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APLIKASI MODEL NERACA AIR HARIAN AGROMETEOROLOGIS UNTUK MEMPREDIKSI LENGAS TANAH PADA PERTANAMAN KELAPA SAWIT

Iman Yani Harahap, Amir Purba, dan Z. Poeloengan

ABSTRAK

Untuk memprediksi keadaan lengas tanah berdasar aplikasi model neraca air pada pertanaman kelapa sawit, maka telah diuji suatu model neraca air harian agrometeorologis di plot percobaan pengujian klon No. BJ 26 S, Afdeling III, tahun tanam 1990, kebun Bah Jambi, Sumatera Utara. Masukan yang utama pada model tersebut adalah data unsur-unsur iklim harian berupa intensitas radiasi matahari (MJ/m/hari), suhu udata rerata (°C/hari), kelembaban relatif udara (%), curah hujan (mm/hari), dan kecepatan angin (m/detik). Di samping unsur-unsur iklim tersebut, model juga memerlukan parameter fisik tanah dan tanaman. Parameter fisik tanah yang diperlukan adalah parameter evaporasi α dan U, tebal lapisan tanah dan kadar air pada kapasitas lapangan dan titik layu permanen. Parameter tanaman yang diperlukan adalah koefisien penadaman (extinction coefficient). *Hasil pengujian menunjukkan model neraca air harian dapat dipakai untuk memprediksi lengas tanah spatial, baik menurut waktu maupun kedalaman. Keluaran model juga dapat menunjukkan variasi cadangan air harian, yang tidak dapat dilakukan oleh model Ochs-Daniel (neraca air bulanan).*

Kata kunci : *Elaeis guineensis* Jacq., neraca air, metode agrometeorologis

PENDAHULUAN

Pendugaan keadaan lengas tanah dan defisit air pada suatu periode pertumbuhan tanaman lazim dilakukan dengan menggunakan metode neraca air. Metode neraca air yang secara luas digunakan pada pertanaman kelapa sawit adalah metode Ochs-Daniel (5) yang efektif dalam menentukan defisit air bulanan, tetapi informasi tersebut belum memadai untuk mendukung analisis fisiologis dan aplikasi model tanaman, yang membutuhkan informasi mengenai kelengasan tanah dengan resolusi yang lebih tajam.

Penghitungan neraca air harian merupakan salah satu cara untuk mempertajam, resolusi tersebut. Penghitungan neraca air harian memerlukan data cuaca harian, parameter fisik tanah dan keadaan penutupan tajuk tanaman dan keluarannya berupa kadar air (lengas) tanah harian. Diharapkan informasi kelengasan tanah yang dihasilkan dari metode neraca air harian ini, dapat mendukung analisis fisiologis untuk pertumbuhan dan hasil tanaman kelapa sawit.

Tulisan ini bertujuan mendeduksi model neraca air harian, menetapkan parameter-parameter model, menguji model dan menerapkan perhitungan serta membandingkan dengan metode Ochs-Daniel.

BAHAN DAN METODE

Lokasi dan bahan tanaman

Penelitian dilakukan di kebun Bah Jambi, Afdeling III, plot percobaan No. BJ

Tabel 1. Beberapa sifat fisik tanah di lokasi penelitian
Table 1. Some of soil physical characteristics at study site

Kedalaman (cm) *Depth* (cm)	Bobot volume g/cm^3 *Bulk density* g/cm^3	Tekstur *Texture, %*			Kadar air *Water content, %*	
		Pasir *Sand*	Debu *Silt*	Liat *Clay*	pF 2,54	pF 4,2
0 - 20	1.23	71	11	18	14.69	23.62
20 - 60	1.24	67	8	25	14.21	24.3
60 - 100	1.39	63.5	8	28.5	15.25	24.3
100 - 140	1.40	67	8	25	15.75	23.98
140 - 180	1.44	73	10	17	14.0	23.21

26 S. Bahan tanaman yang digunakan adalah tanaman asal klon MK 60, tahun tanam 1990. Pengumpulan data dilakukan mulai April sampai Oktober 1996.

Lokasi penelitian memiliki jenis tanah berordo Ultisol, dengan beberapa sifat fisik tanah disajikan pada Tabel 1.

Wilayah penelitian termasuk beriklim basah sepanjang tahun, yang berkelas Af (Koppen), dengan curah hujan 2890 mm/tahun, radiasi matahari 5927 MJ/tahun, suhu rerata harian 24,7°C (1972 - 1994).

Pengukuran klimatologis

Data klimatologis diamati pada stasiun meteorologis khusus Balai Penelitian Marihat (2°59' LU, 9°13' BT, 369 dpl) yang berjarak 4 km dari lokasi penelitian. Data unsur cuaca yang digunakan tersebut adalah curah hujan (mm/hari), kecepatan angin (m/detik), lama penyinaran (jam/hari), kelembaban relatif udara harian (%) dan suhu udara harian (°C).

Radiasi gelombang pendek yang datang ke permukaan tanah (Qo, MJ/m) diukur secara tidak langsung melalui pengukuran lama penyinaran (n, jam/hari), mengikuti persamaan berikut :

$$Qo = 2\,(4,6 + 0,37\,n),\ R2 = 0,90\ ;\ df = 48 \ldots\ldots 1$$

Nilai evapotranspirasi potensial (ETp, mm/hari), dihitung dari data unsur cuaca tersebut mengikuti metode Penman.

Pengukuran evaporasi tanah

Pengukuran evaporasi tanah (Es, mm/hari), menggunakan mikrolisimeter yang terbuat dari pipa PVC yang berukuran diameter 0,08 m dan tinggi 0,12 m dengan dasar lisimeter ditutup dengan cawan petridish. Mikrolisimeter dibenam ke dalam lapisan permukaan tanah hingga meninggalkan sisa 0,5 cm dari mulut pipa bagian atas. Pengukuran dilakukan di bawah tajuk dan lokasi terbuka yang tidak ternaungi vegetasi.

Pengukuran intersepsi curah hujan oleh tajuk

Intersepsi tajuk (Ic, mm/hari), diukur berdasar selisih antara curah hujan yang sampai ke permukaan tanah (baik yang melalui tajuk maupun yang melalui aliran batang). Pengukuran di atas tajuk didekati dengan pengukuran curah hujan di lokasi yang terbuka yang dekat dengan plot percobaan (±100 m), sedang pengukuran curah hujan di bawah tajuk dilakukan pada beberapa titik secara sistematik yaitu 6 titik untuk curah hujan yang melalui batang dan 10 titik di antara pohon. Penampung curah hujan yang digunakan berupa tabung terbuat dari plat seng, yang berukuran diameter 11 cm dan dalam 40 cm.

Penghitungan intersepsi tajuk tersebut sebagai berikut:

$Ic = P - (Ps + Pf)$ 2

dimana :

P = curah hujan di atas tajuk

Ps = curah hujan yang melalui tajuk

Pf = curah hujan melalui batang.

Pengukuran kadar air tanah

Pengukuran kadar air tanah dilakukan pada 5 kedalaman, yaitu 0 - 20 cm, 60 - 100 cm, 100 - 140 cm, dan 140 - 180 cm. Kadar air diukur setiap 5 - 7 hari secara gravime-trik (% bobot). Kemudian kadar air yang ter ukur tersebut dikonversikan ke dalam satuan tebal air dengan persamaan sebagai berikut:

$\theta_i = \theta g_i \cdot BV_i \cdot d_i$ 3

dimana :

θg_i = kadar air gravimetrik pada lapisan ke-i (%)

BV_i = berat volume pada lapisan ke-i (g/cm)

d_i = tebal lapisan ke-i (mm).

Metode neraca air

Model neraca air tersusun dari komponen-komponen sebagai berikut: kadar air tanah (θ), infiltrasi curah hujan (Is), transpirasi tanaman (Tr), evaporasi tanah (Es) dan perkolasi (Pc).

Untuk lapisan permukaan tanah model neraca air dikemukakan sebagai berikut.

$\theta_{m(t)} = \theta_{m(t-1)} + Is_{m(t)} - Tr_{m(t)} - Es_{m(t)} - Pc_{m(t)}$ 4a

Untuk lapisan bawahan berlaku model sebagai berikut.

$\theta_{l(t)} = \theta_{l(t-1)} + Pc_{m(t)} - Tr_{l(t)}, \; l > m$ 4b

dimana

t = menunjukkan waktu harian

m dan l = menyatakan lapisan tanah

Intersepsi tajuk, infiltrasi, dan perkolasi

Curah hujan yang terintersepsi (Ic, mm/hari) hilang sebagai uap. Sisa curah hujan yang mencapai permukaan tanah akan berinfiltrasi ke dalam tanah (Is, mm/hari).

$Is = P - Ic$ 5

Air perkolasi (Pc, mm/hari) pada tiap lapisan zona perakaran akan terjadi apabila kadar air tanah pada lapisan tersebut melebihi kapasitas lapang (θ fc). Pc pada, tiap lapisan tersebut dihitung sebagai,

$Pc = \theta - \theta fc, \quad \theta > \theta fc$ 6

$Pc = 0, \quad \theta f \leq \theta fc$

Nilai θfc ditentukan berdasar kadar air pada pF = 2,7.

Evapotranspirasi

Evaporasi tanah

Evaporasi tanah terjadi pada lapisan permukaan tanah. Evaporasi tanah aktual (Es, mm/hari) dihitung melalui dua tahap (6). Tahap pertama evaporasi setelah terjadi hujan, yang besarnya sama dengan nilai evaporasi tanah maksimum (Em, mm/hari). Setelah nilai Em kumulatif mencapai nilai parameter tanah U, maka evaporasi tanah tahap kedua berlangsung. Pada tahap kedua ini Ea merupakan fungsi waktu pada tahap kedua (t2) ,dan Em.

Tahap-1 : $Ea = Em, \quad \Sigma Em < U$ 7a

Tahap-2 : $Ea = \alpha \, t2^{0.5} - \alpha \, (t2-1)^{0.5}, \; \Sigma Em \geq U$.....7b

Nilai parameter U dan α ditentukan sifat fisik tanah. Pada penelitian ini, nilai parameter tersebut didapat dari pengukuran evaporasi pada daerah terbuka.

Evaporasi tanah maksimum (Em) ditentukan berdasar hukum Beer, mengenai transmisi radiasi surya melalui tajuk tanaman, sehingga Em merupakan fungsi dari Evapotranspirasi potensial (ETp metode Penman)

$$Em = ETm\ (\exp(-k\ LAI)) \quad \ldots\ldots 8$$

ETm (evapotranspirasi maksimum) : 0,8 Etp

k adalah koefisien pemadaman, LAI adalah indeks luas daun.

$$Tm\ (mm/hari) = ETm - Em \quad \ldots\ldots 9$$

Nilai Tm ini digunakan untuk menghitung nilai transpirasi tanaman (Tr).

Transpirasi tanaman

Transpirasi aktual tanaman (Ta, mm/hari) dihitung sebagai jumlah air yang dapat diserap tanaman di seluruh wilayah perakaran (Tr, mm/hari), sehingga transpirasi aktual merupakan fungsi dari air yang tersedia untuk tanaman dan transpirasi maksimum tanaman (Tm) (3).

$$Tr = Tm\ f\theta \quad \ldots\ldots 10$$

f θ : faktor ketersediaan air

Faktor ketersediaan air (fθ), ditentukan dalam beberapa keadaan yaitu,

$$f = 1, \quad \theta \geq fc$$

$$f = 0, \quad \theta \leq \theta wp \quad \ldots\ldots 11$$

$$f = (\theta - \theta wp) / 0{,}4\ (\theta fc - wp), \quad \theta wp < 0 < \theta fc$$

dimana :

θ = kadar air tanah (mm)

fc = kadar air tanah pada kapasitas lapang (mm),

wp = kadar air tanah pada titik layu permanen (mm) (pF 4,2 (mm)

Validasi model dan metode Ochs-Daniel

Validasi model

Validasi model dilakukan dengan dua cara, yaitu pembandingan secara grafis dan uji t berpasangan antara pengukuran/pengamatan dan prediksi. Pembandingan grafis dapat menunjukkan pola plot tiap pasangan pengukuran/pengamatan terhadap garis 1:1. Keabsahan data ditunjukkan dengan mengumpulnya plot di sekitar garis 1:1, sedang teknik uji t berpasangan dilakukan sebagai berikut,

$$Di = pi - mi$$

$$D = \Sigma Di\ n^{-1} \quad \ldots\ldots 12$$

$$SE = \sqrt{\{[\Sigma Di^2 - (\Sigma D1)^2]\ n^{-1}\ [n(n-1)]^{-1}\}}$$

$$t = D\ SE^{-1}$$

dimana :

i = menunjukkan pengukuran/pengamatan individu

Di dan D = berturut-turut adalah perbedaan antara prediksi (p) dan pengukuran (m) individu dan rerata

SE = standar eror

t = nilai t-student.

Metode Ochs-Daniel

Penghitungan neraca air berdasar metode Ochs-Daniel dilakukan sebagai pembanding terhadap metode neraca air harian agrometeorologis. Metode Ochs-Daniel membutuhkan data masukan berupa curah hujan dan hari hujan bulanan.

$$KA_t = KA_{t-1} + CH_t - E_t \quad \ldots\ldots 13a$$

dimana :

KA_t = cadangan air pada akhir bulan ke t (mm/bulan)

KA_{t-1} = cadangan air pada akhir bulan ke-t-1 (mm/bulan)

CH_t = curah hujan pada bulan ke-t (mm/bulan)

E_t = evaporasi selama bulan ke-t (mm/bulan)

Nilai E_t ditentukan berdasar jumlah hari hujan (HH) dalam suatu bulan, yaitu

E_t = 150 mm, HH $<$ 10 ....13b
E_t = 120 mm, HH $\geq$ 10

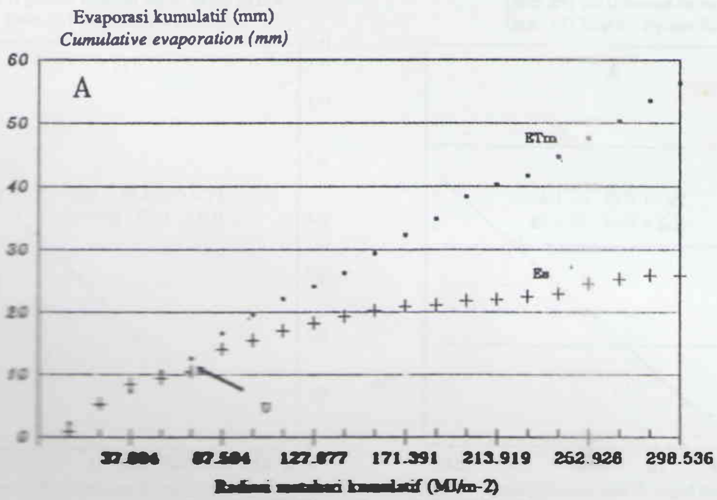
HASIL DAN PEMBAHASAN

Parameter evaporasi tanah

Hasil pengamatan evaporasi tanah pada areal yang terbuka dapat dilihat pada Gambar 1 berikut ini.

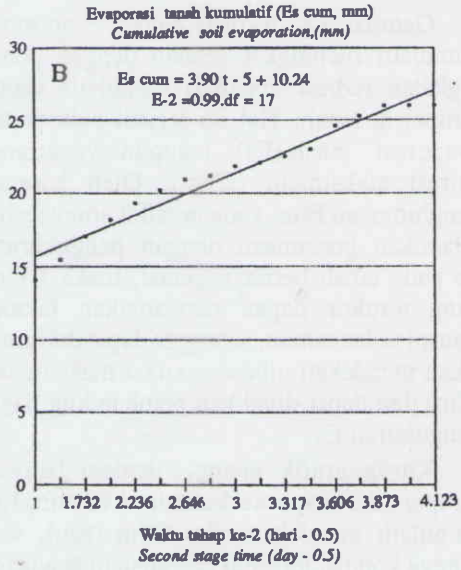
Gambar 1A, terlihat bahwa evaporasi kumulatif meningkat sejalan dengan peningkatan radiasi matahari kumulatif yang sampai di tanah. Hal itu terjadi baik pada evaporasi tanah (Es) maupun evapotranspirasi maksimum (ETm). Oleh karena penghitungan Etm, yang bersifat atmosferik dilakukan bersamaan dengan pengukuran Es pada tanah bebas vegetasi, maka ETm yang terukur dapat mengabaikan faktor transpirasi tanaman, sehingga dapat diasumsikan mendekati nilai evaporasi maksimum (Em) dan dapat dijadikan pembanding bagi pengukuran Es.

Kurva grafik memperlihatkan bahwa sampai nilai evaporasi kumulatif 10 mm, Es kumulatif mendekati nilai ETm (Em), sehingga kondisi tersebut merupakan keadaan evaporasi tanah tahap I teori Ritchie, seperti yang didefinisikan pada Persamaan 7a. Setelah evaporasi kumulatif mencapai nilai 10 mm, maka peningkatan Es dan ETm kumulatif sudah memperlihatkan perbedaan



Gambar 1A. Hubungan antara evaporasi dan radiasi matahari kumulatif pada permukaan tanah terbuka.

Figure 1 A. Relationship between cumulative evaporation and solar radiation on opened land.



Gambar 1B. Evaporasi kumulatif selama waktu tahap kedua pada tanah terbuka

Figure 1B. Cumulative evaporation during second stage time on opened land

yang mencolok dengan meningkatnya radiasi matahari kumulatif yang diterima permukaan tanah. Pada keadaan tersebut, evaporasi tanah telah memasuki tahap II, seperti yang didefinisikan pada Persamaan 7b.

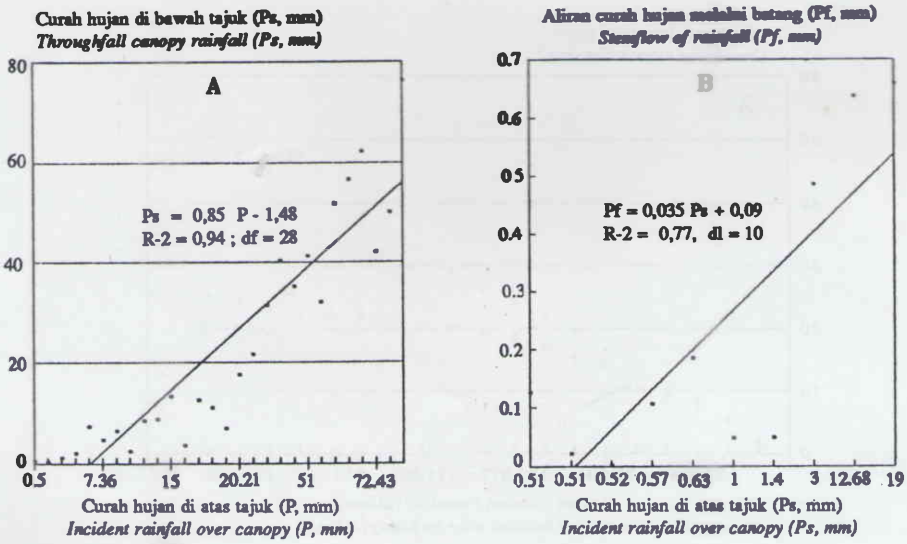
Nilai U dan (dapat diperoleh melalui regresi antara waktu tahap II (t2) dan Es kumulatif, seperti ditunjukkan oleh persamaan :

$\Sigma Es = \alpha \, t2^{0,5} + U$ 14

Hasil teknik regresi mendapatkan nilai (α= 3,9 dan U = 10,2 seperti yang terlihat pada Gambar 1B.

Intersepsi curah hujan

Hasil pengamatan intersepsi curah hujan disajikan pada Gambar 2A dan 2B. Gambar 2A dan 2B memperlihatkan bahwa hanya sekitar 83 % curah hujan yang



Gambar 2. Hubungan antara curah hujan di atas tajuk dengan yang melalui tajuk (A) dan yang melalui batang (B).

Figure 2. Relationship between rainfall falling through canopy (A) and through stem (B).

sampai ke permukaan tanah, yaitu yang melalui tajuk 80 % (Gambar 2A) dan melalui batang 3 % (Gambar 2B). Sedang sekitar 17 % tertahan di tajuk, yang kemudian hilang teruapkan ke atmosfir. Nilai ini diukur pada kondisi tajuk memiliki indeks luas daun (LAI) 4. Hasil pengamatan ini hampir sama dengan yang dilaporkan Squire (7) dan Dufrene *et al.* (2), yaitu berturut-turut 86 % dan 88 % curah hujan yang sampai ke permukaan tanah pada LAI antara 4 sampai 5.

Persamaan regresi pada Gambar 2A, memperlihatkan bahwa curah hujan di bawah 2 mm tidak akan mencapai permukaan tanah, karena keseluruhannya diintersepsi tajuk.

Kadar air tanah

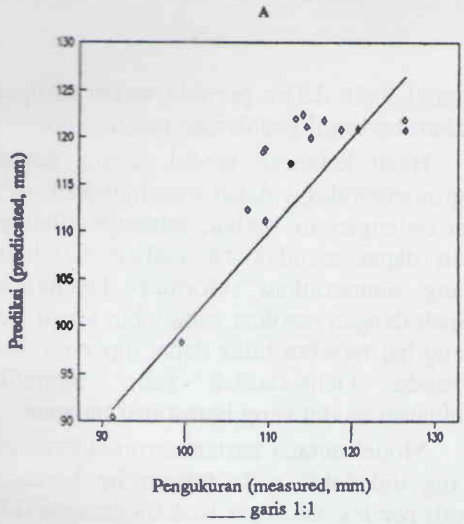
Keabsahan model ditunjukkan dengan nilai t untuk beberapa kedalaman (0,98 - -1,4; x = 0,17, yang semuanya tidak berbeda nyata.

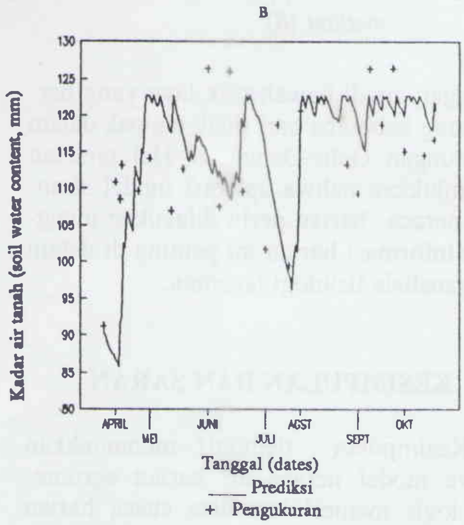
Pada Gambar 3A dapat dilihat jelas keabsahan model dimana seluruh titik pengumpul di sepanjang garis 1 : 1. Gambar 3B menunjukkan prediksi dan nilai kadar air rerata dari April sampai Oktober 1996 juga menunjukkan keabsahan model untuk memprediksi kadar air tanah.

Aplikasi model simulasi

Model simulasi dibangun dengan menggunakan data iklim 1995 Balai Penelitian Marihat. Kemampuannya untuk memprediksi dibandingkan dengan perhitungan menggunakan metode Och-Daniel untuk penghitungan defisit air (Gambar 4B).

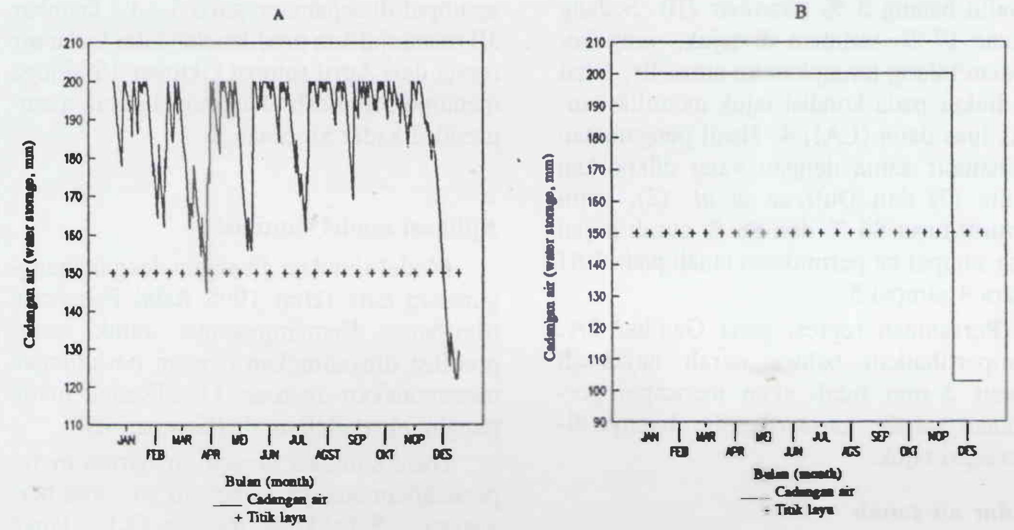
Hasil simulasi neraca air harian memperlihatkan adanya cadangan air yang bervariasi. Sebaliknya metode Ochs-Daniel yang menggunakan data bulanan tidak dapat mengidentifikasi adanya variasi cadangan air, bahkan hasil perhitungan neraca air harian pada April memperlihatkan adanya





Gambar 3. Pembandingan prediksi dan pengukuran kadar air rerata terhadap garis 1:1 (A) dan nilai prediksi dan pengukuran selama pengamatan April-Oktober 1996 (B).

Figure 3. *Comparison between predicted and measured average soil water content values on line 1:1 (A) and the values during April- October 1996 observations (B).*



Gambar 4. Hasil penghitungan cadangan air berdasar model neraca air harian (A) dan metode Ochs-Daniel (B).

Figure 4. Water supply calculation results of daily water balance model (A) and Ochs-Daniel method (B) .

cadangan air di bawah titik layu yang berlangsung beberapa hari tidak tampak dalam perhitungan Ochs-Daniel. Hal tersebut menunjukkan bahwa aplikasi model simulasi neraca harian perlu dilakukan mengingat informasi harian ini penting di dalam menganalisis fisiologi tanaman.

KESIMPULAN DAN SARAN

Kesimpulan deduktif menunjukkan bahwa model neraca air harian agrometeorologis memerlukan data cuaca harian parameter fisik tanah dan keadaan penutupan tajuk (indeks luas daun).

Model neraca harian agrometeorologis valid untuk memprediksi lengas tanah secara spatial, baik dalam periode waktu maupun dalam berbagai kedalaman tanah.

Hasil keluaran model neraca harian agrometeorologis dapat menunjukkan variasi cadangan air harian, sehingga diharapkan dapat mendukung analisis fisiologis yang memerlukan informasi kelengasan tanah dengan resolusi yang lebih tajam, sedang hal tersebut tidak dapat dipenuhi oleh metode Ochs-Daniel yang memiliki keluaran model yang beresolusi bulanan.

Model neraca harian agrometeorologis yang dideduksi pada tulisan ini berdasar pada pendekatan aspek fisik lingkungan (klimatologis), terutama pada perhitungan evapotranspirasi, sehingga aspek atau parameter fisiologis masih kurang dipertimbangkan. Untuk meningkatkan keabsahan model maka aspek fisiologis terutama sifat-sifat stomata konduktans perlu disertakan dalam deduksi model, seperti model-model yang dikembangkan oleh Penman-van Bavel (4, 2, 3)

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Application of daily agrometeorological water balance model to predict soil moisture in oil palm plantation

I. Yani Harahap, Amir Purba, and Z. Poeloengan

Abstract

To predict soil misture condition based on the application of water balance model in oil Div. palm plantation, a particular model of it was tested at clone experimental plot No. BJ 26 S, III, planting year 1990, Bah Jambi estate, North Sumatra. Main inputs of the model were the elements of the climatic data, i.e. daily solar radiation (MJ/m²) , air temperature (°C), relative humidity (%), rainfall (mm/day), and wind speed (m/s). Besides , the model also required soil and plant physical parameters. The soil physical parameters were U and α . depth of soil and soil water content at field capacity and wilting point. Plant parameter requiried was extinction coefficient. The results show that the model was acceptable to predict spatial soil water content, either in time or in depth of soil as well. The output of the model could identify variation of daily water reserve which could not be done by Ochs-Daniel method (monthly water balance).

Key words : *Elaeis guineensis* Jacq., water balance, agrometeorological method

Introduction

Estimation of soil moisture condition and water deficit during plant growth period was usually done using water balance method. The widely water balance method used in oil palm plantation is that of Ochs-Daniel (5). It is effective to determine monthly water deficit, but the information is not sufficient to support physiological analysis and crop modelling application, which require more detailed information on soil moisture condition.

Calculation of daily water balance is one method to increase the resolution of information. Daily water balance calculation requires daily climatic data, soil physical parameters, and situation of plant canopy covering and its output as daily soil moisture content. It is expected that the soil moisture information produced as a result of daily water balance method can support plant growth physiological analysis and oil palm yield.

The aim of this paper is to deduct daily water balance model, to determine its parameters of the model, to test the model, to apply the calculation, and to compare to Ochs-Daniel method.

Materials and Methods

Location and plant material

The experiment was conducted at the breeding program plot No. BJ 26 S, Div. III, Bah Jambi estate, North Sumatra. Plant material used was MK 60 clone, planting year 1990. Collecting data was done since April till October 1996.

Some physical characteristics of the ultisol soil of the experimental plot are showed in Table 1. It has wet climate over the year with Af Koppen typical climate, annual rainfall 2890 mm, annual solar radiation 5927 MJ, and daily air temprature rate 24.7 °C (1972-1994).

Climatology measurement

Climatological data were collected from meteorology station at Marihat Research Station (2°59'N, 9°13' E, altitude 369) that was 4 km away from experimental location. The data used were rainfall (mm/day), wind speed (m/s), sunshine (hour/day), relative humidity (%), and daily air temperature (°C). Short wave radiation (Qo, MJ/m) was measured indirectly through sunshine(n, hour/day) :

$$Qo = 2\,(4.6 + 0.37\,n),\ R^2 = 0.90\ ;\ df = 48 \qquad \text{......1}$$

Based on daily climatic data, potential evapotranspiration (ETp, mm/day) was calculated according to Penman method.

Soil evaporation measurement

Soil evaporation measurement (Es, mm/day), was done using microlysimeter made from PVC pipe with diameter 0.08 m, height 0.12 m the bottom covered with petridish. Microlysimeter which was placed under soil surface till 0.5 cm of its top pipe edge was left above ground. Measurement was taken under canopy and at open location without vegetation shade.

Measurement of rainfall interception measurement by the canopy

Canopy interception (Ic, mm/day), was measured based on the difference between rainfall reaching soil surface (either through the canopy or flowing around the stem). Measurement at the canopy was done by measuring at the open location close to the experimental plot (about 100 m), while measurement of rainfall under canopy were taken at several systematical points i.e. 6 points for stemflow and 10 points are placed among the trees. The rain gauge was made from plat zinc cylinder with diameter 11 cm and 40 cm long. Canopy interception was calculating using.

$$Ic = P - (Ps + Pf) \qquad \text{.............................. 2}$$

where :

P = rainfall on upper canopy
Ps = rainfall through canopy
Pf = rainfall through stemflow

Soil water content measurement

Soil water content was measured at 5 depths, i.e. 0 - 20 cm, 20 - 60 cm, 60 - 100 cm, 100 - 140 cm, and 140 - 180 cm. Gravimetrical measurement of water content (% of weight) was done every 5 - 7 days. Then that value was converted to water thickness unit with the following equation :

$$\theta_i = \theta g_i .. BV_i \ . \ d_i \ \ldots\ldots 3$$

where :

θg_i = gravimetrical measurement at layer i (%)
BV_i = bulk density at layer i (g/cm)
d_i = thick layer i (mm).

Water balance method

Water balance model consists of the following components, i.e.soil water content ((), rainfall infiltration (Is), transpiration (Tr), soil evaporation (Es), and percolation (Pc).

The surface water balance is expressed as follows:

$$\theta_{m(t)} = \theta_{m(t-1)} + Is_{m(t)} - Tr_{m(t)} - Es_{m(t)} - Pc_{m(t)} \ \ldots\ldots 4a$$

and for sublayer as follows,

$$\theta_{l(t)} = \theta_{l(t-1)} + Pc_{m(t)} - Tr_{l(t)} \ , \quad 1 > m \ \ldots\ldots 4b$$

where :
t = daily time
m, l = soil layer

Canopy interception, infiltration and percolation

Intercepted rainfall (Ic, mm/day) will be lost as vapor and the rest reaching soil surface will be infiltrated into the soil (Is, mm/day).

$$Is = P - Ic \ \ldots\ldots 5$$

Water percolation (Pc, mm/day) at every layer of rooting zone will take place if soil water content at the particular layer is more than the field capacity (θfc). Pc at every layer is calculated as

$$Pc = \theta - \theta fc, \quad \theta > \theta fc \ \ldots\ldots 6$$
$$Pc = 0, \quad \theta f \leq \theta fc$$

θfc is determined based on the soil water content at pF = 2.7

Evapotranspiration

Soil evaporation

Soil evaporation occurrs at soil surface. Actual soil evaporation (Es, mm/day) is calculated through 2 steps(Equation 6). First, evaporation after raining which is equal to maximum soil evaporation value (Em, mm/day). After cummulative Em equals soil U, then second step soil evaporation occurrs. On the second step, Ea is time function at the second step (t2) and Em.

$$\text{Phase-1 : } Ea = Em, \quad \Sigma Em > U \ \ldots\ldots 7a$$
$$\text{Phase-2 : } Ea = \alpha \ t2^{0.5} - \alpha \ (t2-1)^{0.5}, \ \Sigma Em \geq U \ \ldots\ldots 7b$$

Values of U and α are determined by soil physical properties. In this experiment, their values were taken from the measurement of evaporation at open location.

Maximum soil evaporation (Em) is determined based on Beer's law i.e. transmission of solar radiation through canopy, therefore Em is a function of potential evapotranspiration (ETp, Penman method).

$$Em = ETm \ (\exp(-k \ LAI)) \ \ldots\ldots 8$$

ETm (maximum evapotranspiration) : 0.8 ETp
(k = extinction coefficient, LAI = leaf area index)

$$Tm \ (mm/day) = ETm - Em \ \ldots\ldots 9$$

Tm was used to calculate plant transpiration (Tr).

Plant Transpiration

Actual plant transpiration (Ta, mm/day) is calculated as the quantity of water which can be absorbed by a crop at whole root zone (Tr, mm/day), therefore actual transpiration is a function of water available and maximum transpiration (Tm) (Equation 3).

$Tr = Tm\ f\theta$ 10

$f\theta$: water availability factor

$f\theta$ is determined in several conditions, i.e.

$f = 1, \quad \theta \geq fc$

$f = 0, \quad \theta \leq \theta wp$ 11

$f = (\theta - \theta wp) / 0.4\ (\theta fc - wp), \quad \theta wp < 0 < \theta fc$

where :

θ = soil water content (mm)

fc = soil water content at field capacity (mm).

wp = soil water content at permanent wilting point (mm) (pF 4.2 (mm)

Model validation and Ochs-Daniel method

Model validation

Model validation is done in 2 ways, i.e. graphical comparison and paired t-test between measurement and prediction. Graphical comparation could show plot pattern at every paired value (measurement-prediction) on 1:1 line. Validity is shown by the concentration of points around 1 : 1 line, while paired t-test technique is done by

$Di = pi - mi$

$D = \Sigma Di\ n^{-1}$ 12

$SE = \sqrt{\{[\Sigma Di^2 - (\Sigma D1)^2]\ n^{-1}\ [n(n-1)]^{-1}\}}$

$t = D\ SE^{-1}$

where :

i = individual measurement

Di dan D = the difference between prediction (p) and measurement (m) individual and mean value respectively

SE = standard eror

t = t-student value.

Ochs-Daniel method

Water balance calculation based on Ochs-Daniel method is used as a comparison to daily agrometeorology water balance. Ochs-Daniel method requires input data, such as rainfall and monthly rainy day.

$KA_t = KA_{t-1} + CH_t - E_t$ 13a

where :

KA_t = a water reserve at the end of month t (mm/month)

KA_{t-1} = a water reserve at the end of month t-1 (mm/month)

CH_t = rainfall at month t (mm/month)

E_t = evaporation during month t period (mm/ month)

E_t is determined based on total of rainy day in certain month (HH), i.e.

$E_t = 150$ mm, $\quad HH < 10$ 13b

$E_t = 120$ mm, $\quad HH \geq 10$

Results and Discussion

Soil evaporation parameter

Soil evaporation observasion results at open location is shown in Figure 1. From Figure 1 A, shows that cumulative evaporation increased with the increasing cumulative solar radiation reaching soil surface. It occurred either in soil evaporation (Es) or in maximum evapotranspiration (Etm). Because ETm (i.e. atmospheric calculation) and Es measurement at open location were taken at the same time, ETm value measured could therefore neglect crop transpiration factor so it could be assumed that the value approached Em which finally could be used as comparison for Es.

The curve showed that upto the value of cumulative evaporation reached 10 mm, cumulative Es approached ETm (Em), so that the condition was similar to the phase I soil evaporation (Richie teory), as defined in Equation 7a. After that value (10 mm), then increasing Es and ETm cumulative showed sharp difference with the increase in cumulative solar radiation received by soil surface. In that circumstance, soil evaporation was in phase II as defined in Equation 7b.

U and α could be found through regression between time in phase II (t2) and the cumulative Es as shown by the Equation

$$\Sigma Es = \alpha\, t2^{0.5} + U \quad \text{.................................14}$$

The values of $\alpha = 3.9$ and $U = 10.2$ are seen in Figure 1 B.

Rainfall interception

Rainfall interception result as shown in Figures 2A and 2B which show that only 83% of the rainfall reached soil surface i.e. 80 % through canopy (Figure 2A) and 3% through stemflow (Figure 2B) while 17% was intercepted by the canopy, which later evaporated to the atmosphere. All of these values were measured when the leaf area index (LAI) of the canopy was 4. These observations are nearly same as reported by Squire (7) and Dufrene *et al.* (2) i.e. 86 % and 88% of the rainfall reached soil surface respectively when LAI 4 - 5.

Regression equation in Figure 2A, shows that when rainfall was below 2 mm, it never reached soil surface, because it was intercepted by the canopy.

Soil water content

T values of different depths (0.98 - 1.49; x = 0.17) were all not significant, indicating the validity of the model. The validity was more clearly shown in Figure 3A, where all points concentrated along the line 1 : 1. Figure 3B which showed the predicted and measured average water contents from April to October 1996 also confirmed the model validity to predict soil water content.

Simulation model application

Simulation model was constructed using 1995 climatic data Marihat Experimental Station (Figure 4B). Its ability to predict was compared the calculation using Ochs-Daniel method of monthly water deficit calculation (Figure 4B).

Results of simulated daily water balance showed that water reserve varied. On the other hand Ochs-Daniel method using monthly data was not be able to detect any variation in water reserve, even daily water balance calculation in April which showed water reserve below wilting point in several days was not detached by Ochs-Daniel Method. This showed that simulation model application of daily balance need to be done because this daily information is important in analyzing plant physiology

Conclusion and Suggestion

Deductive conclusion indicates that daily agrometeorological water balance model required data of daily climate, soil physical parameters, and canopy shading (leaf area index).

The model is valid to predict spatially soil water content either in time period or in soil depth.

The output of model could identify variation of daily water reserve, therefore, it is expected to support physiological analysis which requires higher resolution of soil moisture information, while that requirement cannot be obtained with Ochs-Daniel method.

Daily agrometeorological water balance model deducted in this paper was based on the environmental physical aspect approach (climatological), especially on evapotrnspiration calculation, so physiological aspect is not well considered.

To increase the validity of model, physiological aspect, especially conductant stomatal properties should be included in model deduction.

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