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Leaf Area Index Model for Oil Palm FFB Yield Prediction

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ABSTRACT

Accurate and reliable computer simulation models are alternative sources of information for replacing or enhancing information derived from costly and arduous field experiments, especially for perennial crops like oil palm. Leaf area index (LAI) is an important parameter, which is used in growth modelling of crops. Direct or destructive method of LAI measurement is time consuming, laborious and involves high cost. Hence, in the oil palm, LAI need to be measured indirectly. A computer simulation model was developed using Visual C++ to simulate leaf area index for indirect estimation of LAI. Leaf area index was modelled based on OPSIM approach (Van Kraalingen, 1985). A significant relationship was found between the simulated leaf area index and measured leaf area index. A good relationship was also found between simulated LAI and Yield of the oil palm, which could be used as an indirect means of yield prediction of the oil palm. In sensitivity analysis, results showed that the simulated LAI was sensitive to both Specific Leaf Area (SLA) and extinction coefficient 'k'. From this study, it can be concluded that the LAI could be fairly estimated using the computer program developed.

INTRODUCTION

Estimation of leaf area is one of the important variables to determine plant growth. Leaf area is a valuable index of plant growth and is related to the accumulation of dry matter, plant metabolism and yield. Crop quality and maturity may also be related to leaf area. Accurate estimates of leaf area index (LAI) are needed in ecosystem analysis because of the importance of canopy structure in gas, water, carbon and energy exchange (Chen and Cihlar, 1996; White *et al.*, 1997; Hu *et al.*, 2000). LAI is defined as the projected leaf area per unit of ground area (Lang *et al.*, 1991). This important parameter is difficult to measure directly in oil palm. Direct or destructive method is time consuming, laborious and involves high cost. It is often not permitted in oil palm for possible negative effects on yield. Hence, accurate, rapid and easiest approach for determination of leaf area in oil palm is essential.

Computer simulation modelling is increasingly being used to simulate LAI, forecast yields, determines risk, and/or provides support for management decisions (McCown *et al.*, 1996; Heiniger *et al.*, 1997). Simulation models can replace expensive and time-consuming experiments and can be used as a research tool to support problem solving, risk assessment, and decision-making. It is especially convenient in perennial crops such as oil palm where field experiments are costly and time-consuming (Cox, 1996). The objective of this study was to develop a model to simulate leaf area index of the oil palm, which can be used to estimate crop yields.

LAI and Oil Palm Growth

Fig. 1 shows the basic growth process of the oil palm. Solar radiation is the major driving factor for physical growth and development of the plant. The physical yield of a crop can be determined by dry matter production, dry matter distribution and the dry matter content of the harvestable parts. Dry matter production is driven by physiological processes, such as gross photosynthesis, maintenance respiration and conversion of assimilate into biomass. In the short term, environmental conditions affect these processes in different ways: light influences gross photosynthesis and temperature affects mostly maintenance respiration. Leaf area is an important determinant of light interception. Growth of the leaves is a function of the total dry matter production and the fraction of dry matter partitioned into the leaves. The growth of the oil palm can be divided into vegetative growth and generative or reproductive growth. In other words, total dry matter consists of vegetative dry matter and bunch dry matter. Dry matter production is determined as the sum of production in fronds, bunches and trunk. Bunch dry matter production is usually estimated from fresh bunch weight and a factor of 0.53 is used when converting fresh to dry weight (Corley, *et al.*, 1971).

Simulation of Leaf Area Index

Leaf area index is the key parameter of a plant growth model, which is related to photosynthesis, accumulation of dry matter, plant metabolism and yield. Therefore, simulation of LAI is important to simulate yield. LAI can be simulated in two ways, such as based on growth function of the leaflet and experimental empirical formula. In this model, LAI was simulated based on growth function and then adjusted based on experimental findings.

Leaf area index is a function of leaf area per palm where the Leaf Area per Palm (LAP) can be expressed as a function of the leaflet weight and specific leaf area as shown in equation 1:

$$LAP = f\,(SLA, WOL) \quad (1)$$

where, SLA is the specific leaf area in m^2
WOL is the weight of leaflet in g

SLA or specific leaf area is dependent on age and varies from 3.5 – 8.0 m^2/kg (Corley, 1971). However, based on experimental results, SLA was assumed to vary from 2.5 - 5.5 m^2/kg in this model.

Mathematically, leaf area index (LAI) can be calculated as shown in equation 2:

$$LAI = LAP \times PD / 10000 \quad (2)$$

where, PD is the planting density in number of palms per hectare.

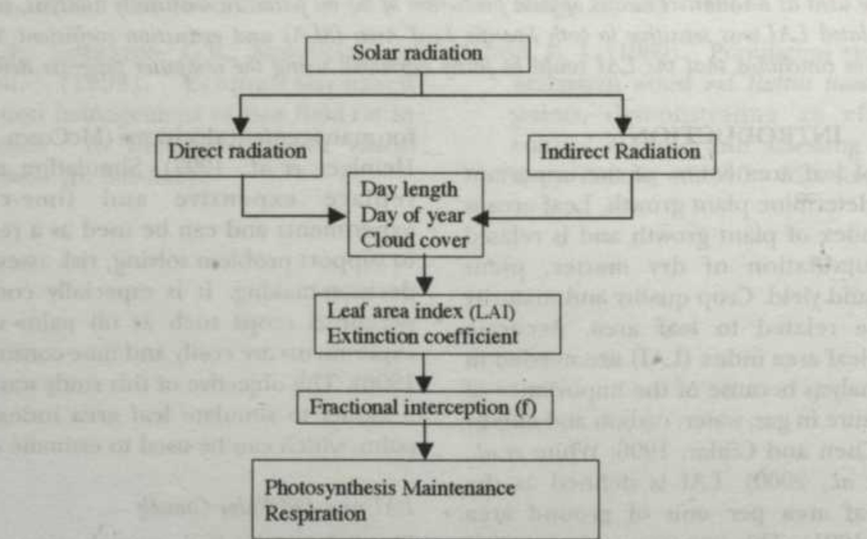

Fig. 1: Basic growth process of the oil palm (Modified from Weng, 1999)

The following shape factor and Dry-mass models were used to adjust the simulated LAI. The Dry-mass model is as shown in equation 3,

$$L_a = 99 \times L_m \quad (3)$$

where, L_m is the mass of leaflet in g, and L_a is the rectangular leaflet area in cm^2. The Shape factor model is represented in equation 4:

$$L_{ac} = 0.80 \times (L \times W) = 0.80 \times L_a \quad (4)$$

where, L_{ac} is the actual leaflet area in cm^2, L is the leaflet length in cm, and W is the leaflet width in cm. So, actual leaflet area can be calculated as shown in equation 5:

$$L_{ac} = 99 \times 0.80 \times L_m \quad (5)$$

Fig. 2 shows the flow charts of oil palm LAI simulation model (OPLAIM). In the algorithm, as represented in the flow chart, leaves growth (increasing) rate, death (decreasing) rate due to senescence and pruning, and weight of leaves were calculated. Then leaf area per palm and leaf area index were calculated. Direct (destructive) method was used to measure LAI from field (Awal, 2006).

RESULTS AND DISCUSSION

Relationship between Simulated LAI and Palm Age

Fig. 3 shows the relationship between simulated LAI and the palm age. A significant linear relationship was found between palm age and simulated LAI. Results indicate a high degree of association (r = 0.97) between palm age and simulated LAI with a standard error of estimation of 0.9. Simulated results also show that LAI of palms increases up to year 16 and then remains constant beyond that age.

Relationship between Simulated LAI and Measured LAI

Fig. 4 shows the relationship between simulated and measured LAI. The simulated LAI was overestimated compared to the measured LAI. Results show that the simulated LAI was overestimated by 13% for younger (2 to 3-year old) palms and by about 40% for palms over 15-years old.

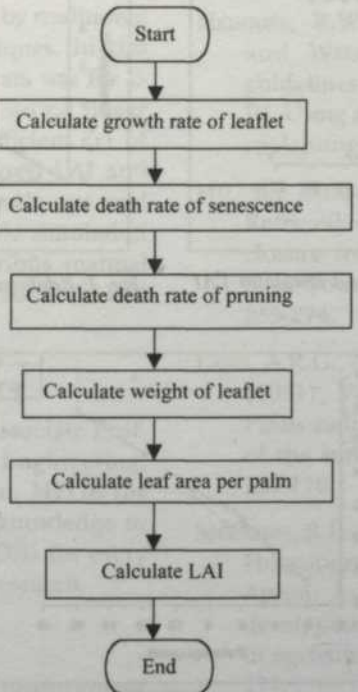

Fig. 2: Flow chart of the oil palm LAI simulation model

Palm Age versus. Simulated LAI and Measured LAI

Fig. 5 shows the simulated and measured LAI for 2 to 16-year old palms. The simulated LAI values were approximately the same as the actual LAI values for immature palms. However, the simulated LAI values were higher compared to measured LAI values for older palms. This is not surprising, since the simulation was done based on ideal conditions, whereas field data was collected from different treatment plots. The simulated LAI can be considered sufficiently accurate for comparison with the measured LAI.

Relationship between Simulated LAI and Simulated Yield

Fig. 6 shows the relationship between simulated LAI and simulated yield. A strong linear relationship was observed between the simulated LAI and the simulated yield with correlation coefficient, (r) = 0.96 and coefficient of determination (R^2) = 0.92 with the standard error of estimation being 1.21. Results indicate that the simulated yield can be adequately estimated from simulated LAI with P≤0.001.

Sensitivity Analysis

Sensitivity analysis was used to ascertain how a given model output varies with the input parameters. On the basis of this experience, specific leaf area and radiation extinction coefficient (k) were used to determine this sensitivity on the simulated LAI (*Fig. 7*). Results show that LAI was highly sensitive to both parameters. *Fig. 7* shows that the sensitivity of LAI to both parameters was similar in case of increasing values of these parameters, however, specific leaf area (SLA) was more sensitive than "k" in case of decreasing values of these parameters. It is therefore important to accurately estimate the value of "k" to be used in the model in order to minimize errors in the estimation of LAI of oil palm.

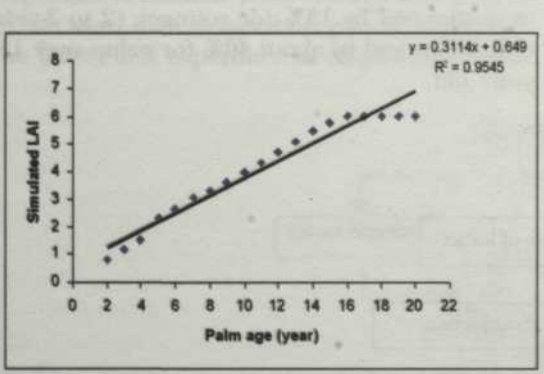

Fig. 3: Relationship between palm age and simulated LAI

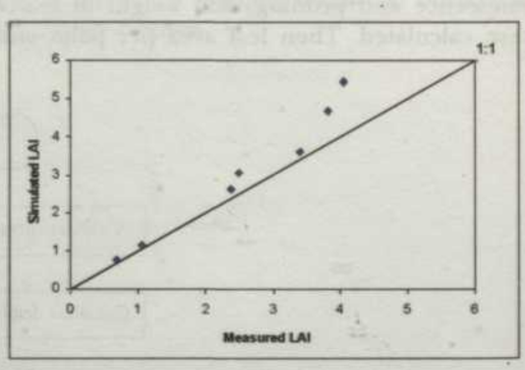

Fig. 4: Relationship between measured LAI and simulated LAI

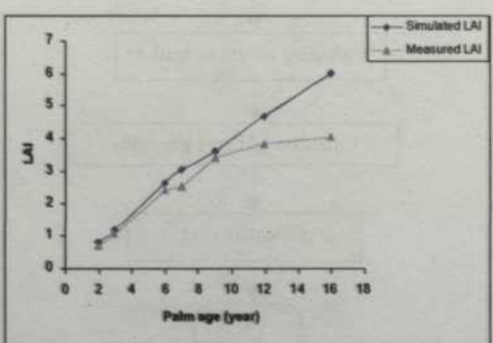

Fig. 5: Simulated LAI and measured LAI for 2 to 16-year old palms

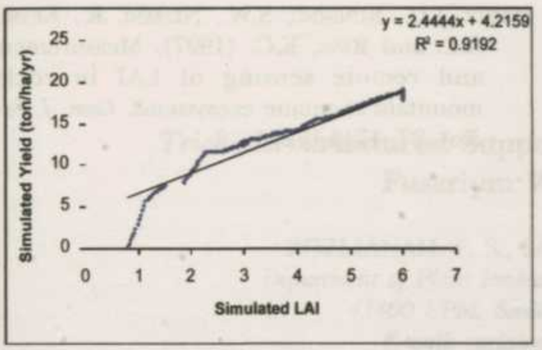

Fig. 6: Relationship between simulated LAI and simulated yield

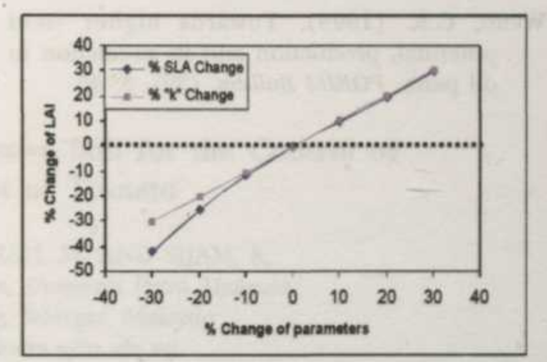

Fig. 7: Sensitivity of simulated LAI with change of SLA and extinction coefficient

CONCLUSION

This leaf area index (LAI) model enables researchers or farm managers to evaluate palm management strategies. It can trigger palm and soil management strategies if they are used as warning systems, e.g. monitoring leaf growth in relation to drought risks and nutrients deficiency. The LAI simulation results were reasonably similar to the field data. However, the predictions by simulation models may differ from actual field observations for a variety of reasons, and such deviations can be revealed instantly by traditional or by new field monitoring techniques. In this study, the LAI field experimental data was for 2-16 year old palms (Awal, 2006). A strong linear relationship with a correlation coefficient (r) of 0.96 was found between the measured LAI and the simulated LAI, and between palm age and simulated LAI (r = 0.97). This simple simulation technique could replace the laborious manual method or costly instruments, to predict the LAI and oil palm FFB yield.

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