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Gearing Oil Palm Breeding and Agronomy for Climate Change

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Response of Oil Palm due to Climate Change: Simulations and Challenges

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INTRODUCTION

By 2050, Malaysia is predicted to be warmer by between 0.4 to 3.4 °C and experience a change in the amount of rainfall by between -0.7 to 32% (Zhao et al., 2005). By that time, world atmospheric CO_2 levels is expected to hit 450 ppmv (by volume) and the ground level ozone (O_3) 60 ppbv (Nakicenovic and Swart, 2000). Because oil palm is Malaysia's main agriculture crop, which currently is grown over 5 mil. ha of the country, we are concern how climate change would affect the growth and yield of oil palm. Mathematical models are immensely useful in this case as climate change field experiments involving such a large tree and long term crop such as oil palm is very challenging, costly, and time consuming. Several oil palm models have been developed such as by Huth et al. (2014), Henson (2009), Khamis et al. (2005), and van Kraalingen et al. (1989). Nonetheless, these models are unable to account for the effects of increased levels of atmospheric CO2 and groundlevel O_3 on the growth and yield of oil palm. Consequently, the purpose of this paper was to present the preliminary results of the ongoing work to develop an oil palm growth model to simulate the change in oil palm yield in Malaysia due to climate change. The other objective was to present some challenges in the modeling work.

MODEL DEVELOPMENT

The model has six core components. The first model component is the meteorology which simulates hourly weather properties based on daily weather data. The second component is the photosynthesis based on Collatz et al. (1991) which describes that photosynthesis is either limited to Rubisco, light, or carbohydrates sink. Leaf photosynthesis is then scaled up to canopy photosynthesis according to the method by Norman (1992). The third component is the estimating the effects of ground level ozone on oil palm photosynthesis based on work by Reich (1987), Seinfeld and Pandis (2006), and Young et al. (2009). The fourth component is the partitioning of the assimilates from photosynthesis for maintenance and growth respiration. The method by van Kraalingen et al. (1989) was adapted. The trunk height growth was based on an empirical relationship established from measured data from previous works. The growth of the oil palm canopy (width and height) was also based on measured data. One major deviation from van Kraalingen et al.'s model is this study's model accounts for the factor of water stress on oil palm growth and yield, where reduction in gross photosynthesis was directly in proportion to the degree of water stress. The fifth core component is the modelling the energy balance in the oil palm environment based on the Shuttle worth-Wallace (Shuttle worth and Wallace, 1985) equation. It allows for the interaction of heat fluxes between the tree and soil. The sixth component is the soil water movement and content (based on Darcy's law and Saxton and Rawls, 2006) for one or more soil depths. Thus, the oil palm growth and yield would decrease in proportion to the critical water level. The oil palm growth and yield model was a spreadsheet model, implemented in Microsoft Excel using a model development add-in known as BuildIt (Teh, 2015).

RESULTS AND DISCUSSION

Before the model could be used for predictions of climate change effects on oil palm yield, the model simulations of the growth and yield of oil palm were first validated against measured data from various published sources: Nazeeb et al. (2008, 1989), Foong (1999), Kwan (1994), Rao et al. (1992), and Tan and Ng (1976). Due to page constraints, Fig. 1 to 7 show the model simulations compared with measured data only for selected parameters and sources. Generally, model simulations agreed closely with measured data with some exceptions. This could be due to the high variability of field conditions that could not be captured by the model. Fig. 3a shows that there was a general close agreement between the simulated oil palm yields with that measured for various planting densities. Nonetheless, Fig. 3b shows that the model prediction errors tended to increase when predicting the oil palm yield for increasingly lower planting densities. One potential source of error is the microclimate conditions could not well captured by the model in conditions of lower canopy cover due to lower planting densities.

Table 1 shows the simulated change in mean oil palm yield due to climate change. Note that Table 1 is the updated results from that previously showed by Teh and Iba (2009). The results from Table 1 can conveniently be summarized into the following multiple linear regression (adjusted $R^2 = 0.925$ and all coefficients significant at 5% level):

$$\Delta Y = -0.917O_3 + 0.287CO_2 + 0.486\Delta R - 10.573\Delta T - 115.798 \quad [1]$$
$$(-0.786) \quad (0.410) \quad (0.304) \quad (-0.221)$$

whereΔY is the percent change in yield; O_3 and CO_2 are the atmospheric levels for ozone (ppbv) and CO_2 (ppmv), respectively; ΔR is the percent change in annual rainfall; and ΔT is the change in air temperature (°C). The values within the brackets in Eq. [1] are the standardized coefficients, and they indicate the relative importance of the variables in predicting, in this case, ΔY.

Eq. [1] shows that increasing CO_2 levels and amount of rainfall would increase oil palm yield, but the yield would instead decrease with higher air temperature and O_3 levels. Comparing the absolute values of the standardized coefficients in Eq. [1] indicates that oil palm yield is most sensitive to groundlevel O_3, followed by CO_2, then rain, and least sensitive to air temperature. That oil palm is rather robust to increases in air temperature but more sensitive to rainfall were also reported by Zhao et al. (2005).

If we take Malaysia, by 2050, to be warmer by 1.5 °C, have an atmospheric CO_2 level of 450 ppmv, and have a higher rainfall by 15%, the predicted mean oil palm yield, using Eq. [1], would increase by 5%, provided groundlevel O_3 does not increase and remain at 0 ppbv. Concentration of groundlevel ozone is difficult to predict as its concentration varies depending on location, elevation, season, and extent of anthropogenic influence. Nonetheless, groundlevel O_3 in the Northern hemisphere show a mean concentration value of 20-45 ppbv and increases by 0.2 to 2% per year (Vingarzan, 2004). If this trend is also true for Malaysia, then by 2050, Malaysia could see a groundlevel O_3 concentration of between 45 to 60 ppbv. This means that the mean oil palm yield, after accounting for the detrimental O_3 effects, could fall by between 36 to 50%.

The model developed thus far has several important assumptions, which are : 1) oil palm physiology does not change in response to climate change, 2) no differences in plantation management, 3) no changes to the influence of pests, diseases, and weeds on oil palm, and 4) increased rainfall does not cause flooding or increased soil erosion that would reduce soil fertility.

Further work is currently being done to improve the model's accuracy. The microclimate conditions under oil palm needs to be further studied, as well as the photosynthetic process of oil palm.

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Table 1. Simulated percent change in mean oil palm yield due to climate change.

		CO_2 (ppm)											
(°C)	(ppb)	400	450	500	550	400	450	500	550	400	450	500	550
ΔT	O_3	-30% ΔR				+0% ΔR				+30% ΔR			
+0	0	-33	-14	3	18	***	21	39	55	23	43	61	77
	30	-50	-33	-17	-3	-28	-10	7	21	-16	2	18	32
	60	-68	-52	-37	-24	-57	-40	-25	-12	-54	-39	-25	-13
	90	-82	-70	-57	-45	-78	-67	-56	-45	-79	-70	-61	-53
+1	0	-47	-29	-12	3	-13	7	26	42	11	32	50	66
	30	-64	-46	-31	-17	-40	-22	-5	10	-27	-8	8	22
	60	-79	-64	-50	-37	-67	-51	-36	-23	-62	-48	-34	-22
	90	-89	-79	-68	-57	-84	-74	-64	-53	-84	-75	-67	-59
+2	0	-62	-44	-27	-12	-26	-6	12	28	-1	20	38	54
	30	-76	-60	-45	-31	-52	-34	-17	-2	-37	-18	-2	12
	60	-86	-75	-63	-50	-76	-61	-46	-33	-70	-56	-42	-30
	90	-93	-86	-78	-68	-89	-81	-71	-62	-88	-80	-72	-64

**** indicates the oil palm annual yield at 14.5 t ha^{-1} which is the simulated mean annual yield under atmospheric CO_2 and O_3 concentrations of 400 ppmv and 0 ppbv, respectively, annual rainfall of 2500 m, mean minimum and maximum air temperature of 24 and 33 °C , respectively, and at planting density of 148 palms ha^{-1}. All other values are the percentage change in oil palm yield due to climate change, where shaded and negative values denote reduced yields.*

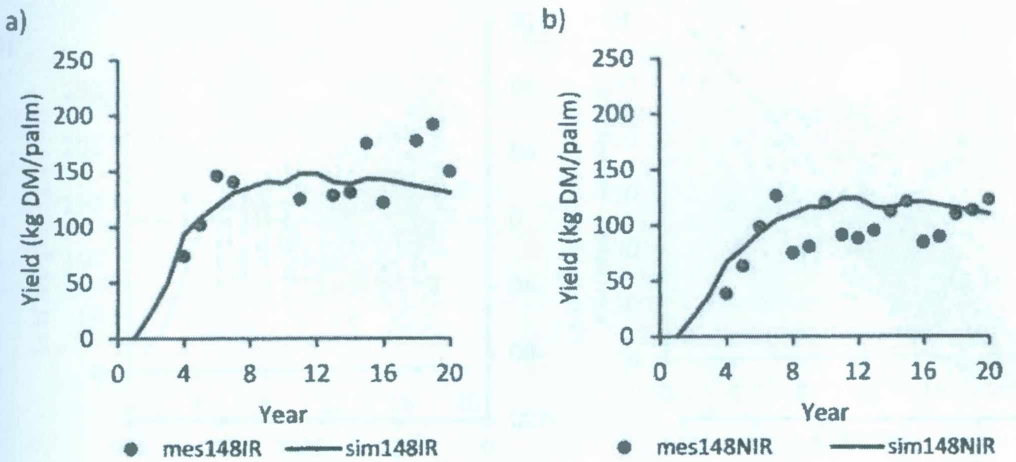

Fig. 1.Comparisons between simulated (sim148) and measured (mes148) oil palm yields at 148 palms ha^{-1} planting density (measured data from Foong, 1999). Oil palm yields: a) under irrigation (sim- and mes148IR) and b) under no irrigation (sim- and mes148NIR).

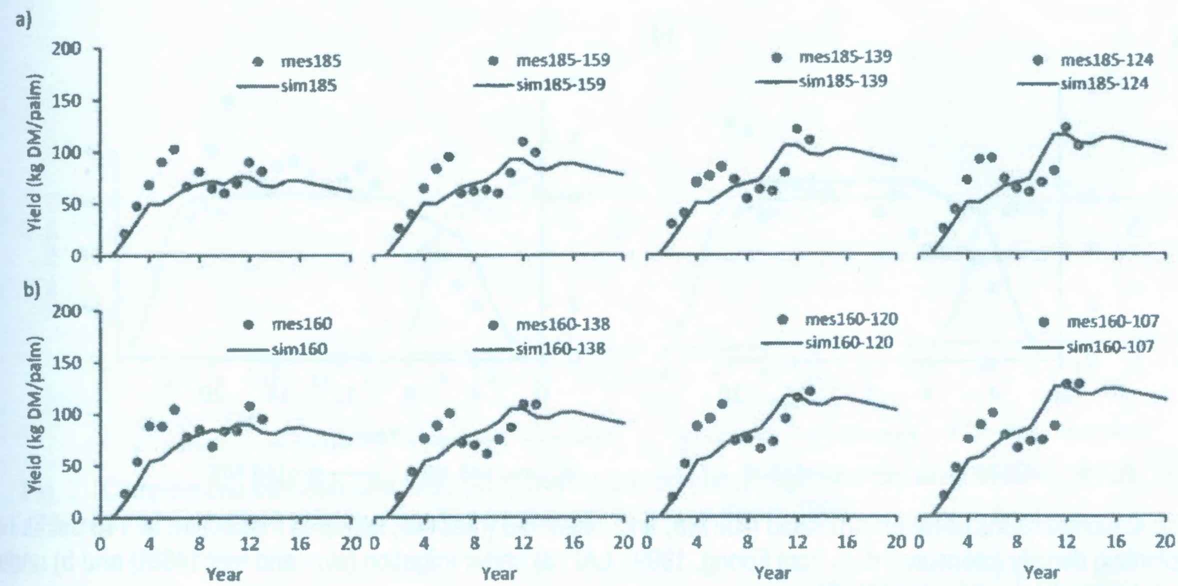

Fig. 2. Comparisons between simulated (sim185) and measured (mes185) oil palm yields at 185 palms ha^{-1}, then thinned to several planting densities (measured data from Nazeeb et al., 2008). Oil palm yields: a) at 185 palms ha^{-1} (far left; sim- and mes185), then at 185 palms ha^{-1}, later thinned to 159 palms ha^{-1} (sim- and mes185-159), 139 palms ha^{-1} (sim- and mes185-139), and 124 palms ha^{-1} (sim- and mes185-124), and b) at 160 palms ha^{-1} (far left; sim- and mes160), then at 160 palms ha^{-1}, later thinned to 138 palms ha^{-1} (sim- and mes160-138), 120 palms ha^{-1} (sim- and mes160-120), and 107 palms ha^{-1} (sim- and mes160-107).

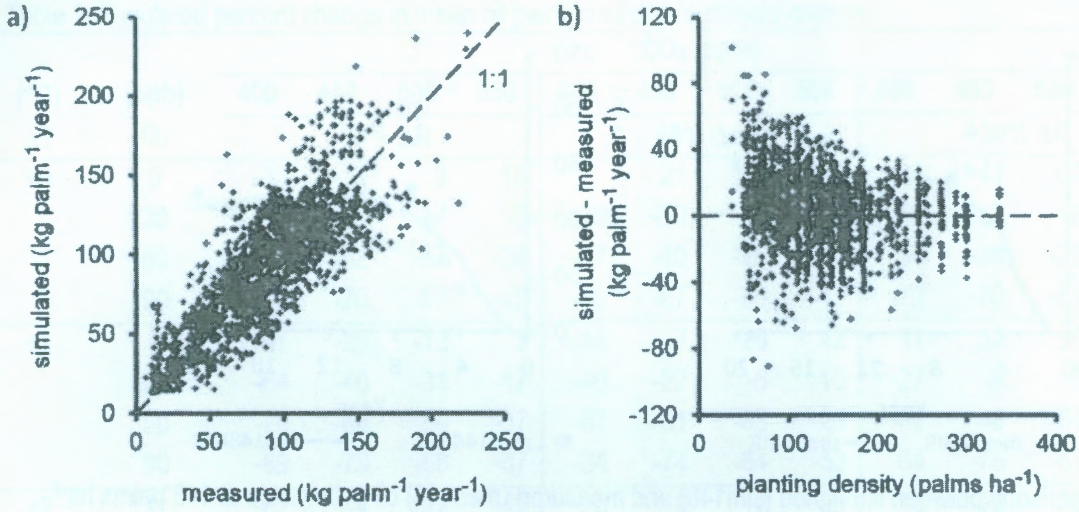

Fig. 3. Simulated and measured oil palm yields at all planting densities: a) comparisons for all planting densities, and b) scatter of prediction errors (difference between simulated and measured values).

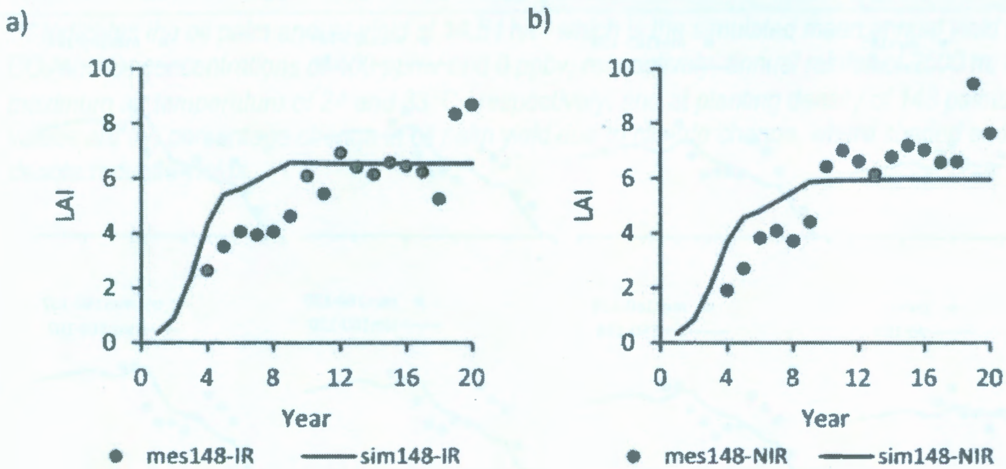

Fig. 4. Comparisons between simulated (sim148) and measured (mes148) leaf area index (LAI) at 148 palms ha^{-1} planting density (measured data from Foong, 1999). LAI : a) under irrigation (sim- and mes148IR) and b) under no irrigation (sim- and mes148NIR).

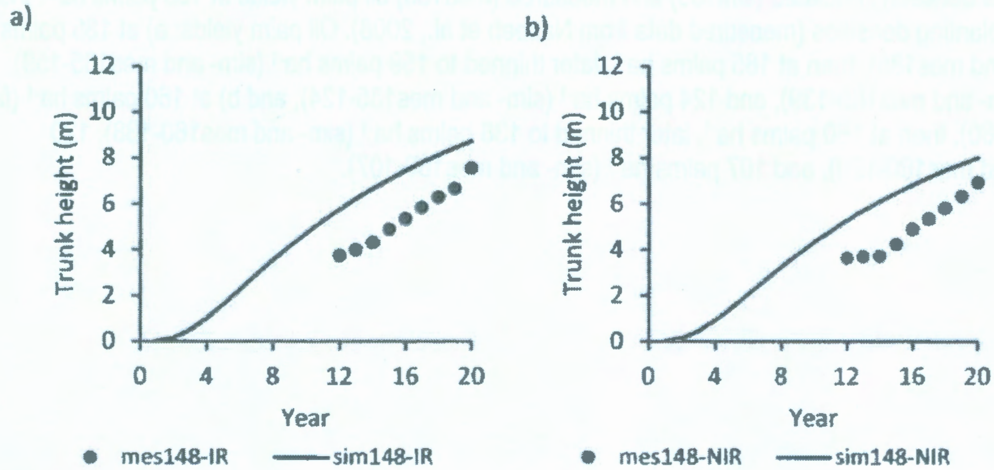

Fig. 5. Comparisons between simulated (sim148) and measured (mes148) trunk height (LAI) at 148 palms ha^{-1} planting density (measured data from Foong, 1999). Trunk height : a) under irrigation (sim- and mes148IR) and b) under no irrigation (sim- and mes148NIR).

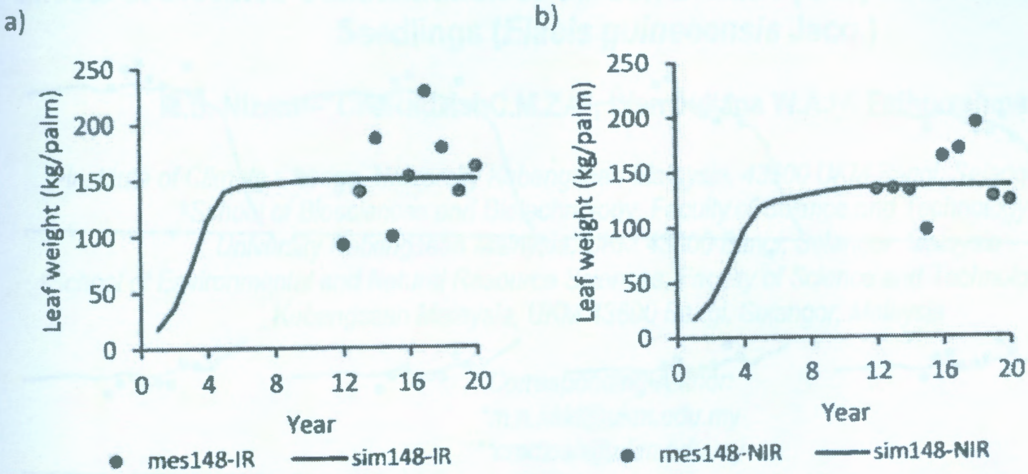

Fig. 6. Comparisons between simulated (sim148) and measured (mes148) leaf dry weight (LAI) at 148 palms ha^{-1} planting density (measured data from Foong, 1999). Leaf dry weight : a) under irrigation (sim- and mes148IR) and b) under no irrigation (sim- and mes148NIR).

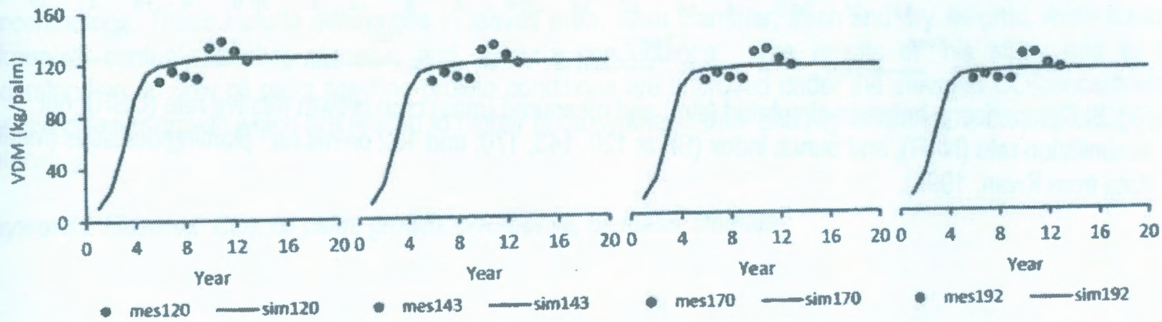

Fig. 7. Comparisons between simulated (sim) and measured (mes) vegetative dry weight (VDM) at 120, 143, 170, and 192 palms ha^{-1} planting densities (measured data from Kwan, 1994).

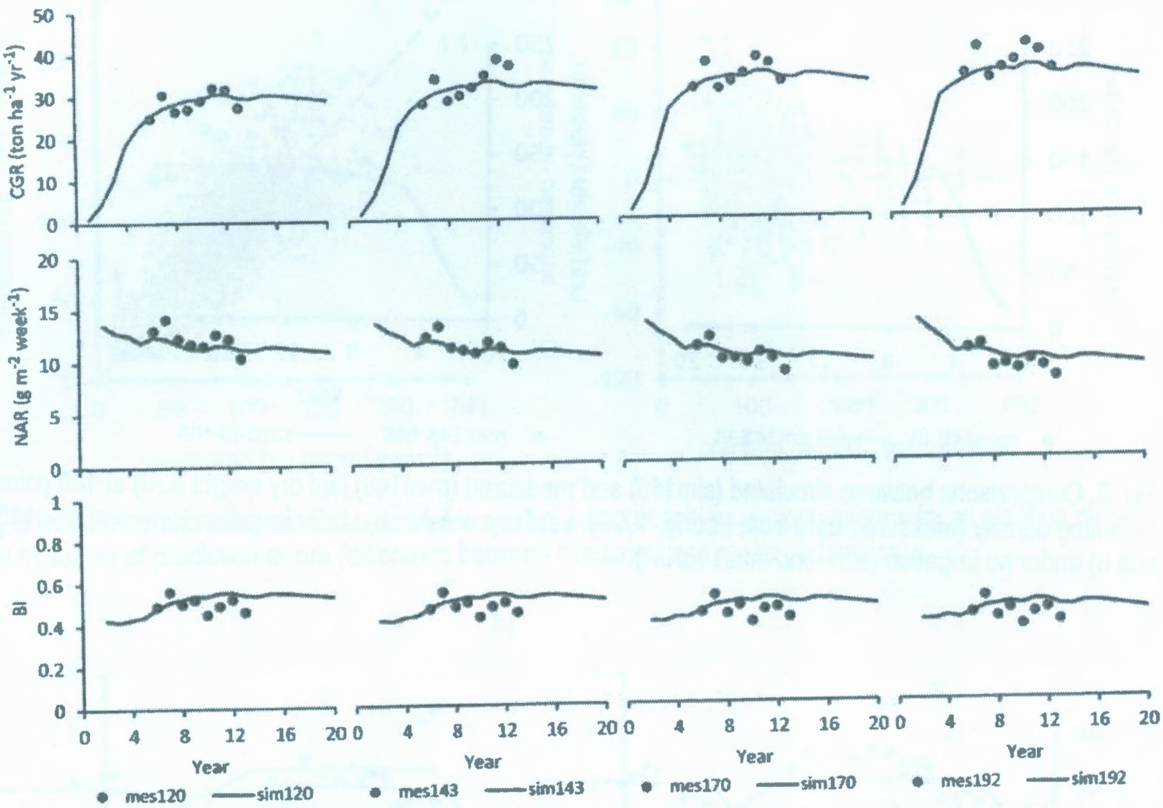

Fig. 8. Comparisons between simulated (sim) and measured (mes) crop growth relative rate (CGR), net assimilation rate (NAR), and bunch index (BI) at 120, 143, 170, and 192 palms ha^{-1} planting densities (measured data from Kwan, 1994).