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Measurement of leaf area index of oil palm using AccuPAR LP-80 (PCA)

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ABSTRACT

Leaf area index (LAI) is a dimensionless index, which can be defined as the assimilative leaf relative to the projected ground area for plant community (one-side area for broad-leaved trees). It is probably the most useful structural variable for quantifying the energy and mass exchange characteristics of terrestrial ecosystem. LAI is frequently used for estimating evapotranspiration and net primary productivity, since the variables are directly related to important issues such as climatic change and global carbon cycles. LAI has been an important driver to some ecosystem models applied at landscape to global scales. Study on the spatial distribution of LAI on the Earth's surface has been helpful to understand the various biological and physical processes within a terrestrial ecosystem, such as photosynthesis, respiration, transpiration, carbon and nutrient cycles, and rainfall interception. Leaf area index is an index of plant growth and is related to the accumulation of dry matter, plant metabolism and yield. It is also related to crop quality and maturity. In this study, measurement of LAI using direct and indirect methods, their advantages, disadvantages and accuracy of the results were evaluated. The AccuPAR LP-80 provides a rapid estimate of leaf area index. The AccuPAR LP-80 gave LAI values which were close to results obtained from the direct method. It was observed from regression analysis, a strong correlation was found between direct and indirect method with regression values (R2>0.92). LAI values were taken three times in a day using AccuPAR LP-80 for several days. LAI values indicate the growth of oil palm. The LAI values which were got from AccuPAR LP-80 are almost accurate for their age. It could be concluded that AccuPAR LP-80 could be used to measure the LAI instead of other methods for its accuracy and less time consuming.

Introduction

Leaf area index (LAI) is a dimensionless index, which can be defined as the assimilative leaf relative to the projected ground area for plant community (one-side area for broad-leaved trees) (Watson, 1947, Lang *et al.,* 1991). It is probably the most useful structural variable for quantifying the energy and mass exchange characteristics of terrestrial ecosystem. LAI is frequently used for estimating evapotranspiration and net primary productivity, since the variables are directly related to important issues such as climatic change and global carbon cycles (Sellers *et al.,* 1986). LAI has been an important driver to some ecosystem models applied at landscape to global scales. Study on the spatial distribution of LAI on the Earth's surface has been helpful to understand the various biological and physical processes within a terrestrial ecosystem, such as photosynthesis, respiration, transpiration, carbon and nutrient cycles, and rainfall interception (Chen and Cihlar, 1966; Gong *et al.,* 1997; Hu *et al.,* 2000). Leaf area index is an index of plant growth and is related to the accumulation of dry matter, plant metabolism and yield. It is also related to crop quality and maturity.

LAI is widely accepted as an indicator of photosynthetic capacity and stress level of forest stands (Waring, 1983). The maximum LAI of a forest stand is limited by nutrient availability, so any deviation from this value can indicate whether the stand will respond to fertilization, given fixed levels of other growth limiting factors, such as soil water and temperature (Vose and Allen, 1988). Thus, monitoring of LAI has a potential application in prescribing of fertilizer treatments. Measurements of leaf area index (LAI) of plant canopies are also essential for environmental applications such as water and carbon cycle modeling.

Many direct and indirect methods have been used for measuring the leaf area index. Hardon (1969) suggested a methodology for estimating leaf area from direct method. He used an equation (A= b (nlw), where A= leaf area, cm^2, n = number of leaflets, l= mean length and w = mid-width of the leaflets, cm) for leaf area calculation of oil palm. An alternative method was suggested for measurement of leaf area by Tailliez and BalloKoffi (1992). Direct methods, such as destructive sampling, may provide the best estimates of LAI, but they are time consuming, difficult, laborious, and costly. Direct measurement of LAI is only practicable on experimental plots of limited size. Consequently, estimating LAI over large areas is problematic (Gobron *et al.,* 1997). Direct method for estimating LAI in native forest involve destructive sampling of representative branches and trees, and using allometric relationships between leaf areas and stem characteristics (Norman and Campbell 1989).

Indirect methods for determining LAI relate total leaf area to the radiation environment below the canopy are generally less time consuming as well as non-destructive. Several non-destructive methods have been developed that utilize light attenuation through the plant canopy to estimate the amount some cases, the orientation of foliage (Feldkirchner Gower, 2001). A commonly used technique to acquire LAI in situ is based on measurements of radiation transmittance through the canopy with optical instruments. The plant canopy analyzer AccuPAR LP-80, which obtains measurements of effective LAI based on gap fraction at five view angles, is designed to work under diffuse light conditions (Leblanc and Chenb, 2001). The AccuPAR LP-80 is a portable integrating radiometer, which provides a no-destructive means of indirectly estimating LAI using gap fraction theory. These instruments require specific illumination conditions. The AccuPAR LP-80 plant canopy analyzer makes use of diffuse light and should, avoid direct sunlight. Therefore, the measurements should be taken on uniform sky conditions found on overcast days, or near sunset or sunrise to avoid the interference of direct sunlight. The AccuPAR LP-80 has been widely used over a range of plant canopies: coniferous and deciduous species (Gower and Norman, 1991), different pines (Law *et al.,* 2001) and boreal forest in Canada (Chen *et al.*, 1997).Many of these studies showed that the LP-80 generally underestimates the LAI from direct measurements. However, Lamade and Setiyo (1996) evaluated the LP-80 on oil palms in Indonesia (i.e., 5 and 9 years after field planting) and found the best accuracy (100%) when only the first three central rings were used. Roslan *et al.,* (2002) compared the LP-80 with the conventional method on five-year old palms I Malaysia and found that the AccuPAR LP-80 gave about the same results as the conventional method. The present study was undertaken to determine the accuracy of AccuPAR LP-80 plant canopy analyzer by comparing with direct measurements of LAI in palm and to establish relationship between LAI and growth of palm oil.

Methodology

Experimental site

The study was conducted at Palm Oil garden belongs to Faculty of Agricultural Engineering & Technology, Bangladesh Agricultural University, Mymensingh. Geographically the experimental area is located at 22° latitude and 92° longitude at the elevation of 18 m above the sea level.

The experiment

The study was designed as Randomized Complete Block Design (RCBD). The number of plant was 5 and number of replication per plant was 12. Number of experiment plot was 1. The length and width of plot was 100 m. Number of line per plot was 5. The line to line and plant to plant distance was 27 ft. 1 inch. Total field area was 100 m ×100 m. For plant population record **a**t growth stage all plants were counted from plot.

Measurement of leaf area index

Many methods have been used to measure leaf area index- LAI (McIntyre *et al. 1991).* Among different methods, an indirect method (AccuPAR LP-80) is the more rapid and non-destructive for estimating LAI. LAI was also calculated by measuring leaf area with automatic leaf area meter (LICOR-3100, USA).

Direct measurement

Direct or semi-direct methods involve a measurement of leaf area, using either a leaf area meter or a specific relationship of dimension to area via a shape coefficient. Leaf area is measured on a sub-sample of leaves and related to dry mass. As direct method only relate to foliage, they are the only ones giving real access to leaf area index. They allow separate computation of the shape, size, and number of leaves. Direct methods provide the reference for the calibration or evaluation of indirect methods.

Description of LI-3100 area meter

The LI-3100 area meter is designed for biological or industrial applications requiring rapid, precise projected area measurements. Samples are placed between the guides on the lower transparent belt and allowed to pass through the instrument.

As items travel under 15 watt florescent light source, the image is reflected by a system of three mirrors to a solid state scanning camera within the rear housing. Object width is sensed by the scanning camera. Length information is provided by the current frequency as related to belt velocity. Area integration is accomplished by components of the main printed circuit board mounted on the instrument rear plate. Data is presented on the light emitting diode (LED) display. Decimal location on the display is changed to suit the 1.0 or 0.1 mm2 resolution requirement. Alternately data can be collected, displayed, and stored using the LI-3100A console.

Measuring technique

In terms of the direct or destructive method, leaf collection and leaf area determination technique are often used. The leaf collection can also be implemented by harvesting method through destructive sampling which collects from a sample plot or some representative trees from a plot. In direct method, palm oil leaf area was determined by LI-3100 Area Meter (Figure 1).

Figure 1: Measurement of leaf area in BAU central lab by LI-3100 Area Meter Instrument.

In experiment leaves were collected from the selected plants. Leaflets were cut with a scissor and sampling with numbering. Then leaf area is measured by LI-3100 Area Meter in Bangladesh Agricultural University (BAU) central laboratory.

Calculation of Leaf Area Index (LAI)

In direct method LAI is needed to calculate from LI-3100 Area Meter, because this instrument gives only leaf area. Leaf Area Index is obtained by the following formula:

$$LAI = \frac{\text{Total area of individual leaves, cm2}}{\text{Projected area, cm2}}$$

Indirect measurement

Indirect methods infer leaf area index from measurements of the transmission of radiation through the canopy, making use of the radiation transfer theory (Anderson, 1971; Ross, 1981). These methods are non-destructive and are based on a statistical and probabilistic approach to foliar element (or its complement, gap fraction) distribution and arrangement in the canopy (Jones, 1992).

Operation technique

To make an above-canopy PAR measurement, press the up-arrow key in this menu. The resulting value will be displayed in the upper right section of the screen. To make measurements below the canopy, press the down-arrow key or the green circular key in the upper right corner of the keypad. An external sensor must be plugged in or an above canopy PAR reading must be taken first before summary data will be updated. Summary data are recalculated after each below canopy PAR reading.

The current calculated Tau (T), LAI value, beam fraction (Fb), leaf distribution parameter (*x*) and zenith angle (z) values are updated and displayed at the bottom of the screen with each subsequent below canopy PAR measurement. If the external sensor is attached and an up or down arrow is pressed, both above and below readings will be recorded. Pressing ENTER brings up the save screen which allows you to save as is, annotate or discard. Pressing ESC discards the values. Both options clear the screen for new data. The values displayed at the bottom of the screen are dependent on how you have set up your instrument in the Setup menu.

With each above or below canopy measurement, a number appears to the right of the *PAR*value, indicating the number of measurements taken. The displayed *PAR*value reflects the average of the samples taken. Therefore, in the above sample screen, four above and three below canopy measurements have been made, so the average of the four above-canopy PAR values is 211 mols, while the average of the three below-canopy values is 20 mols.

Field data analysis

Data communication

The AccuPAR LP-80 control unit stored all readings and it is necessary to transmit this data to a computer. The LP-80 utility version 1.1 communication software for downloading data. This software includes a general purpose communications program for transferring AccPAR LP-80 files to the computer. A simple file format was used for measurement of morphological parameters.

Measurement of morphological parameters

Plant height

Height of five plants from each plot was measured with meter scale. This reading was taken from ground surface to the top of main shoot and mean height was expressed in cm.

Number of frond per plant and leaflet per frond

The average number of frond per plant was 18 and the average number leaflet per frond was 107.

Table 1: Simple file format for measurement of morphological parameters

Record type	Avg. Above PAR	Avg. Below PAR	Tau[T]	Leaf Area Index [LAI]	Leaf Distribuition [X]	Beam Fraction [Fb]	Zenith Angle	Latitude	Longi-tude
SUM	1753.5	450.2	0.558	1.31	1.00	0.91	35°	22°	92°
SUM	1648.0	839.3	0.556	1.32	1.00	0.88	35°	22°	92°
SUM	1631.8	1485.2	0.564	1.29	1.00	0.88	35°	22°	92°

Table 2: Leaf area of 60 leaves of palm oil tree using AccuPAR LP-80

Plant No.	Leaf Number	Leaf area Index	Plant No.	Leaf Number	Leaf area Index	Plant No.	Leaf Number	Leaf area Index)
1	1	0.30	2	1	0.33	3	1	0.05
	2	0.30		2	0.33		2	0.33
	3	0.29		3	0.33		3	0.26
	4	0.29		4	0.32		4	0.21
	5	0.29		5	0.32		5	0.41
	6	0.28		6	0.31		6	0.41
	7	0.28		7	0.31		7	0.36
	8	0..28		8	0.31		8	0.39
	9	0.28		9	0.31		9	0.40
	10	0.27		10	0.30		10	0.46
	11	0.27		11	0.31		11	0.44
	12	0.27		12	0.31		12	0.46
4	1	0.36	5	1	0.43		Mean	0.35
	2	0.37		2	0.42		Std.	0.068
	3	0.38		3	0.42			
	4	0.38		4	0.42			
	5	0.38		5	0.43			
	6	0.37		6	0.42			
	7	0.36		7	0.40			
	8	0.35		8	0.39			
	9	0.34		9	0.37			
	10	0.33		10	0.38			
	11	0.33		11	0.39			
	12	0.32		12	0.38			

Table 3: Leaf area of 75 leaves of palm oil tree using Leaf area meter

Plant No.	Leaf Number	Leaf area (cm^2)	Plant No.	Leaf Number	Leaf area (cm^2)	Plant No.	Leaf Number	Leaf area (cm^2)
1	1	102.41	2	1	75.30	3	1	95.29
	2	101.87		2	74.67		2	97.37
	3	105.05		3	75.93		3	93.21
	4	95.34		4	85.31		4	87.55
	5	97.98		5	86.79		5	78.65
	6	97.12		6	83.84		6	69.55
	7	98.10		7	72.62		7	112.3
	8	96.43		8	73.43		8	114.64
	9	99.79		9	71.82		9	109.96
	10	107.62		10	86.14		10	66.36
	11	108.81		11	87.41		11	67.75
	12	106.44		12	84.85		12	64.99
4	1	91.83	5	1	94.38		Mean	86.668
	2	95.82		2	95.87		Std.	14.27
	3	87.84		3	92.90			
	4	109.60		4	62.63			
	5	111.13		5	66.71			
	6	108.10		6	58.55			
	7	79.51		7	80.73			
	8	81.68		8	83.78			
	9	77.34		9	77.68			
	10	74.14		10	91.75			
	11	75.23		11	93.48			
	12	73.06		12	90.02			

Table 4: Frond length of 25 fronds of palm oil tree using metering tape

Plant No.	Frond Number	Frond length(ft)	Plant No.	Frond Number	Frond length(ft)	Plant No.	Frond Number	Frond length(ft)
1	1	7.75	2	1	6	3	1	6.87
	2	6.91		2	6.54		2	6.25
	3	8		3	6.08		3	6.75
	4	7.5		4	6.91		4	7
	5	7.34		5	6.16		5	7
4	1	7	5	1	7.42	Avg. Length		6.78
	2	6.91		2	6.25			
	3	6.34		3	6.33			
	4	6		4	6.42			
	5	6.75		5	6.80			

Table 5: Leaflet length of 15 leaflets of palm oil tree using metering tape

Plant No.	Leaflet Number	Leaflet length(ft)	Plant No.	Leaflet Number	Leaflet length(ft)	Plant No.	Leaflet Number	Leaflet length(ft)
1	1(Lower)	1	2	1(Lower)	0.96	3	1(Lower)	0.87
	2(middle)	1.84		2(middle)	1.67		2(middle)	1.80
	3(highest)	1.42		3(highest)	1.20		3(highest)	1.12
4	1(Lower)	1	5	1(Lower)	1.20	Avg. Length		1.32
	2(middle)	1.84		2(middle)	1.84			
	3(highest)	0.92		3(highest)	1.12			

Results and Discussion

Determination of LA using AccuPAR LP-80

The leaf areas of 75 leaves from different 5 plants were measured using AccuPAR LP-80 instrument and it presented in Table 2. The average Leaf area Index was 0.35 and standard deviation was 0.068 cm^2.

Determination of LA using leaf area meter

The leaf areas of 75 leaves from different 5 plants were measured using Leaf area meter instrument and it presented in Table 3. The average Leaf area was 86.668 and standard deviation was 14.27 cm^2.

Determination of frond length and leaflet length

The **Length** of 25 fronds from different 5 plants were measured using metering tape and it presented in Table 4. The average frond length was 6.78 ft.

Determination of leaflet length

The Length of 15 Leaflets from different 5 plants were measured using metering tape and it presented in Table 5. The average Leaflet length was 1.32

CALCULATION:

Avg. Leaf Area for 1st Plant $=101.42\ cm \times cm$,
Avg. Leaf Area for 2nd Plant $=79.84\ cm \times cm$
Avg. Leaf Area for 3rd Plant $=88.14\ cm \times cm$
Avg. Leaf Area for 4th Plant $=88.77\ cm \times cm$
Avg. Leaf Area for 5th Plant $=82.37\ cm \times cm$

Tree 1: No. of front = 14 Leaves / front = 79.
Tree 2: No. of front =18 Leaves / front = 94.
Tree 3:No. of front =13 Leaves / front = 88.
Tree 4: No. of front =19 Leaves / front = 96.
Tree 5: No. of front =22 Leaves / front = 102.

Leaf area of 1st Plant = No. of front × No. of leaf × measured leaf area = 14 × 79 × 101.42= 114681.14 $cm \times cm$ = 11.46 m^2

Leaf area of 2nd Plant = 18×94×79.84 =135089.28 $cm \times cm$ = 13.50 m^2.

Leaf area of 3rd Plant=13×88×88.14 = 100832.16 cm × cm. = 10.08 m^2.

Leaf area of 4th Plant=19×96×88.77 =161916.48 cm × cm .=16.19 m^2.
Leaf area of 5th Plant=22×102×82.37 = 184613.88 cm × cm. =18.46 m2

1st Method

There are 148 plants in one hectare.
Leaf area Index (LAI) for 1st Plant = $\frac{148*11.46}{100*100} = 0.169$
Leaf area Index (LAI) for 2nd Plant = $\frac{148*13.50}{100*100} = 0.199$
Leaf area Index (LAI) for 3rd Plant = $\frac{148*10.08}{100*100} = 0.149$

Leaf area Index (LAI) for 4th Plant = $\frac{148*16.19}{100*100}$ = 0.239

Leaf area Index (LAI) for 5th Plant = $\frac{148*18.462}{100*100}$ = 0.275

Average Leaf Area per plant= $\frac{11.46+13.50+10.08+16.19+18.46}{5}$ = 13.93 m^2.

Leaf area Index (LAI) = $\frac{148*13.93}{100*100}$ = 0..206

2nd Method:

For 1st plant LAI= $\frac{leaf\ area\ of\ P1}{projected\ \ area}$= $\frac{114681.14}{3.14*165*165}$= 1.34

2nd plant LAI= $\frac{135089.28}{3.14*125*125}$= 2.75

3rd plant LAI= $\frac{100832.16}{3.14*140*140}$= 1.63

4th plant LAI=$\frac{161916.16}{3.14*120*120}$ = 3.57

5th plant LAI=$\frac{184613.88}{3.14*130*130}$= 3.47

Average LAI= 2.55

The LAI of Palm oil tree for 1st method was found to be 0.206 and for 2nd method 2.55

LAI from AccuPAR LP-80:

At 1ST day

Time	Morning	Midday	Afternoon
For 1ST Plant	0.562	0.186	0.178
For 2ND Plant	1.251	0.278	0.281
For 3RD Plant	0.983	0.266	0.251
For 4TH Plant	1.285	0.296	0.962
For 5TH Plant	1.424	0.302	1.11

At 2ND day

Time	Morning	Midday	Afternoon
For 1ST Plant	0.156	0.261	0.168
For 2ND Plant	0.274	0.352	0.260
For 3RD Plant	0.280	0.345	0.262
For 4TH Plant	0.281	0.364	0.270
For 5TH Plant	0.305	0.373	0.274

At 3RD day

Time	Morning	Midday	Afternoon
For 1ST Plant	0.2830	0.236	0.171
For 2ND Plant	0.343	0.237	0.267
For 3RD Plant	0.315	0.257	0.272
For 4TH Plant	0.356	0.307	0.432
For 5TH Plant	0.403	0.349	0.485

Comparison of plant canopy analyzer with leaf area meter

There was a strong relationship between direct and indirect method of LAI Estimation in Oil Palm. Figure 1 to 9 shows the relationship between AccuPAR Lp-80 and Leaf area Meter in several times.

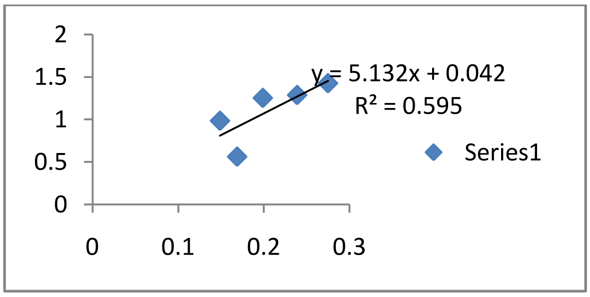

Fig 1 Comparison of LAI Between direct and indirect method at 1ST day morning

In Figure 7 and figure 9 shows a linear relationship R^2 =87 and R^2 =79 indicates that AccuPAR LP-80 more strongly correlated with LAI measured from destructive or direct or Leaf Area Method.

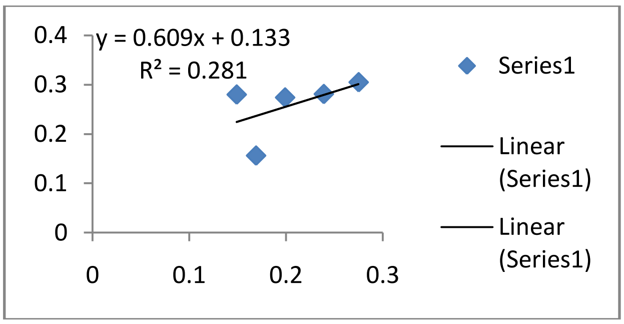

Fig: 2 Comparison of LAI Between direct and indirect method at 2ND day morning

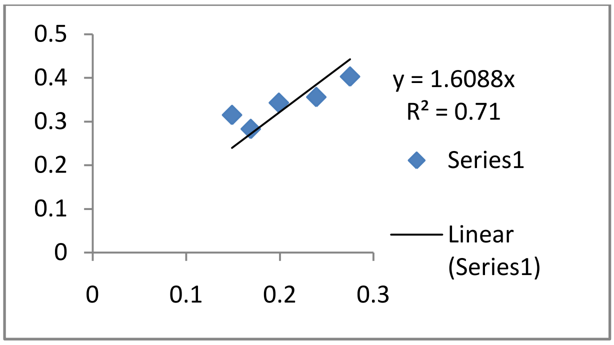

Fig: 3 Comparison of LAI Between direct and indirect method at 3RD day morning

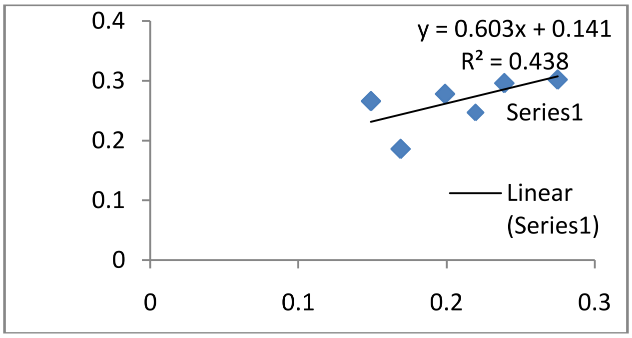

Fig: 4 Comparison of LAI Between direct and indirect method at 1ST midday

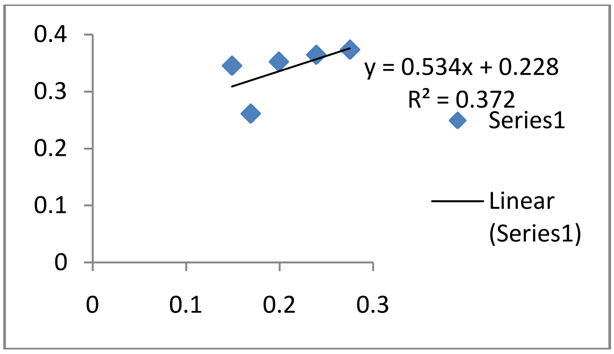

Fig: 5 Comparison of LAI Between direct and indirect method at 2ND midday

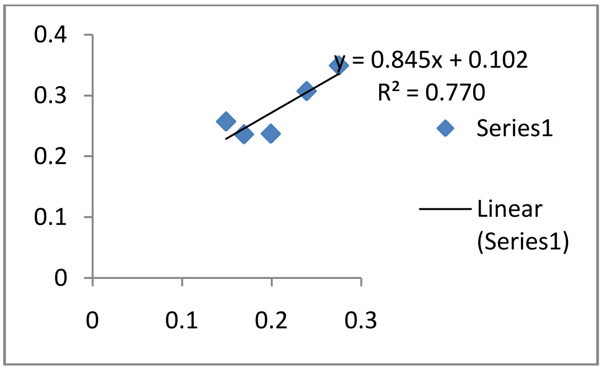

Fig: 6 Comparison of LAI Between direct and indirect method at 3RD midday

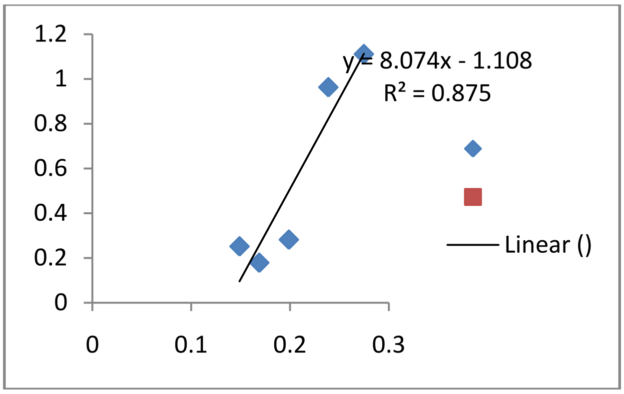

Fig: 7 Comparison of LAI Between direct and indirect method at 1ST day afternoon

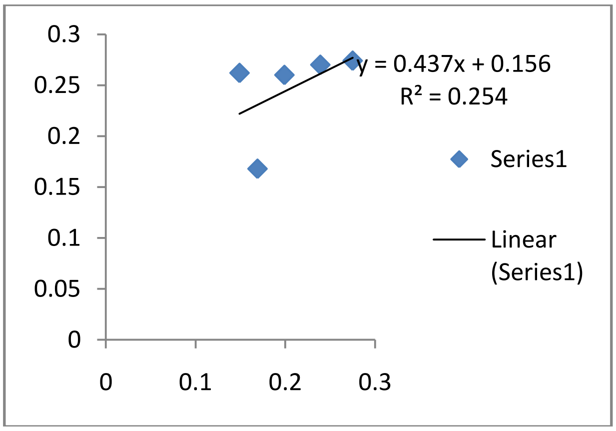

Fig: 8 Comparison of LAI Between direct and indirect method at 2ND day afternoon

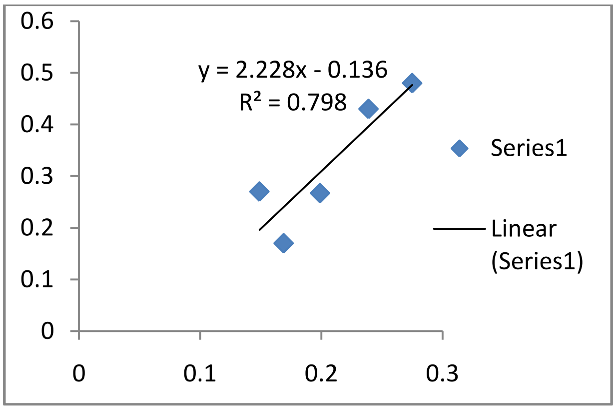

Fig: 9 Comparison of LAI Between direct and indirect method at 3RD day afternoon

The Performance of the AccuPAR Lp-80 Plant Canopy Analyzer (PCA) was compared to the direct methods. The PCA method was more rapid. Non destructive, and can be use over larger areas and for all plants. However, the PCA method has some limitations that the measurements must be made in overcast conditions or at sunrise or sunset. Measurements will not be accurate under direct light or very sunny condition. This may cause underestimation of the LAI.

Conclusion

It is considered that, the measurement of LAI by direct method is more precise, accurate than indirect method. Sometime, it gives underestimated LAI due to shrinkage of leaf, improperly passing through the camera position, dirty belt and wrong calibration. Furthermore, this method is tedious, time consuming, labor intensive and destructive.

The AccuPAR LP-80 is a very quick, non-destructive and easy method with carefully considered sensor position. However, the AccuPAR LP-80 is the least time consuming method to determine LAI. The main limitations of the AccuPAR LP-80 method was that it gave underestimated and inconsistent LAI values, and was severely affected by sunlight conditions, spatial variability and sensor position. However, the ability to easily obtain data without having to correct for limitation of the AccuPAR LP-80 method or other optical methods will likely depend on the ultimate use of data.

The AccuPAR LP-80 had LAI estimates statistically the same (but numerically lower) as direct LAI values. The main differences between two methods are the direct method requires converting LAI from leaf area and indirect method provides LAI values quickly. Both categories of methods are complementary as calibration is still necessary. A strong relationship was found between the direct method and the LAI-2000 PCA method. It was observed that, correlation co-efficient values (R >0.92) were obtained between these two method in all plants.

Generally, leaf area index is closely related to high-yield varieties of oil palm input parameter for growth and development. Highest LAI generates maximum yield and ultimately increased biomass. Besides, high yielding genotypes have taller plant, higher number of branches, nodules, leaves as well as leaf area index.

Further study should be conducted for large scale experimentation for soybean growth, development and energy calculation with various input parameters such as rainfall, temperature, fertilizer application, irrigation recording, biomass and chlorophyll.

Recommendations

After all observation and discussion it is clear that AccuPAR LP-80 is a very quick and easy method than others. All values such as LAI, above PAR, below PAR, leaf distribution, Zenith angle, latitude and longitude are gotten for one time data taken ,where manual method is so time consuming. But if we use AccuPARLP-80 then save time, labor cost and data will be reliable. So we can use this instrument measuring LAI of oil palm. It will be more effective when following precautions most be followed:

a) Should be careful during data taken using AccuPAR LP-80 and LI-3100
b) Leaflet should be fresh not shrinkage
c) Should be careful during distance measurement

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