Simulating Potential Growth and Yield of Oil Palm with PALMSIM

By Munir P. Hoffmann, Alba Castaneda Vera, Mark T. van Wijk, Ken E. Giller, Thomas Oberthür, Christopher Donough, Anthony M. Whitbread, and Miles J. Fisher

The growing demand for palm oil can be met by reducing the gap between potential yield and actual yield. Simulation models can quantify potential yield, and therefore indicate the scope for intensification. A relatively simple physiological approach was used to develop PALMSIM, which is a model that simulates, on a monthly time step, the potential growth of oil palm as determined by solar radiation in high rainfall environments. The model was used to map potential yield for Indonesia and Malaysia. This map could be used to identify degraded areas that have high yield potential for oil palm.

Indonesia (6) and Malaysia (4) have 10 million ha under oil palm and between them produce 81% of global production. The average yield for fresh fruit bunches (FFB) in Indonesia is 17 t/ha and in Malaysia is 22 t/ha. The area under oil palm has increased rapidly over the last 20 years, doubling in Indonesia from 2003 to 2011. Demand for palm oil continues to grow, but it could be met by intensifying production in existing plantations.

Some producers have reported average oil yields of 6 t/ha from 27 t/ha FFB over areas up to 150,000 ha, with yields of single blocks (30 to 50 ha) over 40 t/ha. These data are site and year specific, and offer little insight for intensification on a wider basis. Simulation models are a viable way to assess what potential and attainable yields might be (van Ittersum et al., 2013). But the simulation models that are currently available require detailed data to parameterize the model and run the simulations, which limits their usefulness to apply to a wide range of sites. The PALMSIM model simulates the potential growth of oil palm as determined by solar radiation on a monthly time step. PALMSIM was evaluated against measured yields under optimum water and nutrient management across Indonesia and Malaysia to test its usefulness as a land-use planning tool.

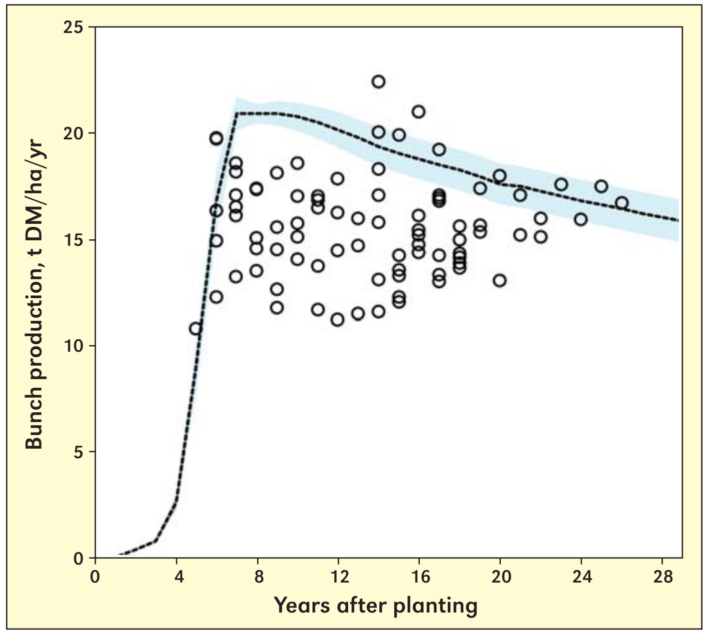

Figure 2. Simulated potential dry bunch weight averaged across all sites (curve) with standard deviation (grey spread) and observed dry bunch weight across sites from fertilizer plots.

Structure of PALMSIM

The model estimates solar radiation for a particular site based on latitude, slope, azimuth, and an index for monthly cloudiness. The general structure of the model is shown in **Figure 1**. It uses the leaf area index, calculated from frond mass using a fixed specific leaf area, to estimate the light extinction coefficient and applies a radiation use efficiency factor to the monthly integral of intercepted radiation. Assimilation is discounted by maintenance respiration and is then allocated for growth of fronds (70%), roots (18%), and trunk (12%) then reduced by factors to account for growth respiration. The mass of fronds is reduced by pruning, the amount depending on stand age, and the mass of roots by senescence; trunk mass is not discounted.

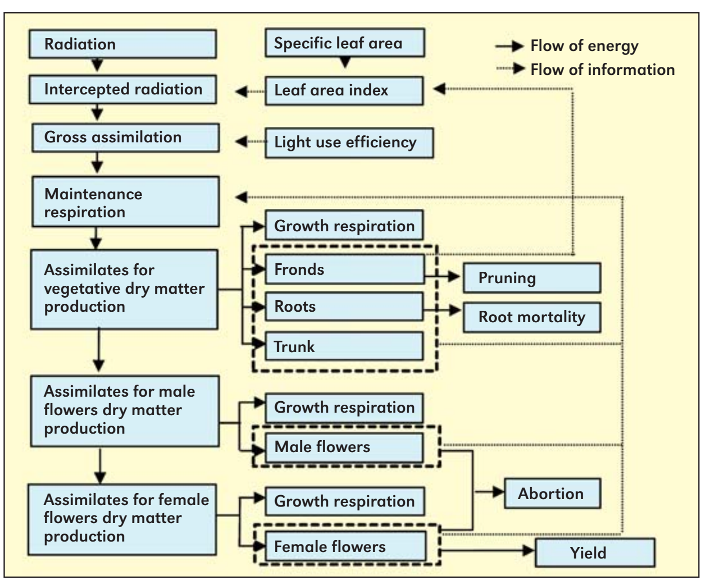

Figure 1. Schematic overview of PALMSIM. Dashed boxes represent standing biomass.

An inflorescence is initialized with each new frond, which after 15 months of age differentiates as male or female, the latter declining from 90% in year 4 to 60% in year 15 and onwards. The flowers develop over 18 months when pollination occurs followed by fruit growth for six months and harvest. Abortion of the inflorescence after pollination is assumed to be 10% per month. Bunch production is a function of calculated gross assimilation, that is, it is source limited.

Model Evaluation

PALMSIM was evaluated by comparing simulated yields with data from 15 trials at 13 sites in Malaysia and Indonesia, grown with optimum fertilizer and management and not water limited. Frond yield was available from 46 observations on 9 trials, and fresh bunch and oil yield from 89 observations on 15 trials. Fresh bunches were assumed to be 53% dry matter. Mean monthly cloudiness data from 2001 to 2010 was

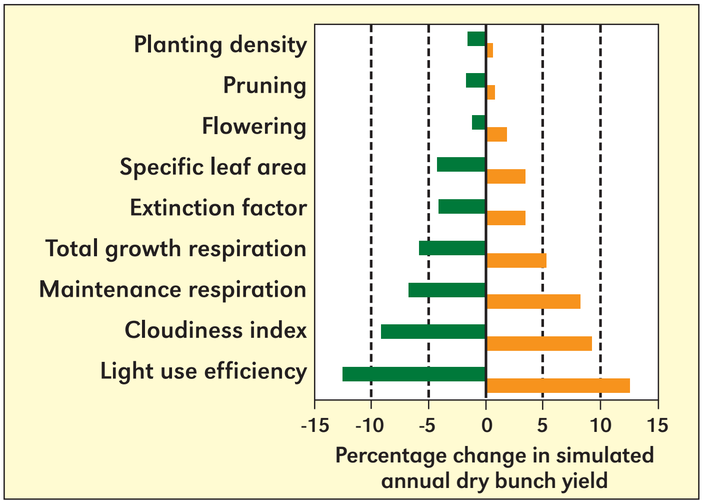

Figure 3. Results of the sensitivity analysis for simulated potential annual dry bunch yield in Sabah. The percentage change in potential yield after increasing or decreasing the value of the parameter along the y-axis with 10% is shown.

extracted from the NASA website. We used root mean square error (RMSE) to assess goodness of fit of the model. A sensitivity analysis was done by adding and subtracting 10% to the default values for 19 physiological, 2 management, and 1 climate parameters.

The PALMSIM model was run for 30 years on a 0.1° grid between 7° N to 6° S latitude and 96° to 129° E longitude, using NASA's mean monthly cloudiness data and digital elevation model, which mapped the simulated FFB yields.

Results

Total palm biomass increased until year 11 and remained constant thereafter. The biomass was initially dominated by fronds, but as the palms matured the trunk became dominant, as might be expected. Production of biomass remained constant after year 11 at 20 t/ha/yr, although fruit production fell as the palms aged. The mean measured yields of 18.5 t/ha/yr compared with 19.3 t/ha/yr for the simulations on palms 7 to 20 years after planting (**Figure 2**). The RMSE for the maximum observed yields and the corresponding predicted values for 12 sites was 1.7 t/ha/yr (8.75%).

The sensitivity analysis (**Figure 3**) showed that the most critical factor was light use efficiency with a 10% change reducing or increasing yield by 12%. Modifying the external driver of cloudiness index changed yield by 9%, while changing respiration changed yield by a little over 5%. Changing specific leaf area and the extinction coefficient gave about 3% change in predicted yield. Modifying flower development had little effect on predicted yield, while changing the agronomic factors of pruning and planting density had almost no effect.

Simulated yields were highest on the coastal plains of eastern and southeastern Sumatra and South Kalimantan Indonesia and Malaysia (**Figure 4**) with FFB yields of 36 to 48 t/ha/yr. Simulated yields were only 9 to 15 t/ha/yr in the mountainous areas of north-eastern Borneo, northern Sumatra and the central peninsular of Malaysia. The differences were largely due to differences in cloudiness.

Conclusions

PALMSIM is a relatively robust simple model that simulates well the potential growth and yield of oil palm across Malaysia and Indonesia. Combining it with maps of soil and land degradation could support the selection of potential new sites for plantations of oil palm. Further development of the PALMSIM model should include the effects of water stress on biomass production and yield of FFB. BC

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Drs. Hoffmann and Whitebread are with Georg-August-Universität Göttingen, Göttingen, Germany; e-mail: mhoffma@gwdg.de. Drs. Castaneda Vera, van Wijk, and Giller are with Wageningen University, Wageningen, The Netherlands. Drs. Oberthür and Donough are with IPNI Southeast Asia, Penang, Malaysia. Dr. Fisher is with Centro Internacional de Agricultura (CIAT), Cali, Colombia.

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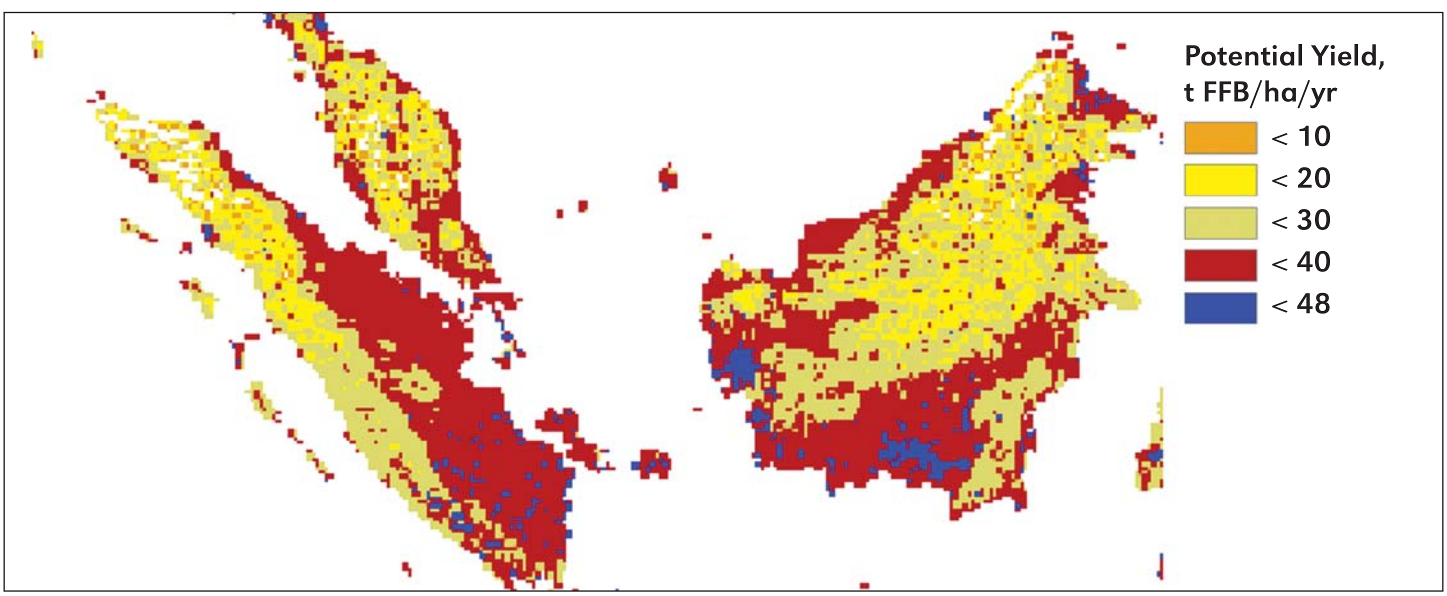

Figure 4. Potential yield (t FFB/ha/yr) map of the main oil palm regions in Indonesia and Malaysia based on simulation runs of the PALMSIM model. Simulation runs take into account incoming solar radiation, but ignore other limitations.