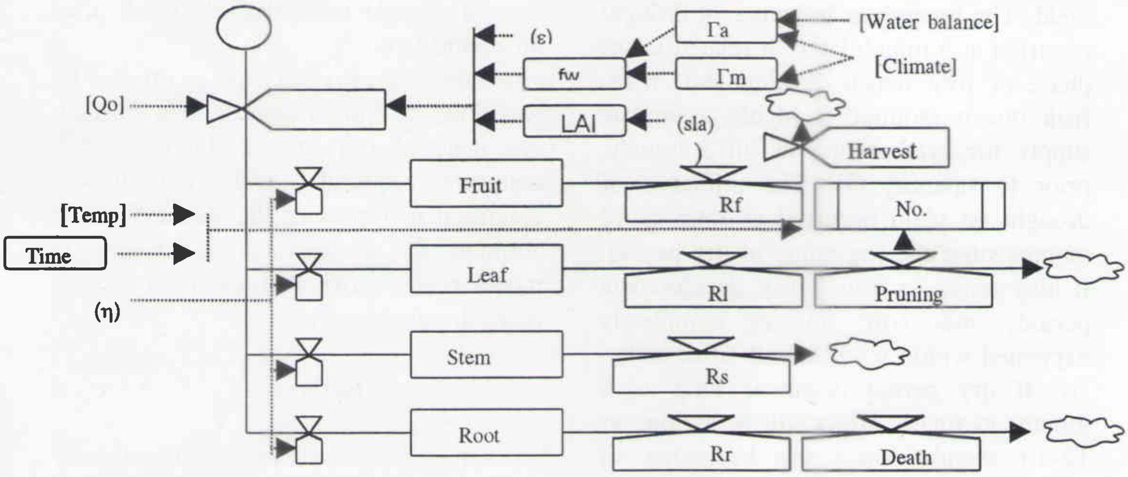
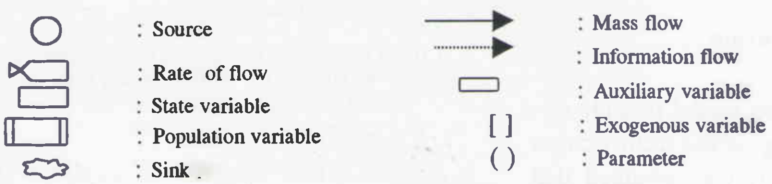
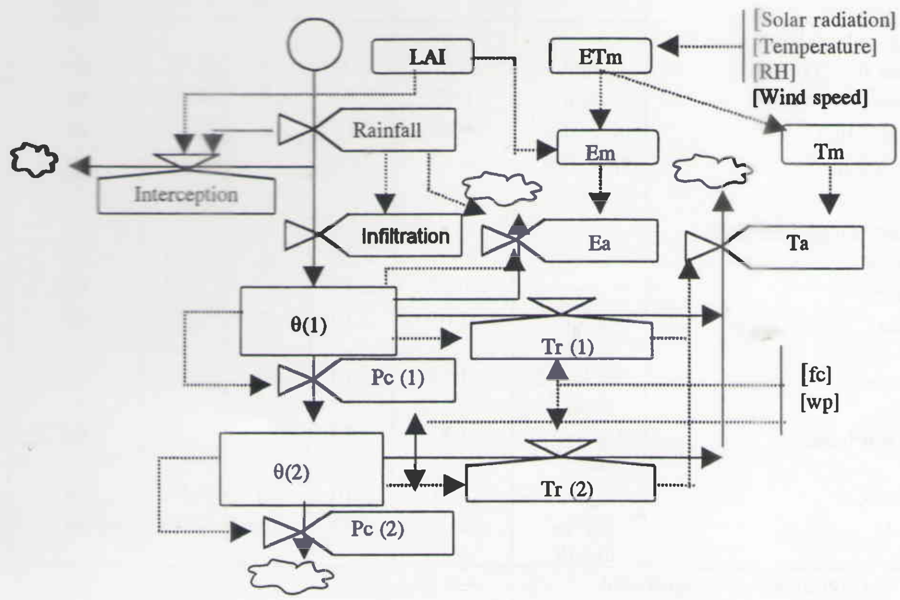
Appendix 1a. Forrester diagram of growth and phenology of oil palm



Notes :



Appendix 1b. Forrester diagram of water balance of oil palm



Appendix 2a. Value of parameters which used in the developed model

Submodel	Parameters	Symbol	Unit	Value
Growth and phenology	Heat unit for each leaf emission	Hue	Day °C	159.7
	Basic temperature	To	°C	15
	Light use efficiency	ε	Kg CH_2O MJ^{-1}	3.1 10^{-3}
	Assimilate partition	η	-	
	Leaf		-	0.64
	Stem		-	0.24
	Root		-	0.12
	Respiration maintenance	Km	-	0.005
Water balance	Rainfall interception	-	-	0.87
	Extinction coefficient	k	-	0.32
	Soil evapotranspiration			
	Phase I	U	Mm	11.1
	Phase II	β	mm $day^{-1.5}$	2.7

Appendix 2b. Testing result using t-test student at 95 and 99 % significant level

Variables	Units	t-calc.	t-table			
			t_005	Deff	t_001	Deff
Water balance submodel						
- Water content 0 – 100 cm	mm	0.53	2.04	ns	2.76	ns
- Water content 0 – 180 cm	mm	1.43	2.04	ns	2.76	ns
- Transpiration actual	mm day^{-1}	-0.48	2.12	ns	2.92	ns
- Evaporation actual	mm day^{-1}	-0.67	2.02	ns	2.70	ns
Growth and phenology submodel						
- Frond emission	-	-0.21	2.13	ns	2.94	ns
- Frond pruning	-	-0.27	2.13	ns	2.94	ns
- Growth of leaf	Kg ha^{-1} 2 $week^{-1}$	-2.63	2.10	*	2.89	ns
- Growth of stem	Kg ha^{-1} 2 $week^{-1}$	-1.23	2.10	ns	2.89	ns
- Growth of fruit bunch	Kg ha^{-1} 2 $week^{-1}$	-1.87	2.10	ns	2.89	ns
- Leaf area index	-	1.69	2.10	ns	2.89	ns
- Monthly yield	Kg ha^{-1} $month^{-1}$	-0.72	2.20	ns	3.10	ns

Notes : ns = non significant; * = significant

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