Physiological study of three constrasting clones in Lampung (Indonesia) under drought in 1997.

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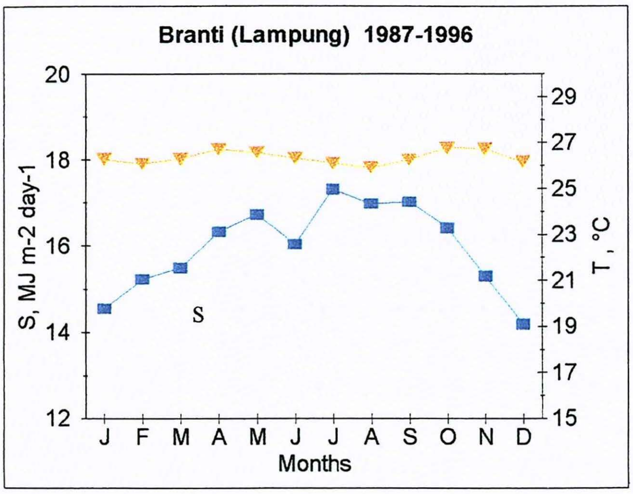
Abstract

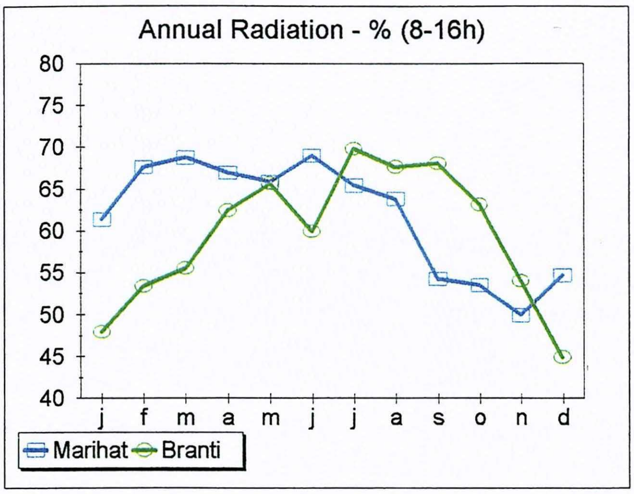
If all the Sumatra island presents a very suitable amount of rainfall for oil palm, some areas such as Lampung, due to the climatic phenomena "El Nino", shows in the annual rainfall distribution an increase in irregularity with some years having a very severe dry season with at least 3 or 6 months under 100 mm. It is well known with oil palm that a lack of rainfall may affect strongly the production, until 70 % with a water deficit of 600 mm upon at least 2 years after. The physiological responses of oil palm trees under drought have already been fully investigated in Benin and in Côte d'Ivoire. Selection criteria investigation regarding drought tolerance/resistance have been undertaken in these countries. With this same purpose in mind, genetic x environment trials were realized in different agroecological zones in Indonesia. In Kebun Bekri (PTPN VII, Bandar Lampung), a genetical trial including 8 clones with different genetical origins was planted in December 1992. Due to abnormality problems, only 3 clones (MK93 ; MK60 ; MK56) were selected to be studied in physiology and phenology. During September 1997, in the middle of a severe dry period, leaf photosynthesis rate and transpiration rate were measured with a portable analyzer LCA2 (ADC, England), between 7 a.m. and 16 p.m. relative to some environmental factors as PAR (Photosynthetically Active Radiation), VPD (Vapour Pressure Deficit), and air temperature. Studied clones were characterised by biometrical trends such as LAI (estimated using the PCA-LAI 2000 of Li-Cor), trunk height and phenological observations (sexe ratio, inflorescences positions). Diurnal trends of leaf gas exchange clearly pointed out that after 8 a.m. there was a very large reduction of the net photosynthesis of the three clones (from 20 $\mu mol.m^{-2}.s^{-1}$ to 5 $\mu mol.m^{-2}.s^{-1}$) which could only compensate for maintenance respiration cost. Stomatal conductance trend was fully related to the net assimilation course (maximum before 8 a. m. with gs around 4 $mm.s^{-1}$; after being very near zero) due to an important increase of the VPD which roze quickly by 2 kPa at 8 a.m. At that time of the year, September 97, the water deficit was already around 300 mm (IRHO method) rising 735 mm at the end of 97. Regarding the effect of the VPD on net photosynthesis, differences between clones were observed with the clone MK93 (GB 30 D x RS 04 T) showing the lowest sensitivity to VPD. From this, it can be expected that it may show a better yield comparatively as was shown in Marihat Research Station on very similar clonal material. Biometrical respective characteristics of the studied material indicated very small differences within clones. Sex sequences inflorescences highlighted the important male cycle which is quite unusual for young trees : this can be attributed, to the severe drought in 1994 which occurred just two years after planting.

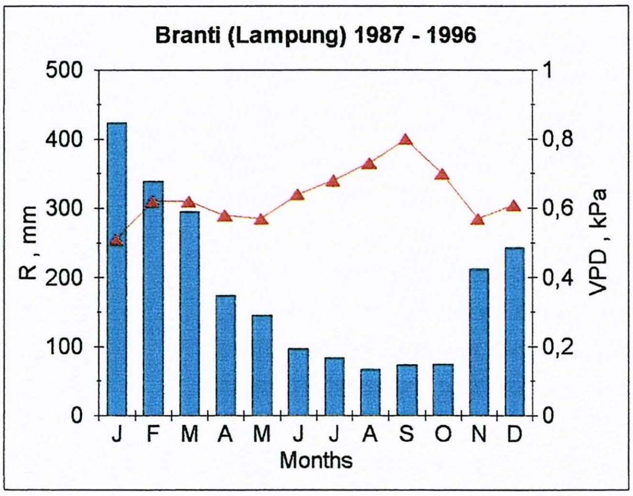
Introduction

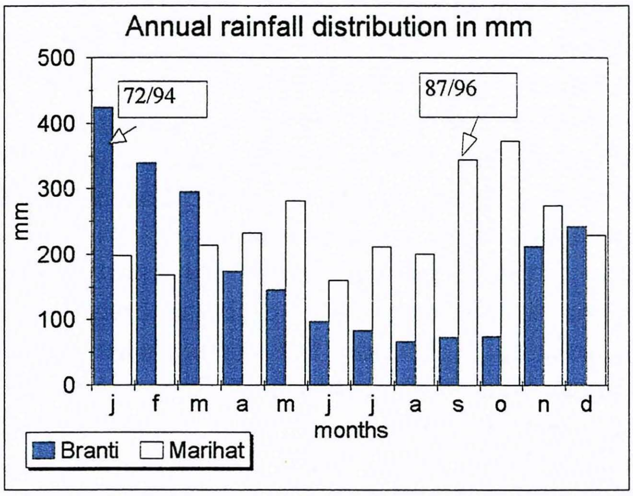
The climatic phenomena "El Nino" provoked a severe drought last year in some parts of South-East Asia including South Sumatra, Java and Papwa New Guinea. In areas such as Lampung, the rainfall distribution shows an increased irregularity over time, with some years having at least 4 or 5 months under 100 mm. During the period 1970-1997, the dryest years being 1972, 1982, 1983, 1987 and 1994) water deficit ranging from 400 to 700 mm were experienced. As far as oil palm is concerned, it has been proven many times that the dry period has a significant effect on yield. According to Hartley (1988), the optimum condition required for the growth and development of oil palm is 2000 mm, well distributed over the year, with less than 3 months under 100 mm. Some agroecological zones such as Pobè (Benin) show water deficits up to 750/800 mm (Cornaire et al.,1993). Many studies have already shown that the variation in annual water deficit can account for 80 to 85 % of the yield variations (Caliman, 1992). Many regressions have been established (Bredas et Scuvie, 1960; Dufour, 1988) between the yield and rainfall experienced one or two years before.

In order to select planting material that was well adapted to the various agroecological conditions in Indonesia, multilocal clonal trials were established by IOPRI in Lampung, Riau, Jambi and Kalimantan. In Lampung, a new clonal trial was set up in PTP Nusantara VII, Kebun Bekri (Afd III, Block 423/463) to identify tolerant planting material for such a zone. Varying sensitivity of some clones to atmospheric drought have been clearly identified (Setiyo et al., 1996). This confirmed that which was observed by Dufrêne (1989) in Côte d'Ivoire on the control family (LM2T x DA10D).There is a clear decrease when the VPD (Vapour Pressure Deficit) is under 1.7 kPa. Also, high correlation between the leaf photosynthesis and the stomatal conductance has been pointed out at saturated light (Lamade et al., 1996) even in areas such as North Sumatra without any water deficit. The main goal of the present study is to follow the physiological behaviour of clones on trial BI 01-S during the severe drought of 1997 and to identify possible differences within them relative to leaf photosynthesis, stomatal conductance and transpiration. In complement , respective sexual sequences are discussed within two contrasting clones MK60 and MK93.









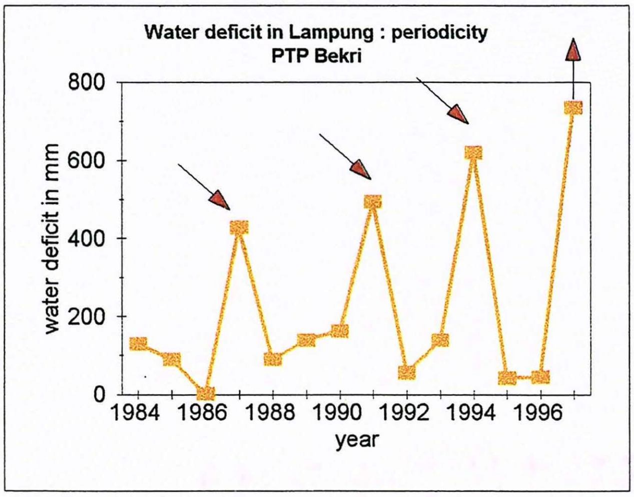


Fig. 1

Meteorological characteristics for South Lampung, Branti Meterological Station (5°16'S, 105°11'E). Comparisons with North Sumatra, Marihat Research Station (2°55' N, 99°05' E).

Material and method

Climatology

Two main sources of climatological data have been investigated to analyse the water deficit in Bekri Estate. The first is the data collection of the Meteorological Station of Branti (5°16'S, 105°11'E) from 1987 to August 1997 (daily record), the second is the monthly records of rainfall and water deficit (following the IRHO method IGM 12) in Bekri from 1987 to August 1997. In Lampung the daily mean radiation is equal to 15.9 $MJ.m^{-2}.day^{-1}$, mean temperature is 26.4 °C (minimum temperature 21.4 °C, maximum temperature : 31.7 °C) and total annual rainfall equal to 2890 mm. The mean daily VPD is 0.63 kPa (minimum : 0.51 kPa in January, maximum in September with 0.8 kPa).These conditions seems not, in average, far from what have been found in Marihat (Lamade & Setiyo, 1996 b) with a mean daily radiation of 16.24 $MJ.m^{-2}.day^{-1}$ and an annual rainfall of 2890 mm. The main difference between Bekri and Marihat is without doubt, the annual rainfall distribution. Fig. 1 shows the different seasonnality trends between Marihat Research Station and Bekri Estate, the latter indicating, several months under 100 mm every year, from July to October. In 1997, the dry period had already started in June. In September, during the experiment the water deficit was around 388 mm and this increase to 735 mm by the end of the year.
Since 1987 "drought cycles" have become shorter, from a 5 year period to 3. 1994 showed a water deficit of around 600 mm. This is more or less comparable to 1997 and was used as the base to simulate photosynthesis.

Soil

Following soil analysis (Table 1), the soil at the studied site does not show texture differentiation along the profile depth.

Table 1. Physical characteristics of the soil in Bekri estate, on block 423/463. Soil samples were collected with a dutch auger with two samples per level.

Depth cm	pH H20	pH KCL	sand (%)	clay (%)	alluvion (%)
0-20	5.28	4.02	33	17	50
20-40	5.26	4.00	22	11	67
40-60	5.17	3.99	26	12	62
60-80	5.11	3.92	24	10	66
80-100	5.09	3.99	24	16	60
100-120	5.05	3.95	26	9	65
120-140	5.15	3.90	26	16	58
140-160	5.19	3.92	26	14	60
160-180	5.30	3.96	30	12	58
180-200	5.34	3.98	29	15	56
220-200	5.50	4.29	28	13	59
220-240	5.25	4.15	28	15	57

It is a clay soil limited at 2.40 m by a concretion table quite impenetrable by the roots.

Along the profile, dark red and grey spots indicate the water table fluctuation previous hydromorphy phenomena. Roots can be found until 2.40 m.

Material

In 1992 a genetical trial was planted in kebun Bekri (Afd III, Block 423/463), including 8 clones (Table 2) with 80 trees per clone.

Table 2. Clonal trial block 423/463 , Afd III. (BI 01 S), planting 1992, Bekri Estate, Lampung. The studied clones are :MK60, MK56 and MK93. For them, abnormality rate are mentioned.

clones	origin	abnormality (%)
MARK 33	LM239T x LM270 D	
MARK 56	DA 123 D x BJ 221 P	3.6
MARK 58	BJ 13 D x LM07 T	
MARK 60	LM07T x DA 128 D	29
MARK 65	LM38T x LM270 D	
MARK 70	LM09T x DA 18 D	
MARK 93	GB 30 D x RS 04 T	3.8
SOC 2202		

Due to abormality problem only 3 clones were chosen to be studied : MK93, MK60 and MK56 which showed reasonnable abnormality rates.

Method

Physiology

The measurements of the leaf photosynthesis and transpiration were done with a Parkinson Leaf Chamber (PLCN2) and an IRGA portable analyzer, LCA2 (ADC, Analytical Development Compagny, Hoddesdon, U.K.). The method followed that of Lamade (1996). All measurements were done on leaf rank N° 9 which was supposed to be the more active . Leaflets around B point were experienced between 7 a.m. to 17 p.m. A total of five trees per clone were sampled for the physiological measurements. Net CO2 assimilation rate (NP) and transpiration rates were calculated following that of Dufrêne & Saugier (1993) . Leaf temperature was calculated from the energy balance equation (Parkinson, 1985) which enabled the calculation of stomatal conductance (gs). Simultaneously, the PAR (Photosynthetic Active Radiation) and air temperature were recorded with specific sensors inside the leaf chamber.

Environmental conditions

During the experiment, an external PAR sensor (JYP 1000, SDEC France) connected to a data logger (Delta T Devices, England) followed the daily radiation trend among the studied trees. A thermohygrometer VAISALA (Finland), placed near each observation point was used to estimate the VPD (Vapour Pressure Deficit) outside the photosynthetic chamber.

LAI

The leaf area index of the respective studied material was estimated with the rapid method already tested in Lamade & Setiyo a (1996) with the PCA LAI-2000 of Li-Cor (USA, Nebraska) and also with the classical IRHO method (Tailliez & Koffi, 1992). Results are shown in Table 3.

Table 3. Vegetative characteristics of studied clones, MK60, MK93 and MK56. Density : 138 trees/ha, nb of fronds per tree : around 39, SLW : specific leaf weight in g. DM.m-2. Samples : 20 trees per clones. s.e. standart error.

clones	LA m2	LAI -PCA	height cm	nb leaflets	SLW
MK93	2.80	3.14	91.8	461	122
s.e.	0.04	0.18	1.39	5.7	2.3
MK60	3.32	3.31	96	538	115.8
s. e.	0.06	0.18	2.78	2.7	6
MK56	2.92	3.67	97.7	500	125
s.e.	0.09	0.12	2.53	8.2	3.6

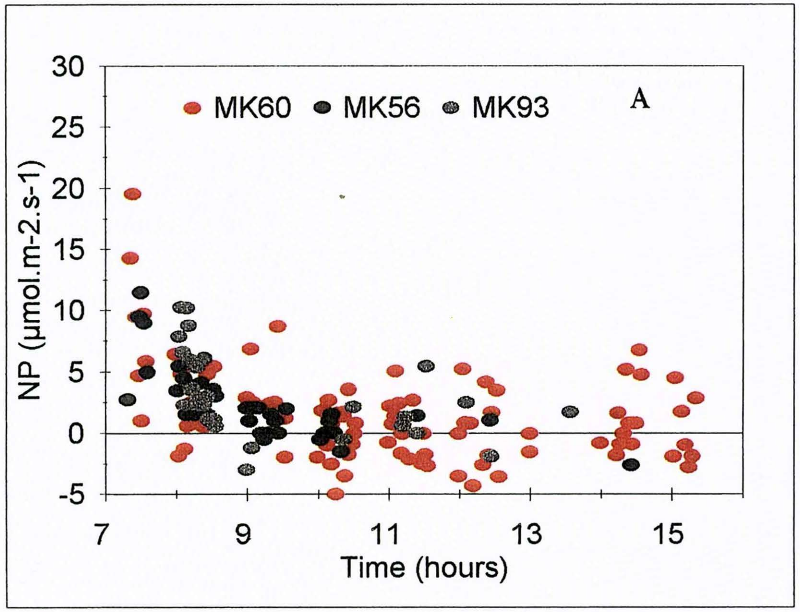
Phenology

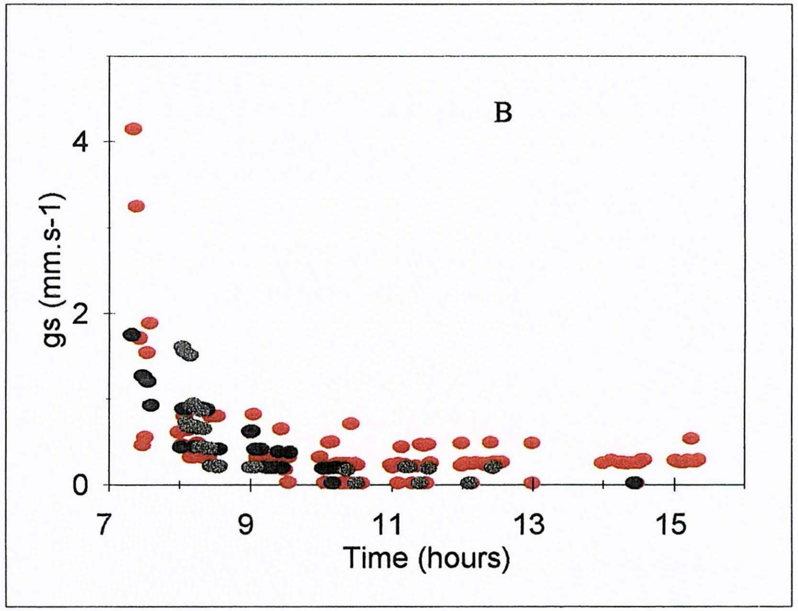
In order to investigate possible effects of the drought on sexualisation cycles, two contrasting clones (MK60 and MK93) were observed following phenological routines described in Lamade et al. (1998). 20 trees have been studied per clone. At each leaf axil, existence and kind of inflorescences existed was determined such as abortion (A), male (M), female (F) or hermaphrodite (H) flowers. Observations involved date of leaf emission, full opening of each successive leaf at rank one, inflorescence anthesis, bunches harvesting and the cut of the leaf. Fruit bunch weight, rachis and petiole lenght were measured were needed.

Results

Analysis of the environmental conditions

In September 1997, the water deficit was appromatively 300 mm and palm trees were already suffering from water stress : around 6 spear leaves non opened to stage rank were identified at this period. This water stress was confirmed by recording daily conditions of humidity and air temperature . Fig.2c shows the quick increase of the outside (outside the assimilation chamber) VPD (a characteristic involving both air temperature and relative humidity). Already by 8 o'clock in the morning, the VPD was up to 2 kPa and increased to 5 kPa by midday. Several studies (Smith, 1989, Dufrene, 1989, Setiyo et al. 1996) have already shown the high sensitivity of oil palm to atmospheric drought. Air temperature was increased quickly between 26°C by 7 a. m. and 38 °C by 10 o'clock. Daily radiation increases quickly to 1500 $\mu mol.m^{-2}.s^{-1}$ (Lamade & Setiyo, 1997) by 10





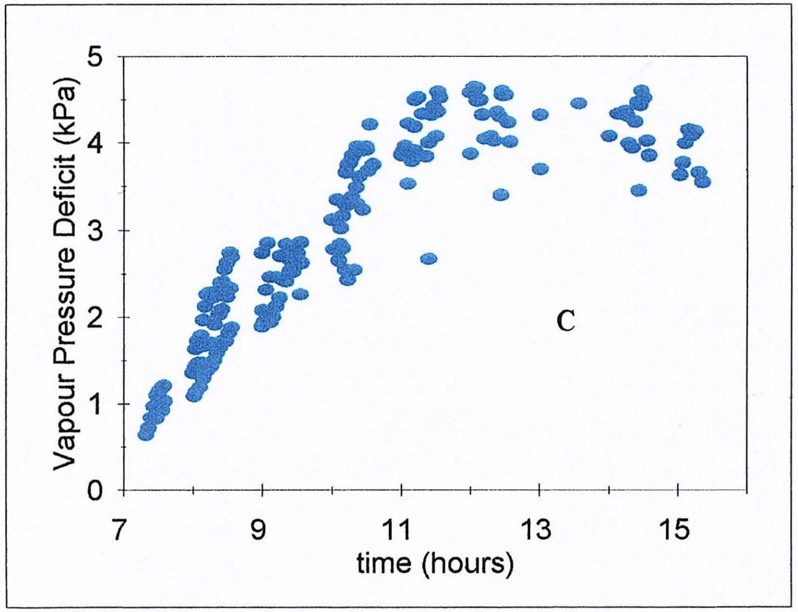


Fig. 2

Diurnal trends for NP, GS and VPD in Bekri on Sept 97
Physiological measurements on clones MK60,MK93, MK56
A: Net photosynthesis NP, and time of the day
B: stomatal conductance GS and time of the day
C: VPD (vapour pressure deficit) and time of the day

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Daily variation of leaf photosynthesis and stomatal conductance.

In Fig. 2 a and 2 b it is possible to see the daily trends of two important physiological parameters : net photosynthesis (NP in $\mu mol(CO2).m^{-2}.s^{-1}$) and stomatal conductance (GS in $mm.s^{-1}$) from 7 a.m. to 17 p.m for three clones (MK60, MK93 and MK56). Obviously, after 8 a.m. a net decrease of photosynthesis was observed for all clones. Low values of -5 $\mu mol.m^{-2}.s^{-1}$, equivalent to dark respiration, were seen in all clones. The clone MK60, showed the highest photosynthetic rate before 8 a.m. (near 20 $\mu mol.m^{-2}.s^{-1}$). This low photosynthetic activity during the day on that specific dry period has to be stared in relation to the stomatal regulation. Simultaneously it may be observed after 8 a.m. a very strong decrease (Fig. 2. B) of the stomatal conductance GS, which show a maximum around 4 $mm.s^{-1}$ between 7 and 8 a.m. (Clone MK60).
Lack of water uptake by the roots is responsible for the low photosynthetic rate compared to the potential seen in Marihat , but high VPD is more responsible for the total decrease in both stomatal conductance and net photosynthesis.

Discrimination within clones by the the relation between the stomatal conductance and the VPD

In Fig. 3.a , the observations for MK60, MK53 and MK93 of GS have been plotted versus the VPD values inside the leaf chamber. Data was fitted with a non linear regression ($GS = A*exp(-B*VPD)$). Estimations of parameters A and B and confident intervals at 95 % are shown on Table 4.

Table 4. Relation between GS (stomatal conductance in mm.s-1) and VPD (Vapour Pressure Deficit in kPa). Experimental data were fitted with a non linear model (GS = A* EXP(- B *VPD)) with A and B as estimated parameters with the SAS system (SAS, 1992). Fisher tests are done on model. Confident interval (c.i.) are given at 95 %.

clones	A	B	Fisher test
MK60	111.13	1.15	271.24
c.i.	(64.71; 157.54)	(1.04; 1.26)	P<0.001
MK56	9.68	1.11	211.12
c.i.	(5.91; 13.45)	(0.93; 1.28)	P < 0.001
MK93	12.49	0.91	192.16
c.i.	(6.21; 18.78)	(0.73; 1.09)	P < 0.001

It is obvious the clone MK60 shows a significantly different pattern to the others: confident interval of A and B estimation are not overlapping. This clone, which at the

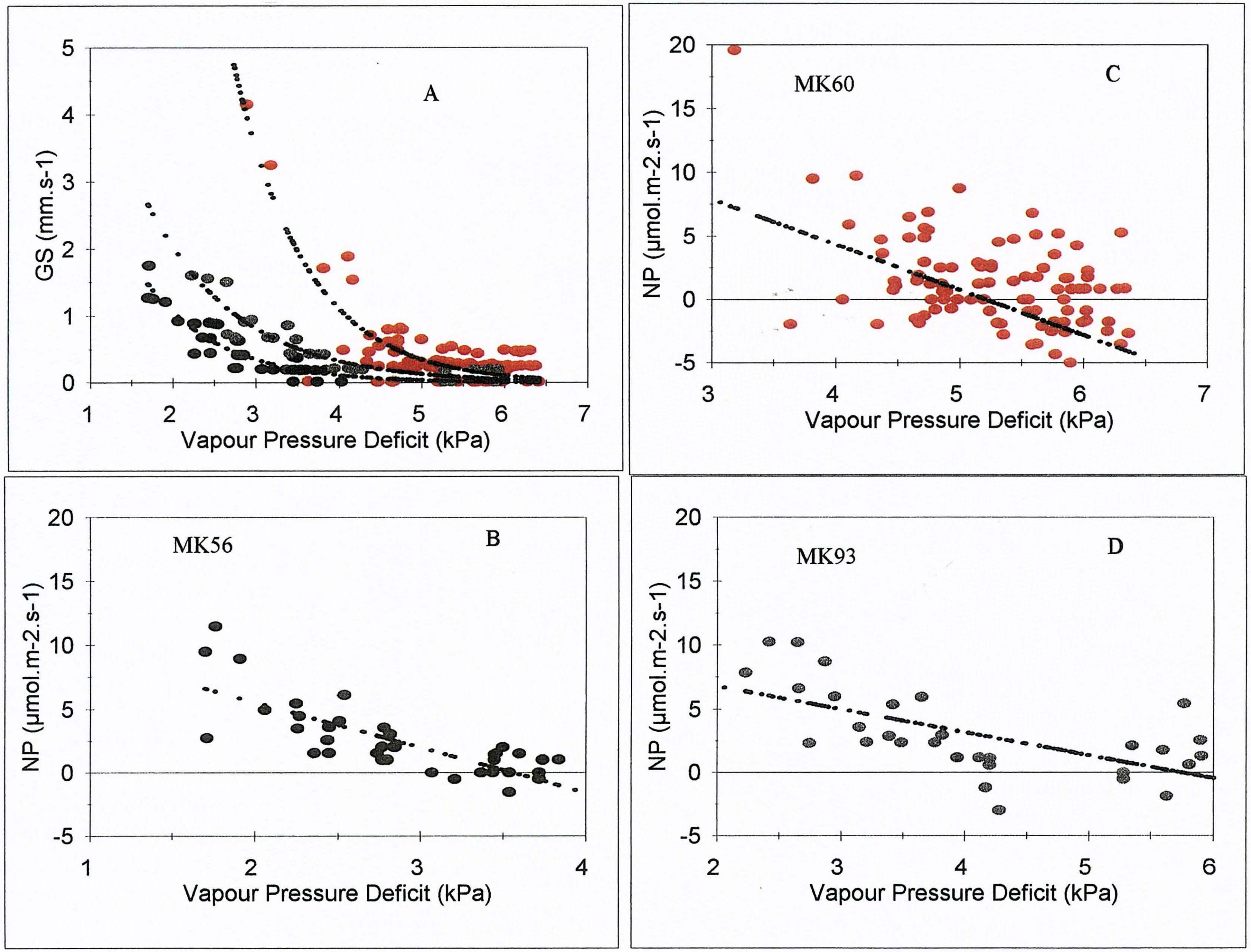

Fig.3 Relation between GS, NP and VPD outside the chamber
A: relation between GS and VPD for the 3 clones
data are fitted with a non linear regression
B,C,D : relation between the net photosynthesis and the VPD
for MK56, MK60 and MK93

same time shows the highest stomatal conductance value, seems to be very sensitive to the VPD. In all these results day effect may be not excluded from conclusions...

Effect of VPD on photosynthesis : difference within clones

Photosynthesis is strongly affected by the VPD. In Fig. 2 b,c,d photosynthesis data versus VPD were fitted with linear regression. Respective regression coefficients, intercepts and correlation coefficients are shown in table 5 for all clones.

Table 5. Effect of the VPD (Vapour Pressure Deficit in kPa) on the net photosynthesis (NP in µmol.2.s-1). Experimental data were fitted with linear model : NP = A-B*VPD with A and B as intercept and slope with the SAS system. Confident interval (c.i) are given at 95 %. Fisher test on model are done for each studied clones. D.f. : degree of freedom. r^2 : correlation coefficient.

clones	A intercept	B slope	r^2	Fisher test
MK56	12.65	-3.56	0.62	62.34
s.e.	1.33	0.45		P< 0.0001
d.f.	38			
MK60	18.59	-3.56	0.29	43.02
s.e.	2.73	0.51		P<0.0001
d.f.	103			
MK93	10.45	-1.82	0.39	18.42
s.e.	1.79	0.42		P<0.0002
d.f.	29			

There is, obviously, an important scattering of the experimental points. This is due to the difficulty in selecting data with radiation values up to 1100 µmol.m^{-2}.s^{-1} which compared to what was done in previous works (Lamade & Setiyo, 1996 b). Poor correlation should also be noted. Nevertheless it is possible to see that the clone MK93 seems less sensitive to the VPD with a gradient of 1.82 compared to MK60 (slope :3.36) and MK56 (slope : 3.55).

Phenology

Using phenological observations both MK93 and MK60 were investigated. They present different sex ratios with 0.4 for MK60 and 0.44 for MK93. If we compare the composition of all individual crown (Table 6), the main difference within both studied clones was the abortion rate : on an average of 18-19 inflorescence on trees, the mean individual crown composition shows an average of 5.21 for MK93 abortion against 7.10 for MK60. That affect strongly the sex ratio more than the respective male/female composition. The respective length of male/female/abortion cycle is also different within both clones MK93 and MK60. On table 6 you can see that the length of the female sequences are longer for MK93 (5.87) than for MK60 (4.73). A similar trend can be seen for the male length sequences. This may be due to the very short length of abortion sequences for MK93. Aborted inflorescences seem to be both male and female. Both clones were started by long male and aborted cycles. 70 % of trees of MK93 are now in female cycle. 30 % have just started a male cycle. For the clone MK60, more than 90 % are in female

Table 6.Phenology and sexual composition of the crowns of studied clones MK93 and MK60.

A= aborted inflo. F = female inflo. M = male inflo.	MK60 nb of trees = 20	MK93 nb of trees = 20
A (mean per tree) s.e.	7.10 3.61	5.21 3.01
F s.e.	7.50 4.30	7.68 2.98
M s.e	4.10 3.61	4.16 4.48
sex ratio	0.4	0.44
A (lenght cycle) s.e.	3.86 3.11	1.8 0.83
F (lenght cycle) s.e.	4.73 2.88	5.59 3.16
M (lenght cycle) s.e.	3.74 3.25	3.90 3.56

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Simulation of the effect of drought on photosynthesis

Using the Dufrêne's model (SIMPALM for the carbon balance) including a water balance model which have been parametrized in Côte d'Ivoire (Dufrêne et al., 1992), a simulation have been done with the daily recording of 1994 (including meteorological parameters as : the global radiation in $kJ.m^{-2}.day^{-1}$), the daily mean temperature in °C, the wind speed in $m.s^{-1}$, the VDP in mbar, the rainfall in mm). In Fig. 5 it can be observed upon one year the drastic effect of drought and water deficit : a lack of 78 % of the photosynthetic assimilate may be observed for a deficit equal to 600 mm. If we compared the simulated values (NP simulated between 10 to 5 $\mu mol.m^{-2}.s^{-1}$) to what was observed with all clones, it may be seen that still the model overestimate the leaf gas exchange by taking into account only the soil water content effect. A new aspect of the model have to be develop taking into account the very strong effect of the VPD on stomatal closure and the regulation of the total leaf gas exchange.

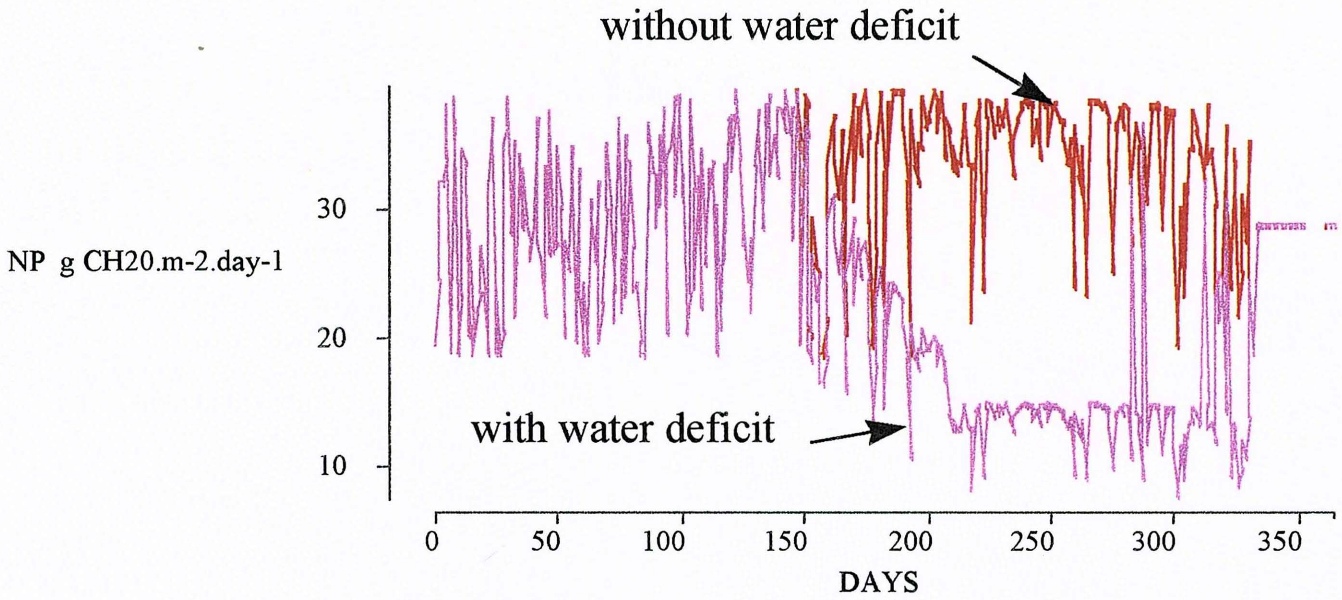

Fig. 4. Example of simulation of water deficit effect on net photosynthesis. Simulation for the year 1994 in Bekri with the Dufrêne's model (1989).

Conclusion

During a strong drought period as experienced in September 1997, it may difficult to see significant differences within clones because all trees are under water stress (water deficit was already approximatively 300 mm before increasing to 735 mm in December). Other reason is that clone is vegetatively propagated and there should not be any segregating alleles. General physiological trends under those drastic conditions were studied out. Leaf gas exchanges for all trees are particularly limited : only a minimum rate may be observed from 7 to 8 a.m. Due to the important increasing of the VPD, there is a very clear closing of the stomata to reduce water loss in tissue.This lack of carbon entrance brings out a slackening in the growth and vegetative development : accumulation of 6-7 spear leaves may be already observed. Leaf gas exchanges are more or less limited to maintenance respiration (around 5 $\mu mol.m^{-2}.s^{-1}$). Due to the soil water deficit no maximal value for photosynthetic rate and stomatal conductance are measured even before 8 a.m. (Another reason is that radiation is not asits height before 8 a. m). Concerning the effect of the VPD on the net photosynthesis, several works (Setiyo et al., 1996; Lamade & Setiyo, 1996) have given strong confirmation that different genetic material may be discriminated with the relation VPD-NP . The yield seems to be positively correlated to the reduced sensitivity of the material. In Marihat, it is the clone MK04 which show both good yield and less sensitivity to the VPD. In Lampung, in Bekri Estate, the clone MK93 showed less sensitivity. The fact that a very low rate of inflorescence abortion may be observed for this clone may be related to this reduction in sensitivity; A good yield for this clone may be expected for the formers years. Because of clonal material , the actual studied sample is small but still may be used as a base to identify several tolerant/resistant material. Nevertheless, phenological observations bring out interesting features and give illustration of the possible effect of a drastic environment on the elaboration of the sexual sequences. All trees for both clones MK60 and MK93 have started their sexual cycles with at least 10 male inflorescences which may be the influence of the severe drought of 1994. Effect of the drought on abortion rate may be quantified in future years. The Lampung, with drought events every 3 to 5 years give us an extraordinary chance to analyse the effect of the drought upon at least 3 years on yield without any interaction (for example , In Benin, where there is a drought every year , results are more difficult to analyse simply due to the length of the sexual development of each inflorescence and the overlapping of the environmental effect) and to quantify thorough the observed yield , the respective carbon allocation to the oleosynthesis, the inflorescence development and the sexual differentiation.

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