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Rainfed rice management adaptation to the increased climate variability in Côte d'Ivoire: application of ORYZA (v3) model to the bimodal areas of San-Pedro and Dimbokro

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ABSTRACT: The increasing rainfall variability in West Africa is a great challenge for crop productivity in small-scale farming systems, thus jeopardizing food security. Rainfed rice is particularly sensitive to inconsistent rainfall, especially during the reproductive stage. It is, therefore, necessary to develop management practices suited to the change of rainfall pattern over the growth seasons. In this study, the modeling technology with the rice model ORYZA (v3) was used to identify appropriate rainfed rice growing seasons for a better adaptation of farmers to climate variability. The potential yields, the favorable sowing periods, the optimum sowing dates, and the attainable yields of two contrasted cultivars were determined. After successfully calibrating and validating the model, it predicted potential yields of 5.5 to 6.5 tons/ha for the early maturing variety WAB56-104 (90-100 days), while potential yields of 4 to and 5.5 tons/ha was predicted for the late maturing variety CG14 (115-125 days). In rainfed conditions, two favorable sowing periods were identified from the model scenario analysis. The first period spans from late February to late April and the second from late July to early September. Farmers can double their actual yield of 1.5 tons/ha if they follow the recommended sowing dates and good agricultural practices. Indeed, the yield of 3.5 tons/ha was found with the variety WAB 56-104 sown on around 16 April in San-Pedro and around 2 April in Dimbokro. The yield of 3 tons/ha for the variety CG14 could be achieved if the sowing is done on around 18 March in San-Pedro and around 21 March in Dimbokro.

KEYWORDS: Côte d'Ivoire, rainfed rice, rainfall variability, adaptation, modeling, ORYZA (v3).

1 INTRODUCTION

Recent climate change has had widespread impacts on human and natural systems [1]. In West Africa and particularly in Côte d'Ivoire, where agriculture supports the livelihood of millions of small-scale farmers, climate change is experienced as rainfall amount decrease and as higher rainfall variability [2].

In that context, there are thousands of rural households whose life is tied to upland rice. As traditional farmers, they grow rice in rainfed conditions for consumption or/and for making cash. Without water control, their activity contributes to supply annually 480,000 tons of milled rice to the country [3]. Each year, they have only to take advantage of the rainy season in their rice growing. The recent increase of rainfall variability is a synonym of serious difficulties to cope. They have a problem to identify the onset and the end of the growing seasons [4]. Moreover, the risk of intra seasonal drought has become important [5]. That situation is acute in the bi-model localities of San-Pedro and Dimbokro where it is frequent for households to experience famine because of an unsuitable sowing dates in the preceding year.

That situation was studied by two research teams [6],[7] to help farmers in addressing it appropriately. The first group oriented his work on determining the beginning, the end and the variability extent of the rainy season in the entire country. Using the threshold method of Sivakumar [8], their results showed the extent of the rainy season variability in the entire country. The second team intending to help rice farmers in the middle-west localities of the country, they did climate data analysis to determine the probable sowing dates for the named specific area. The use of both outputs for rational rainfed rice management in the bimodal environment of San-Pedro and Dimbokro remains limited or unsuitable.

It could be best for farmers to be given a glimpse of the yield to which any sowing date of the year could lead to, raising the need for long-term experiments to be carried out in each locality. But these kinds of experiments are still expensive in terms of resources and time. Worldwide, crop models are tools implemented and used by the scientist community to reduce the expensiveness of such experiments [9]. Designed to mimic the soil-plant-atmosphere systems in a virtual world, they are widely used in many research fields, namely bioclimatology, soil sciences, breeding, etc [10]. The present work uses crop modeling technology to provide tailored information for taking rationally climate variability into account in rainfed rice management. It is specifically focused on determining, for rainfed rice, the potential yields, the favorable sowing periods, the optimum sowing dates, the most attainable yields, and the climate yield ceiling in the bi-modal areas of San-pedro and Dimbokro. For this purpose, the rice model ORYZA (v3) is applied to two genetically contrasted cultivars, WAB56-104 (*Oryza sativa*) and CG14 (*Oryza glaberima*).

2 METHODOLOGY

2.1 ORYZA MODEL VERSION 3

ORYZA (v3) is an explanatory, dynamic eco-physiological model that simulates growth and development of rice in potential production, water limitations, and nitrogen limitations. It is assumed that, in all these production situations, the crop is well protected against diseases, pests, and weeds and that no reductions in yield take place [11]. The model simulates rice plant phenology, leaf area development, biomass production, yield and nitrogen accumulation in response to some key environmental variables, namely temperature, solar radiation, soil water content and nitrogen fertilizer management. The required data of ORYZA are four categories described in files named accordingly: weather file, soil file, crop file, and experiment file. The weather data are daily step and encompass rainfall (mm), minimum and maximum temperature (°C), solar radiation (kJ.m-2), vapor pressure (kPa), and wind speed (m.s-1). The soil data deal with both physical and chemical properties of the soil layers explored by plant roots. Crop data are the parameters describing the cultivars response to the farming environment. And the experiment data are those describing the farmer choices in the field management.

As described by [12], ORYZA follows a daily calculation scheme for the rate of biomass production and the rate of phenological development. Phenological development rate is tracked in both models as a function of daily average ambient temperature and/or photoperiod. By integrating these rates over time, dry matter production and development stage are simulated throughout the growing season. The total daily rate of canopy CO2 assimilation is calculated from daily incoming radiation, prevailing temperature, and leaf area index (LAI). Daily assimilation rate is obtained by integrating instantaneous rates of leaf CO2 assimilation over the day and over all leaf layers in the canopy using Gaussian integration.

Being a Rice farming decision tool, ORYZA is used into two worldwide agricultural technology transfer frameworks, namely the Decision Support System for Agrotechnology Transfer (DSSAT) [13] [14] and the Agricultural Production Systems sIMulator (APSIM) [15]. ORYZA is quite fitted in rice management optimization studies for both lowland and upland environments.

2.2 FIELD DATA

Rice varieties were selected on the basis of growth duration and detailed field data availability. Because of the shortening trend of the rainy season observed over the last decades [6], long duration varieties are no more recommended. So this work was focused on growth duration less than 125 days. Moreover, since crop models were not being used in local scientist activities, finding available secondary field data for crop model calibration is so far an impediment. But some secondary data on the varieties WAB56-104 and CG14, belonging respectively to the contrasted rice species *Oryza sativa* and *Oryza glaberima* were obtained. It is known that *Oryza sativa* varieties are relatively high yielding and responsive to nitrogen inputs but not adapted to the weeds and diseases prone environments of Africa. *Oryza glaberima* varieties are more adapted to African conditions but their potential yields are lower [16].WAB56-104 has a short growth duration (around 90-105 days) and CG14 has a medium duration (around 110-120 days).

The obtained field data (Table 1) are mainly from experiments carried out on an upland environment in 1995 and, 1997 at the AfricaRice research station of Mbé (7°52', 5°6', 300 m asl) in Côte d'Ivoire [17] [18]. Another field data set is from experiments carried out on the same site in 2014, and 2015. The soil was approximately the same for all experiments. The soil characteristics (Table 2) were read on the detailed soil survey of the AfricaRice research site [19].

Table 1. Field experiments and data

Experiments	Sowing dates	Treatments	Density (cm)	Varieties	Designations	Available data
1	25 June 1995	Full irrigation + 80 kg N/ha	25 X 25	WAB56-104 CG14	Varietal characterization (Charact80)	Phenology + AGB + LAI + Yield
1	25 June 1995	Full irrigation + 0 kg N/ha	25 X 25	WAB56-104 CG14	Varietal characterization (Charact0)	Phenology + AGB + LAI + Yield
2	5 July 1997	Rainfed + 80 kg N/ha	25 X 25	WAB56-104 CG14	Water Limited (WL)	Phenology + Yield
2	5 July 1997	Rainfed + 0 kg N/ha	25 X 25	WAB56-104 CG14	Water & Nitrogen Limited (WNL)	Phenology + Yield
3	30 June 2014	Full irrigation + 186 kg N/ha	20 X 20	WAB56-104	Yield Gain Trial Irrigated 2014 (YGTIR14)	Phenology + Yield
3	30 June 2014	Rainfed + 186 kg N/ha	20 X 20	WAB56-104	Yield Gain Trial Rainfed 2014 (YGTR14)	Phenology + Yield
4	30 June 2015	Full irrigation + 186 kg N/ha	20 X 20	WAB56-104	Yield Gain Trial Irrigated 2015 (YGTIR15)	Phenology + Yield
4	30 June 2015	Rainfed + 186 kg N/ha	20 X 20	WAB56-104	Yield Gain Trial Rainfed 2015 (YGTR15)	Phenology + Yield

Table 2. Field experiment soil of Mbé, Côte d'Ivoire

Depth (cm)	Clay (%)	Silt (%)	Sand (%)
0 - 20	25	13	62
20 - 40	33	14	53
40 - 70	43	13	44
70 - 100	53	12	35
100 - 125	38	18	44

2.3 WHEATHER DATA

Weather data encompass daily readings of maximum and minimum air temperature, rainfall, relative humidity, solar radiation, and wind speed. Data collected with a nearby automatic weather station during the field experiments (calendar years 1995, 1997, 2014 and 2015) were used for calibrating and validating the model. Historical data series were used to do the simulations. These historical data were provided by the Société de Développement et d'Exploitation Aéronautique, Aéroportuaire et Météorologique (SODEXAM). The stations' coordinates are (6W39', 4N45', 8 m asl) for San-Pedro and

(4W42’, 6N39’, 113m asl) for Dimbokro. The series spans from 1981 to 2015. Data quality was preliminarily screened. Years having missing rainfall values were eliminated. But years with missing values for variable other than rainfall were corrected by filling the gap with the moving average.

2.4 CALIBRATION AND VALIDATION OF ORYZA (V3)

- Calibration

Calibrations were done with the 1995 experiments field data. For each variety, it firstly consisted in determining the phenological development rates and calculating the above ground biomass partitioning fractions. The ORYZA annex tools DRATE (v2) and PARAM (v2) were used for those operations. Then, AutoCalibration (v2), another ORYZA (v3) annex tool, was used to compute the crop parameter set that gives the best agreement between observed and simulated values. Normalized Root Mean Square Error (NRMSE) of time course above ground biomass (AGB) and leaf area index (LAI) were used to judge the calibration. NRMSE close to zero is a synonym of good fitness between observations and simulations.

$$NRMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{n}} \Big/ \bar{O} \times 100\%$$

For a given experiment variable: O_i is an observation, S_i the simulated value at the observation event, n the total of observations, and $\bar{O}$ the mean of observations.

- Validation

Before any simulation for the considered intermittent-drought prone areas, a validation of the calibrated crop file in such environment was required. Even the remaining experiments (1997, 2014 and 2015) had no time course measurement, they were used in validation by comparing simulated and observed yields. The focus was firstly put on the experiment carried out in the drought condition of 1997. In that experiment, the cultivars underwent an important early drought stress during 28 days before irrigation. So we firstly tested the model accuracy in simulating the obtained yields of the varieties. Moreover the 2014 and 2015 field data were used to test the model accuracy in other rainfed and irrigated conditions for WAB56-104.

2.5 SIMULATIONS AND STATISTICS

Potential yields (without biotic and abiotic constraints) and nitrogen potential yields (in water limited conditions) were simulated on the basis of ''blind'' sowing on each day of the year, giving 365 or 366 simulations per year. The nitrogen potential simulations were conducted under full nitrogen supply in rainfed condition. The sowing density was set to 20 × 20 cm2. The simulations were completed for all available weather data series, 29 years for Dimbokro and 25 years for San-Pedro. Simulated yields, the grain biomass plus 14% moisture, for each sowing day were used in statistical analysis to identify the best sowing dates. For each sowing date, the simulated yields were analyzed statistically for highlighting the yields at 75% occurring probability. Those probably yields are the attainable yields in rainfed condition. The obtained chart is used to characterize the favorable sowing period and the optimum sowing date. The highest attainable yields in 3 years out 4 were also sought for assessing the yield ceiling in rainfed condition. That yield ceiling allows farmers to get some understanding of the permanent climatic yield gap.

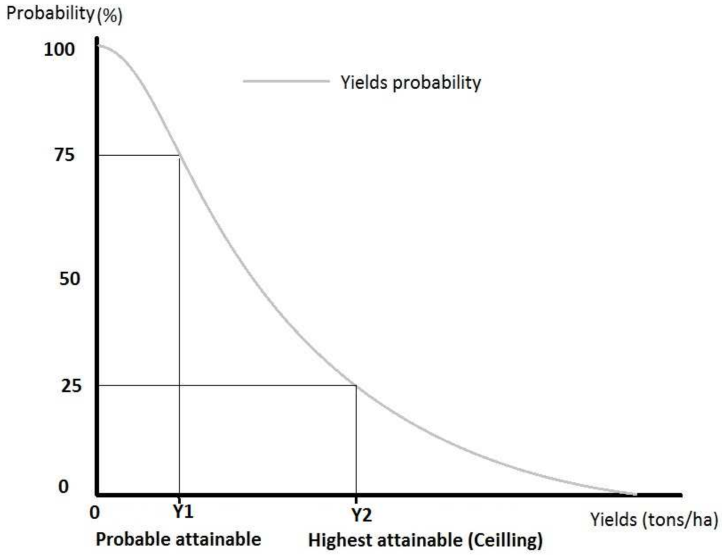


Fig. 1: Attainable and highest attainable yields for a probability level of 3 years out 4

In addition, the yield coefficients of variation (CV) were calculated for highlighting the yield variability over years on each sowing date. CV close to zero is a synonym of yield stability for the given sowing date. In the contrary, a higher CV highlights important yield variability putting doubts on the reliability of the sowing date.

3 RESULTS AND DISCUSSION

3.1 CALIBRATION OUTPUT

- WAB56-104 calibration

WAB56-104 calibration NRMSEs were16.4 % and 11.8 % respectively for the AGB and the LAI. A good agreement between observed and simulated values is obtained over the enter season (Fig. 1).

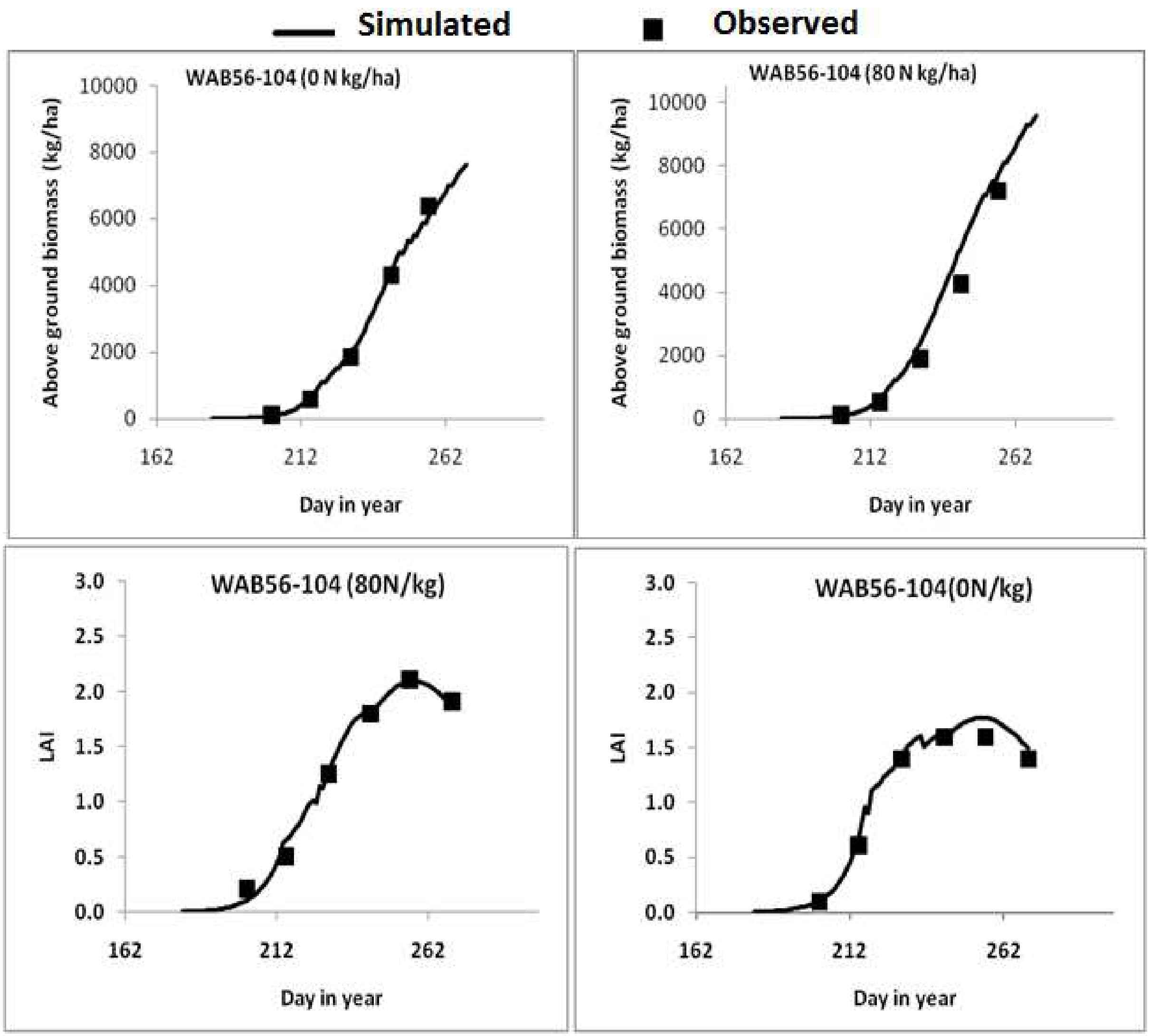


Fig. 2 : Observed and simulated values (biomass and LAI)after calibration of WAB56-104

- CG14 calibration

After calibration, CG14 NRMSEs were 18.4 % and 31.8 % for AGB and LAI, respectively. The elevated NRMSE of LAI is driven by the maximum canopy estimation (LAImax), since LAImax is overestimated in a low nitrogen condition and underestimated in high nitrogen condition. It quite appears that the LAI follows an exponential trend at the heading stage for CG14.

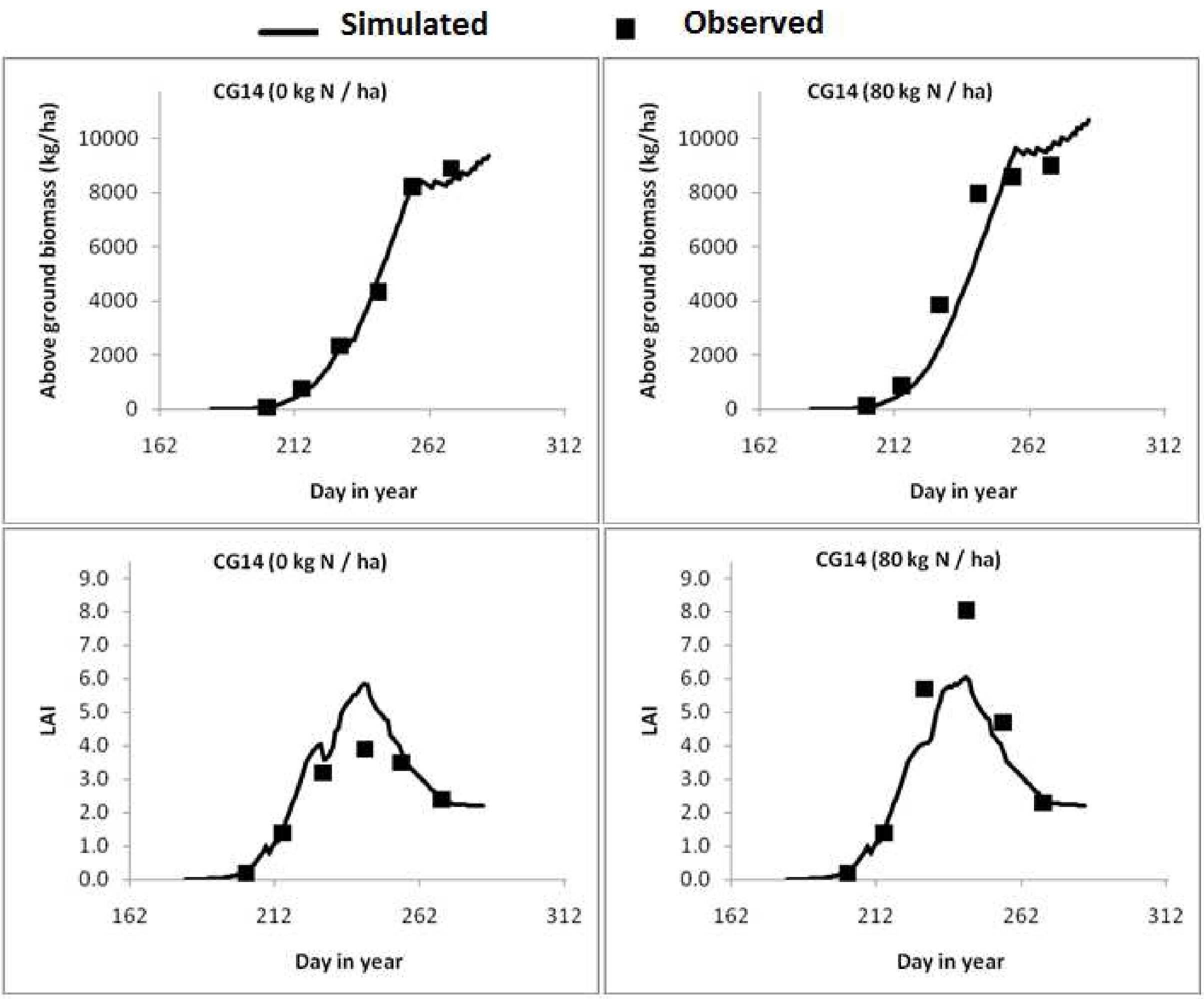
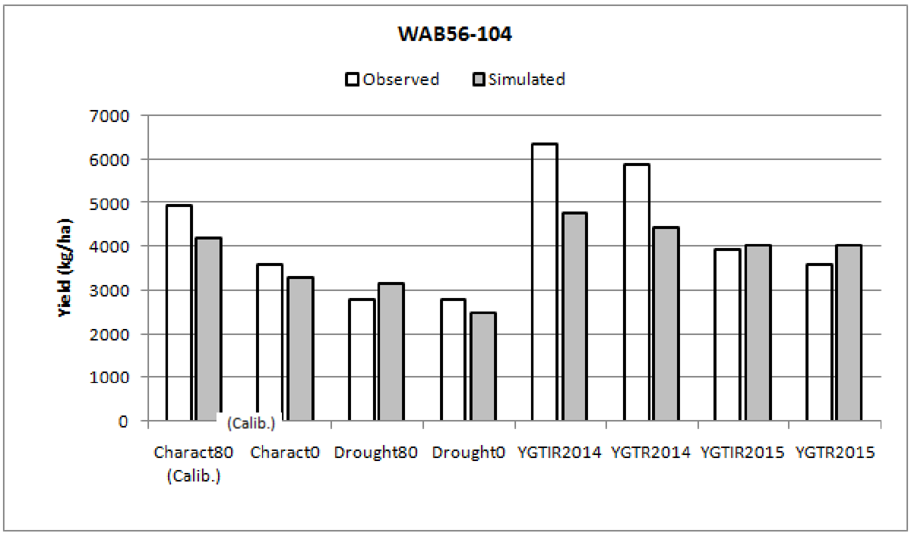


Fig. 3 : Observed and simulated values (biomass and LAI)after calibration of CG14

3.2 VALIDATION OUTPUT

In 1995 and 1997, WAB56-104 observed yields were between 2 ton/ha (Water limited) and 5 tons/ha (Full irrigated). Those obtained in 2014 and 2015 were between 3.5 and 6.5 tons/ha. This difference is basically due to the sowing densities. The sowing density of the first experiments was 0.25 × 0.25 m2 and the seconds' was 0.20 × 0.20 m2.

At validation, the simulations were in agreement with the observations. Particularly in drought experiments, simulated yields of WAB56-104 are in agreement with the observed yields. For CG14, experimental yields were under 3 tons/ha. At validation in a drought condition, a fair agreement between simulated and observed yields is also obtained, showing the fitness of the model to simulate CG14 in drought condition. At this point, ORYZA (v3) can be used to simulate the studied varieties in Côte d'Ivoire.



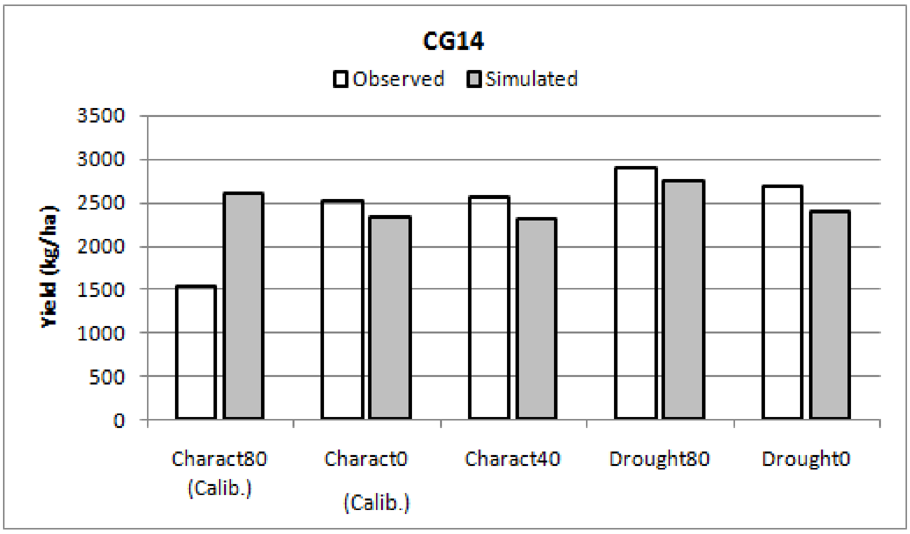


Fig. 4 : Observed and simulated yields of rice cultivars at validation

3.3 SOWING PERIODS

- Sowing periods in San-Pedro

There are two (02) sowing periods for each variety in San-Pedro. For WAB56-104 (Figure 4), the first favorable time spans from 24 February to 5 May, and the second from 28 August to 25 September. The first sowing period has 75 days and the second 29 days.

With CG14, the early sowing dates are between 25 February and 11 April. The late sowing dates are between 12 August and 10 September. The first period lasts around 47 days and the second 30 days. For both rice varieties, the second sowing period is shorter and lower yield prone than the first.

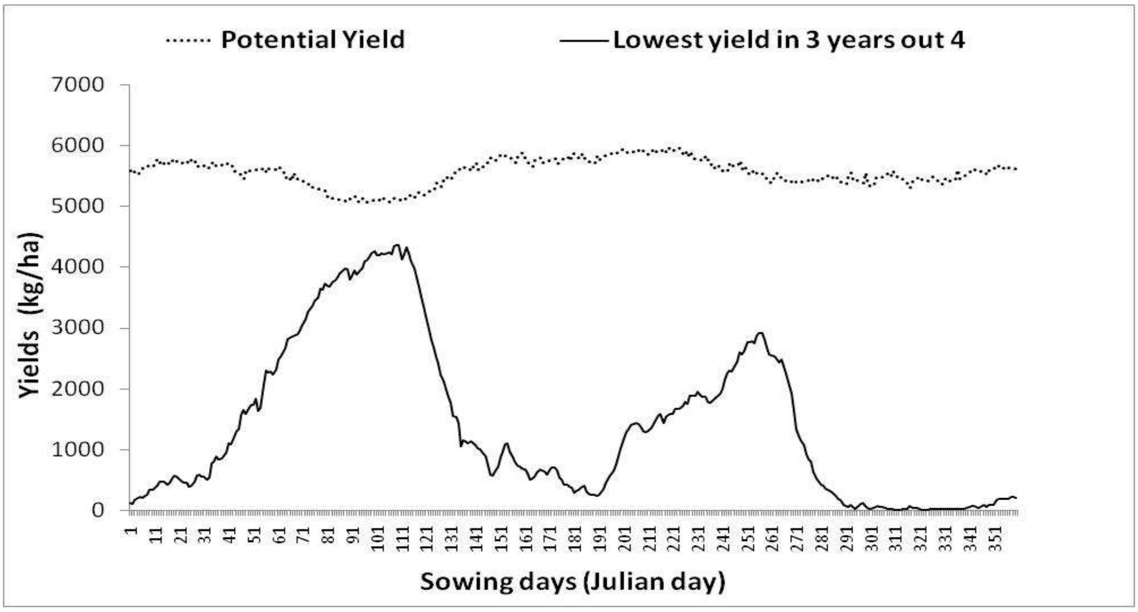


Fig. 5 : Simulated yields for WAB56-104 in San-Pedro

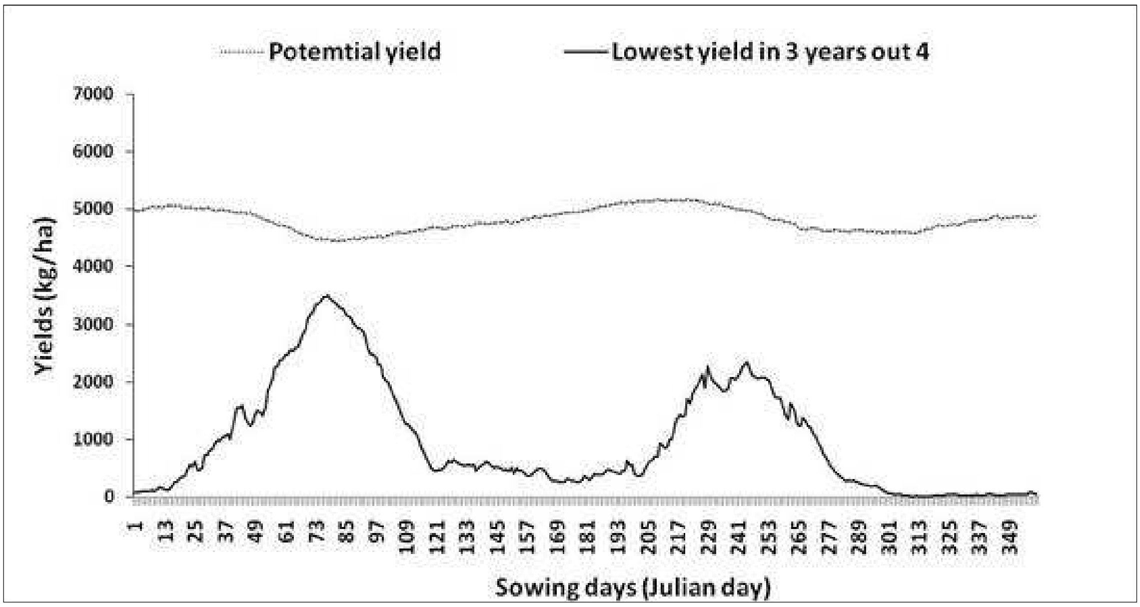


Fig. 6 : Simulated yields for CG14 in San-Pedro

- Sowing periods in Dimbokro

Rainfed rice farmers in Dimbokro have also two favorable sowing periods. For WAB56-104, the first favorable sowing dates are between 17 March and 29 April, giving 46 sowing days. The second are between 29 July and 18 August. For CG14 the first sowing period spans from 15 March to 14 April, lasting around 30 days, and the second lasts only five (05) days, spanning from 24 to 28 July. The first sowing period in Dimbokro is also larger and gives more grain yields than the second.

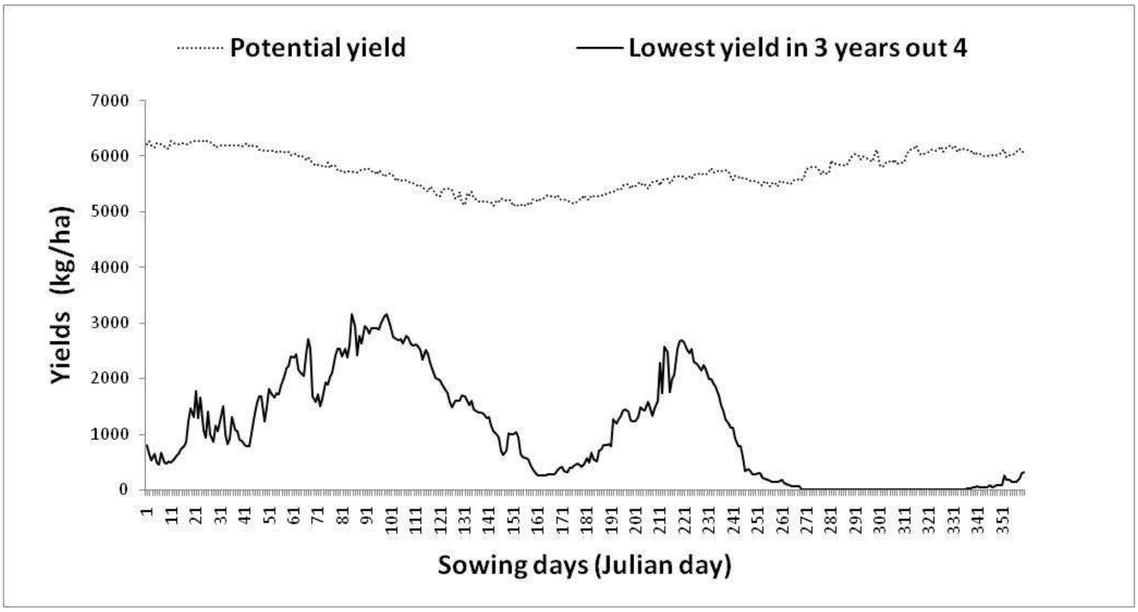


Fig 7 : Simulated yields for WAB56-104 in Dimbokro

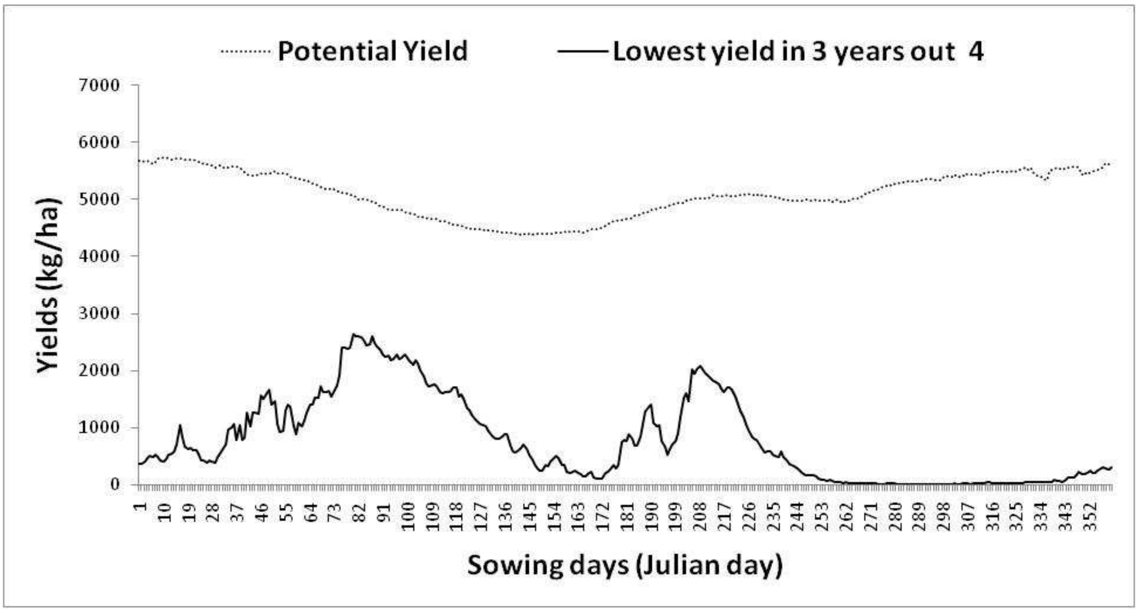


Figure 8 : Simulated yields for CG14 in Dimbokro

3.4 OPTIMUM SOWING DATES AND YIELDS

For WAB56-104, optimum sowing dates in both localities are in the first fortnight of April. The potential yield are between 5 and 7 tons/ha. Even the potential yields are higher in Dimbokro than San-Pedro, yields in rainfed condition are higher and more regular for San-Pedro than Dimbokro. Climate limitation is acuter in Dimbokro (Table 4). The permanent climatic yield gap on optimum sowing date are not too much for both localities, 17% in Dimbokro and 5% in San-Pedro.

Table 3: Sowing dates of WAB56-104 (90-105 days variety)

	First sowing periods		Second sowing periods	
	San-Pedro	Dimbokro	San-Pedro	Dimbokro
Best sowing dates of the window	15 April	5 April	13 September	05 August
Potential yields (kg/ha)	5 140	5 760	5 525	5 820
Climate ceiling yields (kg/ha)	4 894	4 768	3 942	3 940
Most attainable yields(kg/ha)	4 350	2 900	2 915	2 537
Yield Coefficient of Variation (rainfed condition) (%)	15	33	32	50
Permanent climatic yield gap (% of the potential)	5	17	29	32
Optimum sowing date of the year	15 April	5 April	---	---

The optimum sowing dates of CG14 are in the second fortnight of March. The potential yields are also higher in Dimobro than in San-Pedro. They are more than 4 tons/ha and less than 5.8 tons/ha. Rainfall yield limitation for CG14 is more important in Dimbokro than in San-Pedro. Also because of the high climate variability, yields are very unstable. Even with the optimum sowing dates, yield variability is at least 41% and the permanent climatic yield gap is 20%.

Table 4 Sowing dates of CG14 (110-120 days variety)

	First sowing period		Second sowing period	
	San-Pedro	Dimbokro	San-Pedro	Dimbokro
Best sowing dates of the window	18 March	21 March	1 September	26 July
Potential yields (kg/ha)	4 470	5 029	4 981	5 020
Climate ceiling yields (kg/ha)	4 061	4 045	3 802	3 335
Most attainable yields (kg/ha)	3 494	2 604	2 344	2 091
Yield Coefficient of Variation (rainfed condition) (%)	13	41	40	46
Permanent climatic yield gap (% of the potential)	9	20	24	34
Optimum sowing date of the year	18 March	21 March	---	---

3.5 DISCUSSION

Potential yields are higher in Dimbokro than San-Pedro. In the contrary, the expected yields are lower in Dimbokro than San-Pedro. This contradiction is explained by solar radiation and intra-seasonal dry spells. In fact, radiation is higher in Dimbokro, leading to a higher potential photosynthesis rate there. Dry spells being acuter and more frequent in Dimbokro, the permanent climatic yield gap is very marked in that locality leading to lower expected yields. Moreover, it appears that the average actual yields which are known to be less than 1.5 tons/ha [20] can be raised to 3 tons/ha in both sites if farmers get to sow on the optimum sowing dates and adopt good agricultural practices.

Aside from the yield aspects, the optimum sowing dates are remarkably in the first season regardless of the sites, precisely in April for the short duration variety and March for the medium duration variety. But farmers have to be careful when using these results. They cannot be extrapolated on other bimodal site systematically, because it appears that, not all the bimodal areas of the country have this characteristic, since [7] shown optimum sowing periods in the second season for some other areas. Even they used a different method than ours, it is certain that their results highlighted first season more drought-prone than the second for their studied areas.

4 CONCLUSION

This study was undertaken to help small scale rice farmers of the bimodal areas of Dimbokro and San-Pedro in adapting their rainfed rice management to the increased rainfall variability. After calibrating and validating the rice model ORYZA (v3), simulations were performed to study the potential yields, the optimum sowing dates, and the expected yields of two contrasted upland rice varieties. The output indicated potential yields around 5.5 tons/ha for the short duration variety WAB56-104 and 4.5 tons/ha for the medium duration variety CG14. The optimum sowing dates of WAB56-104 are16 April in San-Pedro and 5 April in Dimbokro while CG14's are18 March in San-Pedro and 21 March in Dimbokro. In the rainfed conditions of both areas, it is possible for farmers to get tons/ha instead of 1.5 tons/ha in rainfed condition with recommended optimum sowing dates and good agricultural practices.

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REFERENCES

[1] IPCC, Climate change 2007: the physical science basis: contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. , 2007

[2] Brou Y. T. Impact des modifications bioclimatiques et de l'amenuisement des terres forestières dans les paysanneries ivoiriennes : Quelles solutions pour une agriculture durable en Côte d'Ivoire. Cuardernos Géogrãficos, 45(2009-2), pp13-29., 2009.

[3] Anonymous, Office National de Développement Rizicole (ONDR), 2013.

[4] Brou Y. T., Akindes F., Bigot S. La variabilité climatique en Côte d'Ivoire : entre perceptions sociales et réponses agricoles. Cahiers Agricultures vol. 14 no6, 8 p, 2005.

[5] Koulm G., Claire H., Martin C. Ana M., Et Martin S.. Drought in the Sahel, an example of Climate Change. Climate Change workshop ENPC-Département VET.46, 2005.

[6] Goula B.T.A., Srohorou B., Brida A.B., N'Zué K.A., Goroza G. Determination and variability of growing seasons in Côte d'Ivoire. International Journal of Engineering Science and Technology Vol2(11), 5993-6003, 2009.

[7] Kouakou K. E., Kouassi A., Kouassi F. W., Goula B. T. A., and Savane I. Détermination des périodes optimales de semis du riz pluvial au Centre-ouest de la Côte d'Ivoire. International Journal of Innovation and Applied Studies. Vol. 3 No. 3, pp. 719-726, 2013.

[8] Sivakumar M. V. K.: Predicting rainy season potential from the onset of rains in Southern Sahelian and Sudanian climatic zones of West Africa. Agricultural and Forest Meteorology 42,4,295-305, 1988.

[9] V. Murthy R. K., Crop growth modeling and its application in agricultural meteorology. Satellite remote sensing and GIS application in agricultural meteorology. Proceeding of the training workshop 7-11 April, 2003, Dehra Dun, India, 235-263.

[10] Mourice S.K., Rweyemamu C.L., Tumbo S.D. and Amuri N. Maize Cultivar Specific Parameters for Decision Support System for Agrotechnology Transfer (DSSAT) Application in Tanzania. American Journal of Plant Sciences 5, 821-833, 2014.

[11] Bouman B. A. M., Kropff M. J., Tuong T. P., Wopereis M. C. S., Ten Berg H. F. M. ORYZA2000: Modeling lowland rice. Los Baños (Philippines): International Rice Research Institute, and Wageningen: Wageningen University and Research Centre. 235 p, 2001.

[12] Bouman B. A. M., Van Laar H.H. Description and evaluation of the rice growth model ORYZA2000 under nitrogen-limited conditions. Agricultural Systems 87.249–273, 2006.

[13] G. Hoogenboom, J.W. Jones, P.W. Wilkens, C.H. Porter, K.J. Boote, L.A. Hunt, U. Singh, J.I.Lizaso, J.W. White, O. Uryasev, R. Ogoshi, J. Koo, V. Shelia, and G.Y. Tsuji. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.6 (www.DSSAT.net).DSSAT Foundation, Prosser, Washington, 2015.

[14] Jones J.W., G. Hoogenboom, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, P.W. Wilkens,U. Singh, A.J. Gijsman, and J.T. Ritchie. DSSAT Cropping System Model. European Journal of Agronomy 18:235-265, 2003.

[15] Holzworth D., Meinke H., DeVoil P., Wegener M., Huth N., Hammer G., Howden M., Robertson M., Carberry P., Freebairn D., and Murphy C. (2006). The development of a farming systems model (APSIM) – a disciplined approach. In: Voinov A., Jakeman A., Rizzoli A. (eds). Proceedings of the iEMSs Third Biennial Meeting: "Summit on Environmental Modeling and Software". International Environmental Modeling and Software Society, Burlington, USA, July 2006. [Online] Available: http://www.iemss.org/iemss2006/sessions/all.html (November, 2016)

[16] Linares, O.F. African rice (*Oryza glaberrima*): history and future potential. Proceedings of the National Academy of Sciences of United States of America99, 16360–16365, 2002.

[17] Dingkuhn M., Jones M. P., Johnson D. E. Growth and yield potential of Oryza sativa and *Oryzagla berrima* upland rice cultivars and their interspecific progenies. Field Crops Research 57.57-69, 1998.

[18] Dingkuhn M., Audebert A. Y., Jones M. P., Etienne K., Sow A. Control of stomatal conductance and leaf rolling in *O. sativa* and *O. glaberrima* upland rice. Field Crops Research 61. 223-236, 1999.

[19] Hakkeling, R.T.A., Smaling, E.M.A. and Diatta, S. Detailed soil survey and land evaluation of the WARDA experiemntal area, Bouaké, Côte d'Ivoire. Report 22 The Winand Staring Centre, Wageningen. 60pp, 1989.

[20] Doumbia Y. et Sidibé B. Évaluation de l'effet des cultures de diversification sur la fertilité du sol et sur le rendement du riz dans une rotation à base du riz pluvial NERICA. Gestion des ressources naturelles. Actes 4 Rs 2004 : 239 - 247, 2004.