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PENDUGAAN LAJU RESPIRASI DAN *TURNOVER* AKAR KELAPA SAWIT TIPE TENERA ASAL SEMAIAN

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ABSTRAK

Kelangkaan data fisiologi karbon terutama laju respirasi dan turnover *akar kelapa sawit bisa menjadi kendala bagi pengembangan model simulasi pertumbuhan dan hasil secara luas. Salah satu metode penentuan besarnya kedua proses tersebut adalah dengan menganalisis aliran karbondioksida (CO_2) dari sistem tanah atau lazim disebut respirasi tanah. Dengan memadukan teknik pengukuran di lapangan dan di laboratorium dapat diperkirakan laju respirasi akar. Kemudian, dengan model neraca ekosistem karbon diduga jumlah alokasi karbon untuk* turnover *akar. Percobaan disusun dalam rancangan acak kelompok dua faktor: bahan tanaman (2 taraf) dan letak pengukuran (4 taraf). Bahan tanaman yang digunakan berumur 9 tahun sesudah tanam. Hasil percobaan menunjukkan bahwa peubah respirasi tanah dan respirasi akar berbeda nyata hanya menurut perbedaan letak pengukuran. Pada tanggal pengamatan tertentu ditemukan hubungan linier positif dan nyata antara suhu tanah dan respirasi tanah. Ada kecenderungan laju respirasi akar tanaman DxP La Me lebih tinggi daripada Bah Jambi. Karbon total yang dikeluarkan dari permukaan tanah diduga antara 49,1 - 50,8 ton CO_2. ha^{-1} th^{-1}, dengan proporsi untuk respirasi dan* turnover *akar berturut-turut 0,60 - 0,90 dan 0,01 - 0,27.*

Kata kunci : *Elaeis guineensis*, respirasi akar, *turnover*, respirasi tanah

PENDAHULUAN

Pengembangan model simulasi pertumbuhan dan hasil kelapa sawit (3, 7, dan 11) akan dibatasi oleh kurang tersedianya data fisiologi karbon terutama laju respirasi dan *turnover* akar. Sejauh ini, produksi karbon akar kelapa sawit diasumsikan sebagai proporsi dari produksi bahan kering total. Misalnya, di Malaysia dan Papua New Guinea ditetapkan sekitar 10% (1). Angka tersebut jauh berbeda dengan laporan studi di *Ivory Coast* - Afrika yaitu sebesar 50% (2). Kedua data tersebut mengimplikasikan bahwa pertumbuhan akar sangat dipengaruhi oleh keragaman zona agroklimat. Sementara itu, penentuan besarnya respirasi akar untuk keperluan modeling pertama kali dilakukan dengan menggunakan koefisien yang dibuat berdasarkan kandungan hara jaringan (1, 3).

Perkembangan teknologi analiser gas infra merah (IRGA) dan kemampuan memodifikasi suatu *chamber* akhir-akhir ini memungkinkan untuk mendeteksi dan menganalisis aliran CO_2 dari tanah atau respirasi tanah. Lamade *et al.* (10) berhasil mengembangkan suatu pendekatan yang memadukan teknik pengukuran lapangan dan laboratorium untuk memilah dua sumber CO_2 utama dari tanah. Dengan menerapkan model neraca ekosistem karbon yang diajukan oleh Raich dan Nadelhoffer (18) dapat ditentukan besarnya alokasi karbon untuk respirasi dan *turnover* akar. Pendekatan tersebut relatif lebih baik dari segi memperoleh data yang seketika daripada teknik perangkap CO_2 tanah

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dengan *sponges* yang dilumuri larutan KOH seperti yang dilakukan oleh Henson (5). Lebih jauh dinyatakan bahwa teknik perangkap KOH cenderung memberikan nilai dugaan aliran CO_2 yang lebih tinggi daripada teknik IRGA (15).

Respirasi tanah menjelaskan tentang CO_2 total yang dihasilkan oleh seluruh fungsi metabolik tanah. Respirasi tanah meliputi beberapa proses biologis yaitu aktivitas respirasi akar (autotrof) dan respirasi mikroorganisme tanah (heterotrof) terutama yang terlibat mineralisasi bahan organik. Oleh karena itu respirasi tanah biasanya digunakan sebagai indeks aktivitas biologis (kesuburan) tanah yang sekaligus memberikan informasi yang tepat mengenai dinamika sistem akar.

Tujuan dari penulisan ini adalah untuk memaparkan hasil analisis percobaan respirasi tanah pada areal tanaman kelapa sawit tipe tenera (DxP) asal semaian dari dua orijin yang berbeda dan dikombinasi dengan empat letak pengukuran yang berbeda (variasi spasial). Selanjutnya, besarnya perkiraan respirasi dan *turnover* akar tahunan serta faktor-faktor yang mungkin membedakan angka peubah juga diuraikan dalam tulisan ini.

BAHAN DAN METODE

Tempat dan bahan tanaman

Penelitian dilakukan di kebun Marihat, PT. Perkebunan Nusantara IV, Sumatera Utara di petak percobaan pemuliaan dan genetika. Bahan tanaman yang digunakan dua famili DxP asal semaian orijin La Me (DA 18 D self x LM 7 T *self*) dan Bah Jambi (BJ 13 D self x BJ 21 P) umur 9 tahun sesudah tanam. Kerapatan tanam sekitar 130 pohon ha^{-1}. Iklim kebun dicirikan berdasarkan pengamatan di stasiun SPMK Marihat (02°55' LU, 99°05' BT, 369 m dpl.). Dalam periode pengamatan dua dekade terakhir ditunjukkan bahwa curah hujan sangat basah (rata-rata di atas 2.750 mm per tahun). Berdasarkan perhitungan keseimbangan air bulanan (17), pada areal tersebut tidak terjadi defisit air dan ditemukan kelebihan air (drainase) tahunan sekitar 1.400 mm. Komponen iklim lainnya diuraikan secara rinci oleh Lamade *et al.* (9); Lamade dan Setiyo (11).

Jenis tanah adalah *Typic Dystropept* (podsolik coklat kekuningan), dengan lapisan atas (0-40 cm) bertekstur lempung berpasir, struktur remah dan konsistensi sangat gembur, sedang lapisan bawah bertekstur lempung liat berpasir, gumpal dan gembur dengan drainase yang baik. Eksponen hidrogen (pH H_2O) antara 5,31 dan 5,51 (dari kedalaman 0-80 cm). Kandungan nitrogen dan bahan organik sangat tinggi dengan nisbah C/N berselang 9,54-10,71. Kapasitas tukar kation termasuk sedang (7,7 - 10,9) (14, 20).

Teknik pengukuran

Aliran CO_2 dari tanah diukur secara langsung *in situ* di lapang (8). Teknik pengukurannya menggunakan sistem semi tertutup dengan analiser gas infra merah (*Analytical Development Co.*, Hoddesdon, Herts, UK) dan ruang silinder yang dimodifikasi. Selama pengukuran berlangsung, udara yang dipompakan oleh analiser tidak dimasukkan kembali dalam sirkuit. *Chamber* silinder dibuat dari metal berdiameter 40 cm dan tinggi 50 cm. *Chamber* dapat dipindahkan dan dimampatkan pada pendukung 15 cm dan ditekan ke dalam tanah sehingga kedap udara. Silinder dihubungkan ke analiser portabel melalui pipa karet butil diameter 3 mm dengan spesifikasi

yang tepat. Di dalam silinder disusun dua kipas (Micronel, 80 mm, 12 V) untuk menjamin homogenisasi udara secara efektif, dan satu termistor (Sagimeca, 10K3 A1), yang dihubungkan ke multimeter (Fluke 70 II), untuk mengukur suhu udara ruang. Dua termometer standar dimasukkan ke dalam tanah di bawah *chamber* untuk mengukur suhu tanah. Sebelum analisis, contoh udara dikeringkan menggunakan pengering magnesium perklorat guna melindungi batas kekeringan analiser dari interferensi uap air dengan CO_2 selama pengukuran (13). Contoh pertama diambil saat penepatan silinder terhadap pendukungnya dan diperlakukan sebagai referensi. Dua contoh berikutnya ditentukan setiap lima menit secara berurutan.

Pengukuran CO_2 di laboratorium dimaksudkan untuk menduga bagian respirasi akar dalam aliran total yang diukur. Prosedur kerjanya diuraikan dalam Lamade (8), yaitu contoh tanah diambil dari dasar tempat peletakan *chamber*. Sesudah membuang akar dengan ekstraksi kering, contoh tanah diinkubasi dengan kadar air yang meningkat hingga ke kapasitas lapang. Perubahan CO_2 diukur dari dua contoh udara yang masing-masing diambil setiap setengah jam berurutan per ulangan. Respirasi bagian akar kemudian diperkirakan dari perbedaan antara pengukuran yang dilakukan *in situ* dan yang diambil di laboratorium pada tanah bebas akar.

Satuan percobaan merupakan kombinasi antara orijin bahan tanaman dan letak pengukuran. Lokasi pengukuran tersebut : (i) di dekat dasar batang (*T*), (ii) di jalan panen (*HP*), (iii) di bawah tumpukan pelepah (*FP*) dan (iv) di baris tengah gawangan mati (*IR*). Secara umum diketahui bahwa keempat lokasi tersebut mengimplikasikan perbedaan kepadatan akar dan bahan organik tanah. Dari letak pengamatan tersebut dimungkinkan untuk mendapatkan variasi ruang. Pada tiap tempat pengukuran diambil sekurang-kurangnya lima kali penyesuaian mengikuti jam pengamatan per individu pohon. Dalam perhitungan respirasi digunakan persamaan konvensional untuk pengukuran sirkuit tertutup (13). Data dianalisis secara statistik mengikuti rancangan acak kelompok faktorial (16, 19).

Pendugaan jumlah karbon yang dialokasikan ke akar.

Pendugaan jumlah karbon mengikuti prinsip perhitungan yang diuraikan oleh Raich dan Nadelhoffer (18). Dengan asumsi jumlah karbon total yang dikembalikan ke tanah oleh residu tanaman, baik dari bagian atas tanah (Pa) dan bagian bawah tanah (Pb) akan sama dengan jumlah karbon tanah yang dimineralisasi oleh respirasi heterotrof. Kemudian, bila Rs menerangkan aliran CO_2 total dari tanah dan Rr respirasi akar, maka :

$$Rs = Pa+Pb+Rr \quad \ldots\ldots (1)$$

Dalam hal ini Pb+Rr menjelaskan alokasi seluruh karbon kepada sistem akar. Dalam penerapan metode pendugaan tersebut disusun beberapa asumsi sebagai berikut : (i) masukan karbon ke dalam tanah hanya berasal dari bahan buangan pelepah daun dan akar, (ii) hanya anak daun yang dianggap berkontribusi terhadap bahan organik tanah, sedang bagian pelepah lainnya terdekomposisi di permukaan, (iii) pengaruh interaksi antara aktifitas mikroba dan pasokan karbon, misalnya dengan bahan buangan, terhadap dekomposisi bahan organik tanah (*priming effect*) tidak dipertimbangkan. Untuk asumsi metode lainnya, disajikan dalam Lamade *et al.* (10).

HASIL DAN PEMBAHASAN

Respirasi tanah total *in situ*

Karena secara umum diketahui bahwa laju respirasi dipengaruhi oleh perubahan suhu (10), maka semua data respirasi dikoreksi terhadap suhu. Interaksi antara bahan tanaman x letak pengukuran selama percobaan tidak berpengaruh nyata terhadap respirasi tanah. Rerata laju respirasi tanah hasil sidik peragam disajikan pada Tabel 1. Kisaran besarnya respirasi sebanding dengan hasil laporan sebelumnya (6, 10). Analisis statistik menunjukkan bahwa hanya letak pengukuran yang berpengaruh sangat nyata ($p = 0{,}001$) terhadap respirasi tanah. Laju respirasi tanah dari yang tinggi ke yang rendah berturut-turut ditemukan di bawah tumpukan pelepah (FP), dekat dasar batang (T), gawangan mati (IR) dan jalan panen (IP). Kecenderungan laju respirasi tanah yang lebih tinggi di tumpukan pelepah daun bisa disebabkan tingginya akumulasi bahan organik yang membuat kondisi tumbuh lebih sesuai dan kerapatan akar lebih tinggi. Hasil tersebut konsisten dengan laporan sebelumnya (6, 10). Sementara itu, laju terendah yang ditemukan di jalan panen berbeda dengan yang dinyatakan Henson (5) yang menunjukkan nilai terendah terdapat di gawangan mati. Perbedaan tersebut mungkin disebabkan oleh perbedaan cara pengambilan contoh dan tingkat kepadatan tanah di areal kebun.

Tabel 1. Rerata respirasi tanah total (Rs), respirasi tanah tanpa akar (Rm), respirasi akar (Rr) dan suhu tanah (Ts)

	Rs*)	Rm*)	Rr*)	Ts
		μmol $CO_2.m^{-2}.s^{-1}$		°C
Ulangan				
1	2,92	0,82	2,30	27,16 c
2	3,74	0,88	2,81	28,86 a
3	3,57	0,90	2,61	29,06 a
4	3,78	0,85	2,78	27,94 b
5	3,76	0,96	2,86	27,80 b
Orijin				
Bah Jambi	3,53	1,01	2,15	27,73 b
La Me	3,58	0,76	3,20	28,60 a
Lokasi				
T	4,08 ab	0,84	3,23 ab	28,04
IP	2,02 c	0,81	1,24 c	28,03
FP	4,67 a	0,88	3,71 a	28,23
IR	3,44 b	1,00	2,52 b	28,34

Keterangan: *) Angka dikoreksi terhadap suhu; angka pada kolom sama yang diikuti huruf berbeda diuji lanjut dengan BNT taraf α=0,05

Respirasi tanah tanpa akar (respirasi mikrobia)

Hasil sidik peragam interaksi antara orijin bahan tanaman x lokasi pengukuran terhadap respirasi tanah tanpa akar di laboratorium juga menunjukkan perbedaan yang tidak nyata. Selanjutnya, hasil sidik peragam peubah tersebut, dengan kovariat suhu, juga menunjukkan perbedaan yang tidak nyata untuk semua faktor perlakuan tunggal. Walaupun demikian, respirasi tanah tanpa-akar (respirasi mikrobia) pada DxP orijin Bah Jambi cenderung lebih tinggi daripada La Me, dengan proporsi bahan tanaman Bah Jambi terhadap La Me sekitar 1,33. Bila diperhatikan bahwa

proporsi biomassa tegakan akar DxP Bah Jambi terhadap La Me sebesar 0,69 (11), maka dapat dinyatakan bahwa biomassa tegakan akar berkorelasi negatif dengan respirasi mikrobia. Rerata respirasi tanah tanpa akar yang sudah dikoreksi disajikan pada Tabel 1. Dengan menggunakan model neraca karbon ekosistem, bagian respirasi mikrobia sebesar 10,4 - 40,4 % dari respirasi tanah total (seperti ditunjukkan pada Tabel 2). Besaran tersebut sebanding dengan laporan sebelumnya, yaitu berkisar 30,5 – 45 % (6, 10).

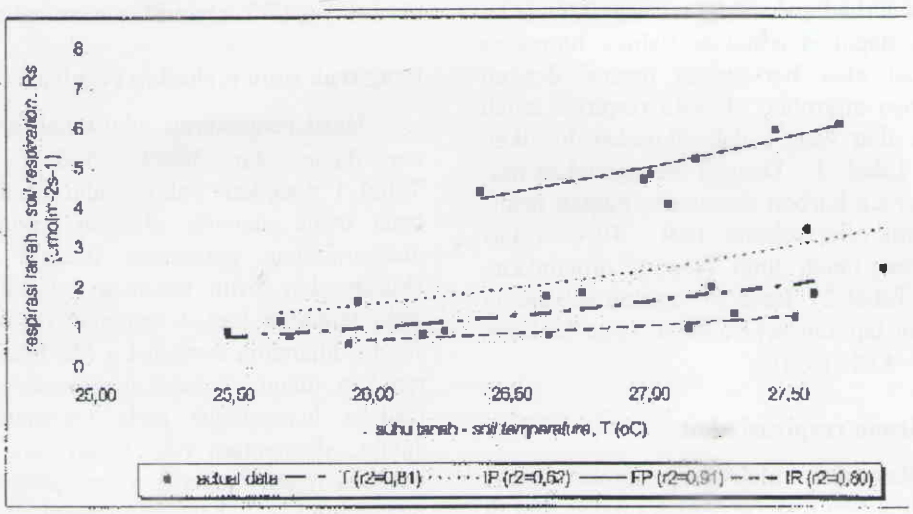
Perkiraan respirasi akar

Respirasi akar diperkirakan dari selisih antara respirasi tanah total *in situ* di lapangan dan respirasi tanah tanpa akar di laboratorium, yang masing-masing dikoreksi terhadap suhu. Laju respirasi akar sangat berbeda nyata (p=0,001) hanya menurut letak pengukuran, sedang menurut orijin bahan tanaman dan interaksinya tidak berbeda nyata. Rerata nilai terkoreksi disajikan pada Tabel 1. Perubahan laju respirasi akar menurut letak pengukuran sejalan dengan laju respirasi tanah. Respirasi akar DxP La Me cenderung lebih tinggi daripada Bah Jambi. Berdasarkan data yang disajikan Lamade dan Setiyo (11), proporsi biomassa tegakan akar bahan tanaman La Me terhadap Bah Jambi sebanding dengan proporsi respirasi akarnya. Hal ini sesuai dengan laporan sebelumnya (1, 3) bahwa respirasi akar, terutama komponen respirasi pemeliharaan, berkorelasi positif dengan biomassa tegakan. Henson (4, 6) mempelajari pemisahan komponen respirasi akar menggunakan nilai ukuran biomassa akar, produksi biomassa akar bersih dan koefisien respirasi. Ia menunjukkan bahwa respirasi akar total tanaman kelapa sawit umur 9 tahun terdiri atas 83 % respirasi pemeliharaan dan 17 % respirasi pertumbuhan.

Pengaruh suhu terhadap respirasi tanah

Hasil pengukuran suhu tanah berfluktuasi dalam selang 26,49 - 30,32 °C. Pada Tabel 1 disajikan bahwa suhu tanah berbeda nyata menurut ulangan, yang juga mencerminkan perbedaan tanggal pengukuran, dan orijin tanaman. Rendahnya suhu tanah di bawah tanaman orijin Bah Jambi dibanding dengan La Me bisa dikarenakan tingginya taraf penutupan kanopi (indeks luas daun) pada tanaman Bah Jambi. Sementara suhu tanah yang tidak berbeda nyata menurut lokasi pengukuran mencerminkan bahwa kanopi antara individu pohon telah menutup sempurna (11).

Dari analisis seluruh data pengamatan yang dilakukan selama percobaan (n = 769) tidak ditemukan hubungan antara suhu dan respirasi tanah yang erat. Namun pada tanggal tertentu, dengan pengukuran parameter menurut jam pengamatan dijumpai korelasi yang nyata antara suhu dan respirasi tanah, seperti disajikan pada Gambar 1. Penyesuaian terbaik diperoleh dari bentuk kurva empirik eksponensial sederhana ($Rs = a * \exp(b*Ts)$) yang secara umum digunakan untuk menggambarkan proses biologis (12). Beberapa faktor kemungkinan dapat mempengaruhi lemahnya hubungan suhu dengan respirasi tanah, yang tidak dipelajari secara khusus dalam percobaan ini, misalnya kelengasan tanah. Sebagaimana Lamade *et al.* (1996) menyatakan bahwa suhu berpengaruh terhadap respirasi tanah hanya pada tanah 'basah', yang taraf kelengasannya cukup memperkenankan populasi mikroba beraktivitas.



Gambar 1. Hubungan antara respirasi dan suhu tanah pada orijin Bah Jambi

Perkiraan alokasi karbon ke akar

Dari model neraca karbon ekosistem yang diajukan oleh Raich dan Nadelhoffer (18) dinyatakan bahwa alokasi karbon total untuk akar sama dengan selisih antara respirasi tanah total dan jumlah bagian atas tanaman (yaitu pangkasan pelepah) yang dikembalikan ke tanah. Pada kondisi demikian, alokasi karbon dimanfaatkan untuk respirasi dan pembaruan jaringan mati, dan karenanya pertambahan biomassa diabaikan. Dari Tabel 2 ditunjukkan bahwa karbon total tahunan untuk akar pada kedua bahan tanaman relatif serupa, yang besarnya 42 - 46 ton $CO_2.ha^{-1}.thn^{-1}$, dengan pembagian untuk *turnover* akar sekitar 0,3 - 13,1 ton CO_2 ha^{-1} thn^{-1} (1-31 %) dan untuk respirasi akar 29,3 - 45,5 ton CO_2 ha^{-1} thn^{-1} (69-99 %). Angka tersebut sebanding dengan yang dinyatakan oleh penulis sebelumnya (6, 10).

Tabel 2. Hasil perhitungan respirasi tanah total, respirasi akar dan alokasi karbon untuk *turnover* akar tahunan menurut perbedaan bahan tanaman.

	La Me	Bah Jambi
	(μmol $CO_2.m^{-2}.s^{-1}$)	
Respirasi tanah total *)		
Gawangan	3,62	3,26
Jalan panen	2,20	1,84
Tumpukan pelepah	4,45	4,90
Piringan	4,04	4,11
Perkiraan respirasi akar *)		
Gawangan	2,74	1,80
Jalan panen	1,52	0,69
Tumpukan pelepah	3,75	3,31
Piringan	3,28	2,79
	ton CO_2 ha^{-1} $tahun^{-1}$	
Rerata-terboboti dari plot **)		
Respirasi tanah total (Rs)	50,75	49,15
Respirasi mikrobia (Rm)	5,27	19,86
Respirasi akar (Rr = Rs-Rm)	45,48	29,29
Massa pelepah yang jatuh ke tanah, Pa ***)	4,96	6,76
Turnover akar, Pb (= Rs-Rr-Pa)	0,31	13,10
Alokasi C total ke akar		
Pb+ Rr (= Rs-Pa)	45,79	42,39
Proporsi		
Rm/Rs	0,10	0,40
Rr/Rs	0,90	0,60
Pb/Rs	0,01	0,27

Keterangan : *) = data dikoreksi terhadap suhu; **) = terboboti menurut persentase luas total yang dicakup oleh masing-masing letak pengukuran; ***) = dihitung berdasarkan pelepah yang dipangkas : produksi pelepah, luas daun dan biomassa spesifik daun

KESIMPULAN

Dari analisis data pengamatan laju respirasi tanah total *in situ* ditunjukkan bahwa peubah tersebut berbeda nyata hanya menurut perbedaan letak pengukuran (variasi spasial), sedang faktor bahan tanaman dan interaksi bahan tanaman x letak pengukuran tidak berpengaruh nyata. Seluruh data percobaan menunjukkan hubungan yang lemah antara suhu dan respirasi tanah. Namun demikian, pada tanggal pengamatan tertentu ditemukan hubungan positif dan nyata antara suhu dan respirasi tanah, yaitu di dasar batang (r^2=0.81), di jalan panen (r^2=0,62), di bawah tumpukan pelepah (r^2=0,91) dan di tengah gawangan mati (r^2=0,80). Dengan memadukan pengukuran respirasi di lapangan dan di laboratorium dimungkinkan untuk menduga besarnya respirasi akar tanaman. Selanjutnya dengan mengaplikasikan model neraca ekosistem karbon dapat diperkirakan jumlah alokasi karbon untuk *turnover* akar. Walaupun secara statistik tidak berbeda nyata, laju respirasi akar tanaman DxP orijin La Me (3,20 μmol CO_2 m^{-2} s^{-1}) cenderung lebih besar daripada Bah Jambi (2,15 μmol CO_2 m^{-2} s^{-1}). Beberapa faktor peubah lingkungan selain suhu yang berpengaruh terhadap respirasi tanah, misalnya kelengasan tanah, bahan organik dan kepadatan akar, perlu untuk dilibatkan dalam pengukuran respirasi tanah.

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Estimation of respiration and turnover of DxP oil palm roots

Indra Eko Setiyo, Amir Purba, and E. Lamade[1]

Abstract

Inadequate data of carbon physiology, such as root turnover and respiration, will be a limiting factor for developing simulation models of oil palm growth and yield. One of the methods for determining both processes is by analyzing CO_2 efflux from soil system or soil respiration. Integrating field and laboratory measurements can estimate root respiration. Amount of carbon allocated to root turnover may be determined by using ecosystem-carbon balance model. The experiment was established by randomized block design with two factors: varieties (2 levels) and measurement sites (4 levels). Nine years after planting of DxP oil palms were used for this experiment. The results indicated that soil and root respiration were different statistically only for measurement sites. In certain observation dates, positive and linear correlation between temperature and respiration was found. There was a tendency that root respiration of D x P La Me was higher than D x P Bah Jambi. Total carbon released from soil surface was estimated at 49.1 - 50.7 ton CO_2 ha^{-1} yr^{-1}, in which proportion of root respiration and root turnover were 0.60-0.90 and 0.01-0.27, respectively.

Key words: *Elaeis guineensis*, soil respiration, root respiration, root turnover

Introduction

Development of simulation model of oil palm growth and yield (3, 7, and 11) is usually limited by lack of understanding of carbon physiological process, especially root respiration and turnover. So far, root production of oil palm was assumed as a proportion of total dry matter production, which was usually obtained by non-destructive method. For example, in Malaysia and Papua New Guinea, it was determined about 10 % (1). The value is different compared to the experimental result done in Ivory Coast, i.e. 50 % (2). Both studies imply that root growth was much affected by variation in agroclimate. Meanwhile, root respiration for modeling at first was determined by coefficient based on nutrient content of tissue (1, 3).

The advancement of infrared gas analyzer (IRGA) technology and modification of the chamber provides a better opportunity to detect CO_2 efflux from soil system or soil respiration. Lamade *et al.* (10) have developed successfully an approach that integrated the technique for measuring CO_2 efflux in the laboratory and field. The technique was able to separate two main sources of soil CO_2. Using carbon balance model proposed by Raich and Nodelhoffer (18), amount of carbon allocated for root turnover can be determined. The IRGA method is better than CO_2 trap method because of its instantaneous. Furthermore, trap method tends to overestimate CO_2 efflux from soil.

Soil respiration explains the total amount of CO_2 released from overall soil metabolic function. It includes several biological processes, namely root (autotroph) respiration and soil microbial (heterotroph) respiration activities, especially microbial respiration activities that involve in mineralization of organic matter. Therefore, soil respiration is often be used

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as soil biological activity (fertility) index that gives a precise information about root system dynamic.

The objective of the experiment was to study the soil respiration of two different oil palm varieties at four different sites of measurement (spatial variation). Then, amount of annual root respiration and turnover were estimated.

Materials and Methods

Location and planting material

The experiment was conducted on the IOPRI genetic and breeding trials, in Marihat estate, PT. Perkebunan Nusantara IV, North Sumatra. The planting materials were La Me (DA 18 D self x LM 7 T self) and Bah Jambi (BJ 13 D self x BJ 21 P) varieties observed at nine years after planting. The palms were planted at the density of 130 palms ha^{-1}. The climatic condition was characterized based on routine observation in SMPK Marihat, Marihat Research Station (02°55' N, 99°05' E; altitude 369 m). In the last 20 years of observation, average annual rainfall was extremely wet (>2,750 mm). Based on the calculation of monthly water balance (17), the water deficit was not found while excessive water (drainage) was about 1,400 mm per year. The other components of climate were described in detail by Lamade et al. (9); Lamade and Setiyo (11).

The soil type was *Typic Dystropept* (yellowish brown podzolic), at which the upper layer (0-40 cm) was sandy loam texture, crumb structure, and very friable consistency while the lower layer was sandy clay loam, blocky, and friable with good drainage. Hydrogen exponent (pH (H_2O) was between 5.31 and 5.51 (from 0 to 80-cm depth). Nitrogen and organic matter content were high with C/N ratio in the range of 9.54 - 10.71. Cation exchangeable capacity (CEC) was moderate, 7.7 - 10.9 (14, 20).

Techniques of measurement

CO_2 released from soil was measured directly *in situ* on the field (8). Measurement used an infrared analyzer (Analytical Development Co., Hoddesdon, Herts, UK.) and modified cylindrical chamber. Cylinder was made of metal (diameter 40 cm, height 50 cm) and can be moved and fitted hermetically to support 15 cm pushed into soil. Cylinder was connected to analyzer via butyl - rubber tube with diameter 3 mm. Inside cylinder, it was arranged two fans (Micronel, 80 mm, 12v) to ensure effective air homogenization, and one thermistor (Sagimeca, 10K3 A1) connected with multimeter (Fluke 70 II) to measure chamber air temperature. Two standard thermometers were pushed into soil beneath chamber to measure its temperature. Before analysis, sampled air was dried up by using magnesium perchlorate to protect analyzer arid limit from interference between vapors with CO_2 during measurement (13). The first sample was taken when cylinder was fitted to its support and served as a reference.. Two following samples were taken consecutively every five minutes.

CO_2 measurement in laboratory was set up to estimate the share of root compartment respiration in total CO_2 efflux. The procedure was explained by Lamade (8), in which the soil sample was taken from the same site of chamber. After root removal by dry extraction, the sample was incubated in field capacity condition. CO_2 was measured from two air samples and was taken per thirty minutes per

replication. Then, root compartment respiration was deduced from the difference between measurement taken *in situ* on the field and in root-free soil in the laboratory.

Experimental unit was the combination of planting material and measurement site. The measurement sites were: (i) near the trunk base, T, (ii) along the harvesting path, HP, (iii) beneath the frond piles, FP and (iv) in the middle row between two palms-interrows, IR. In each location, CO_2 was measured at least five times of chamber fitting with hour per palm. Respiration rate was calculated using the conventional equation for measuring closed circuit (13). Data was statistically analyzed following the randomized complete block design with two factors (16, 19).

Estimation of carbon quantity allocated to the root

Carbon quantity was estimated by Raich and Nadelhoffer model (18). The calculation assumed that the total annual carbon returned to the soil by plant residue, both in the form of above-ground parts (Pa) and below-ground parts (Pb), should be equal to the amount of soil carbon mineralized by heterotroph respiration. Moreover, if Rs represents the total CO_2 released from the soil and Rr is root respiration, the relation can be written as

$$Rs = Pa + Pb - Rr \quad (1)$$

Pb−Rr explained the total of carbon allocated to the roots. The estimation was conducted with some assumptions, (i) the carbon input into the soil come only from frond and root litter, (ii) only leaflets were considered to contribute to soil organic matter, while the rest of fronds was decomposed on the surface, (iii) the effect of interaction between microbial activity and carbon supply, such as litter, to the decomposition of soil organic matter (priming effect) was ignored. The other assumptions were explained by Lamade *et al.* (10).

Results and Discussion

Total soil respiration in situ

The respiration rate is always affected by change in temperature (10). Therefore, all respiration data was corrected by temperature. During the experiment, the interaction between planting material and measurement site did not significantly affect to soil respiration. Average soil respiration rate was shown in Table 1. Range of the value was comparable to the previous results (6, 10). Statistic analysis indicated that only site of measurement significantly affected ($p=0.001$) to the soil respiration. The decrease in the instantaneous value was obtained respectively from beneath frond pile (FP), near trunk (T), interrow (IR) to harvest path (HP) location. The highest instantaneous respiration in frond pile was consistent with the previous report. This case was caused by the accumulation of organic matter that makes more favorable growing conditions in that zone and the higher root density (6, 10). Meanwhile, the lowest rate of soil respiration found at the harvest path was different from that found by Henson (5). It may be caused by difference in soil compacting level.

Root-free soil (microbial) respiration

Analysis of covariance, with temperature covariate, on interaction between planting material and measurement site

showed no significantly difference of soil microbial respiration. For all two single factors, the corrected respiration was also no significantly different. However, there was a tendency that root-free soil respiration in Bah Jambi was higher than that in La Me, with the proportion of BJ to LM was 1.33. The proportion of root standing biomass of Bah Jambi to La Me planting material of 0.69 (11) implied that the microbial respiration negatively correlated to the root biomass. Mean of corrected root-free soil respiration was presented in Table 1. By using ecosystem carbon balance model, share of microbial respiration was in the range of 10.4 - 40.4 % of total soil respiration (Table 2). These values were comparable to the previous report (6, 10), about 30.5 - 45 %.

Estimated root respiration

Root respiration was deduced from the difference between the measured CO_2 released from soil *in situ* in the field and that from root-free soil in laboratory, in which each value was corrected to temperature. The effect of measurement site was highly significantly different ($p=0.001$) for the estimated rate of root respiration, whereas the effect of planting material and the interaction of both factors were not significant. Mean of corrected value was presented in Table 1. For each measurement site, the pattern of the change in the value with measurement site was similar to that of soil respiration. Root respiration of La Me tend to be higher than that of Bah Jambi. Based on data presented by Lamade and Setiyo (11), proportion of root standing biomass of LM to BJ (1.46) corresponded to that of the root respiration. This was consistent with the previous reports (1, 3) in which root respiration, mainly maintenance respiration component, positively correlated to standing biomass. Henson (4, 6) studied to separate the component of root respiration using the measured values of root biomass, net root biomass production, and established respiratory coefficients. According to Henson, the total root respiration of nine-year old stand comprised nearly 83 % maintenance and 17% growth respiration.

Table 1. Mean of total soils respiration (Rs), root-free soil respiration (Rm.), root respiration (Rr) and soil temperature (Ts)

	Rs*)	Rm*) μmol $CO_2.m^{-2}.s^{-1}$	Rr*)	Ts °C
Replication				
1	2.92	0.82	2.30	27.16 c
2	3.74	0.88	2.81	28.86 a
3	3.57	0.90	2.61	29.06 a
4	3.78	0.85	2.78	27.94 b
5	3.76	0.96	2.86	27.80 b
Planting material				
Bah Jambi	3.53	1.01	2.15	27.73 b
La Me	3.58	0.76	3.20	28.60 a
Location				
T	4.08 ab	0.84	3.23 ab	28.04
IP	2.02 c	0.81	1.24 c	28.03
FP	4.67 a	0.88	3.71 a	28.23
IR	3.44 b	1.00	2.52 b	28.34

Notes: *) The number was corrected to temperature ; Number in the same column followed a different alphabet was tested further by LSD at $\alpha = 0.05$

Effect of temperature to soil respiration

During measurement, soil temperature fluctuated in the range of 26.49-30.32 °C. Table 1 indicates that soil temperature was significantly difference with replication, which reflected difference of measurement date, and planting material. Tendency of a lower soil temperature in Bah Jambi material may be related to the canopy cover level (leaf area index) of Bah Jambi, which was higher than that of La Me. Meanwhile, soil temperature was not significantly different within measurement site. This indicates that canopy between palms have completely covered (11).

Analysis on all data observed during the experiment (n=769) did not find a close and significant correlation between soil temperature and respiration. In certain date, however, we found a positive correlation between them, as presented in Figure 1. The best fitting was obtained with a simple exponential empirical curve ($Rs = a * exp.(b*Ts)$) generally used to describe many biological processes (12). Possible factors determining the weak relationship was not studied in this experiment, for example, factor of soil moisture content. As Lamade *et al.* (10) pointed out that temperature only affected to the soil respiration at 'wet' soil, when the level of moisture was sufficient to permit a substantial activity by the microbial population.

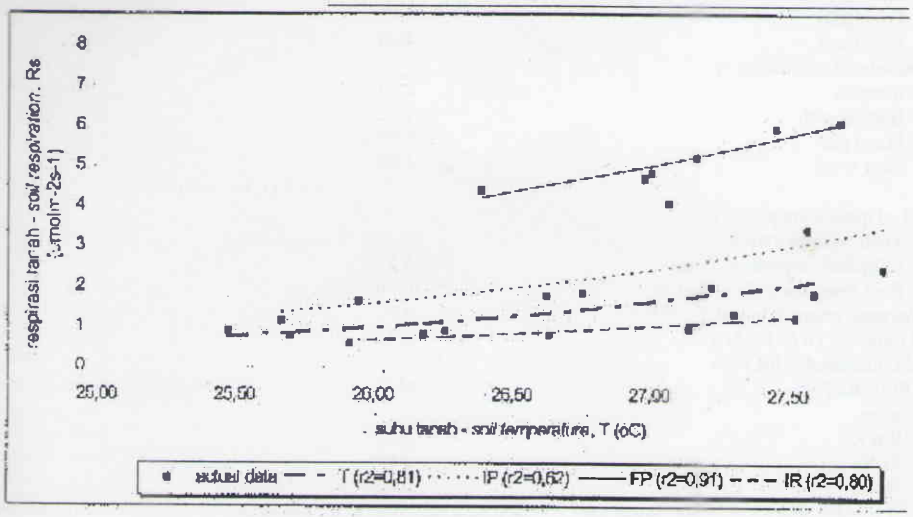

Figure 1. Relation between soil respiration and temperature in Bah Jambi material

Estimation of carbon allocated to the roots

The model of ecosystem carbon balance proposed by Raich and Nadelhoffer (18) stated that total carbon allocated to the roots were equal to the difference between total soil respiration and amount of above part of palms (i.e. fronds cut) returned to soil. In such condition, the allocated carbon was only used for respiration and renewal of dead tissue. Hence, increment of biomass was negligible. Table 2 presented that the annual total carbon to the roots for both planting materials were relatively similar in the range of 42-46 ton CO_2 ha^{-1} yr^{-1}, partitioning for root turnover around 0.3-13.1 ton CO_2 ha^{-1} yr^{-1} (1 - 31 %), and for root respiration 29.3 - 45.5 ton CO_2 ha^{-1} yr^{-1} (69-99 %). These numbers were comparable to those found by Henson (6) and Lamade *et al.* (10).

Table. 2. The calculation of annual total soil respiration, root respiration, and carbon allocated to the root compartment for turnover with two different planting materials

	La Me	Bah Jambi
	(μmol CO_2 m^{-2} s^{-1})	
Total soil respiration*)		
Interrow	3.62	3.26
Harvest path	2.20	1.84
Frond pile	4.45	4.90
Near trunk	4.04	4.11
Estimated root respiration *)		
Interrow	2.74	1.80
Harvest path	1.52	0.69
Frond pile	3.75	3.31
Near trunk	3.28	2.79
	ton CO_2 ha^{-1} $tahun^{-1}$	
Weighed mean from plot **)		
Total soil respiration (Rs)	50.75	49.15
Mikrobial respiration (Rm)	5.27	19.86
Root respiration (Rr = Rs-Rm)	45.48	29.29
Leaves mass returned to soil, Pa ***)	4.96	6.76
Root turnover, Pb (= Rs-Rr-Pa)	0.31	13.10
Total C allocated to the roots		
Pb+ Rr (= Rs-Pa)	45.79	42.39
Proportion		
Rm/Rs	0.10	0.40
Rr/Rs	0.90	0.60
Pb/Rs	0.01	0.27

Notes: *) number was corrected to temperature ;**) weighted according to the percentage of total area occupied by each site; ***) calculated based on the frond cut: leaf turnover, leaf area, and specific leaf biomass

Conclusions

It was found that total soil respiration *in situ* in the field was highly significantly different with variation in measurement site (spatial variation), whereas effect of planting material and interaction of planting material x measurement site did not significantly different. All experiment data showed a weak correlation between soil respiration and temperature. In certain date, however, positive significant

correlation between them was found, viz in trunk base (r^2=0.81), harvest path (r^2=0.62), beneath frond pile (r^2=0.91) and interrow (r^2=0.80). Palm root respiration was estimated by integrating respiration measurement in the field and the laboratory. Using model of ecosystem carbon balance, total carbon allocated to the roots for turnover was determined. Although not significant, there was a tendency that the estimated root respiration of La Me (3.20 µmol CO_2 m^{-2} s^{-1}) was higher than that of Bah Jambi (2.15 µmol CO_2 m^{-2} s^{-1}) planting material. Several environment factors affecting to soil respiration, such as soil moisture, soil organic matter and root density, should be involved in measuring soil respiration.

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