# Rescaling of the optimal sowing period for rainfed rice in the Ivorian pre-forest zone

**Running title:** New rainfed rice optimal sowing period in Ivory Coast

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## Abstract

Climate change in the pre-forest zone of Ivory Coast has led to a mismatch between cropping periods and new seasons, challenging the sowing periods usually recommended for rain fed rice cultivation in this area. Our study aims to determine the optimal sowing period for two rainfed rice varieties cultivated in this pre-forest zone of the country.

The in silico agro-climatic analysis, carried out over the period 1980-2017, consisted in determining, for a given sowing date, the probability of meeting the water requirements for the development and growth of rainfed rice, particularly for the emergence, flowering and maturation stages. The sowing date periods corresponding to the highest probabilities of meeting water requirements were identified as favorable and optimal sowing periods.

The agro-climatic analysis carried out over the period 1980-2017 allowed to determine the optimal dates for sowing rice, which ensures, with the maximum probability, the crop's water satisfaction over its entire cycle. This analysis showed that for an annual probability of success over 80%, the optimal sowing period ranges from March 22 to April 26 for the 120-day average cycle rainfed rice variety and, from March 27 to May 11, for the 100-day short cycle rainfed rice variety. These periods allow a good water supply for the crop's first cycle, but it is not possible to implement a second cycle with the same water supply levels in this area.

**Keywords**: Climate change, Optimal sowing period, Rainfed rice, Pre-forest area, Ivory Coast

## Résumé

**Détermination de la période optimale de semis du riz pluvial en zone pré-forestière ivoirienne**

**Titre court :** Nouvelle période optimale de semis du riz pluvial en Côte d'Ivoire

Le changement climatique dans la zone pré-forestière de la Côte d'Ivoire a conduit à une inadaptation entre les périodes de culture et les nouvelles saisons, remettant ainsi en cause les périodes de semis habituellement recommandées pour la culture du riz pluvial dans cette zone. Notre étude vise à redéfinir la période optimale de semis pour deux variétés de riz pluvial cultivées dans cette zone pré-forestière du pays.

L'analyse agro-climatique in silico, réalisée sur la période 1980-2017, a consisté à déterminer, pour une date de semis donnée, la probabilité de satisfaction des exigences hydriques du développement et de la croissance du riz pluvial, notamment pour les stages de levée, de floraison et de maturation. Les périodes de dates de semis correspondantes aux probabilités les plus élevées de satisfaction des exigences hydriques ont été identifiées comme périodes favorable et optimale de semis.

Cette analyse a montré que pour une probabilité annuelle de satisfaction des besoins hydriques supérieure à 80%, la période optimale de semis s'étend du 22 mars au 26 avril pour la variété de riz pluvial à cycle moyen de 120 jours et, du 27 mars au 11 mai, pour la variété de riz pluvial à cycle court de 100 jours. Ces périodes permettent une bonne alimentation en eau pour le premier cycle de la culture, mais il n'est pas possible de mettre en place un second cycle avec les mêmes niveaux d'alimentation en eau dans cette zone.

**Mots clés :** Changement climatique, Période optimale de semis, Riz pluvial, Zone pré-forestière, Côte d'Ivoire.

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## 1. Introduction

Rice (*Oryza sativa*) is a staple food for the whole Ivorian population. It is the fourth largest food crop in terms of volume of production after yam, cassava, and plantain banana (Depieu *et al.,* 2010). In 2009, rice production accounted for about 10% of national food production (FAO, 2009). The annual consumption was estimated to 66 kg per capita in 2011 and represented an increase of a factor of 1.8 compared with 1960. The overall use of rice in Côte d'Ivoire in 2011, compared with 1960, was tenfold increased to 1.43 million tons, with about 50% of domestic demand not covered by the national production (Bahan *et al*., 2012; JICA, 2013). Consequently, Côte d'Ivoire relies on massive importations to satisfy the local demand for rice. In 2009, imports amounted to 919,000 tons at the cost of around 235 billion CFA francs (ONDR, 2012).

In response to this issue, the country is engaged in an ambitious National Rice Sector Development Program in order to achieve food self-sufficiency by increasing the productivity of the rice sectors as one of its primary objectives (ONDR, 2012). Emphasis has therefore been focused on rainfed rice, which was previously grown mainly in the western regions but has now spread in varying proportions throughout the country. As a result, rainfed rice occupies 86% of the cultivated areas and contributes to 80% of the national paddy production (Zingore *et al.*, 2014). However, rice productivity is still low and strongly constrained by the adverse effects of climate changes in the study region. Indeed, there has been an average reduction in rainfall of 6% throughout the country (Djè, 2014; Yao *et al.,* 2013) and studies conducted by the National Meteorology Office (DMN) show that over the past five decades, the country has warmed up by an average of 0.5°C. Also, climate forecasts for this country indicate a 3°C increase in temperature by 2100 over most of the country and an 8% daily decrease in rainfall during the April to July period (Djè, 2014).

Changes in climate parameter averages over the past three decades (CCNUCC, 1992) have resulted in a mismatch between major weather parameters and current crop season dates (Djè, 2014). This is particularly true in the pre-forest zone of Côte d'Ivoire, where the bimodal four-season rainfall regime is gradually being replaced by a monomodal two-season rainfall regime (Diomandé *et al.*, 2008); thus, challenging previously recommended sowing periods for rainfed rice. Therefore, an update of the cropping calendar is needed for the development of rainfed rice cultivation in this area. This study aims to address, like several studies carried out in other regions (Koné, 1990; Kouakou *et al.,* 2013), this problem by determining the optimal sowing period for rainfed rice grown in the pre-forest zone of Côte d'Ivoire.

## 2. Materials and Methods

### 2.1. Study area

The department of Yamoussoukro (latitude 6.85 North; longitude 5.29 West; altitude 214 m) is the study area (Figure 1).

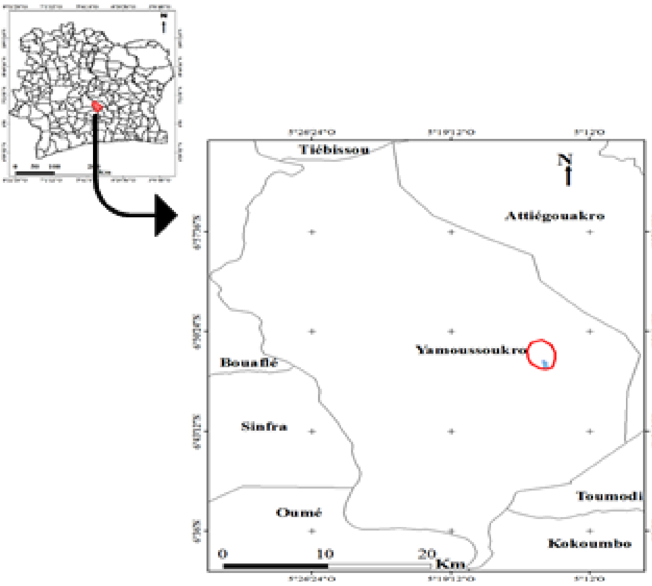


Fig 1. Study area: Administrative department of Yamoussoukro

The climate of the study area is a transitional equatorial type with annual rainfall between 1000 and 1500 mm and a monomodal rainfall regime with two seasons, according to Gaussen's criteria (Gaussen, 1957). The rainy season begins in March and ends in November. The wettest month is June, with an average of 160 mm of rain. The less wet months are July and August, with averages between 95 and 101 mm of rain. The dry season is also known as *Harmattan,* begins in December and ends in February with averages rainfed ranging from 7.57 mm to 38.90 mm. The monthly temperatures range from 25.46°C to 28.5°C, with an average of 26°C.

The annual relative humidity of the study area varies between 75% and 85% but drops to 40% during the *Harmattan*. The soils are sandy-clay, and their pH ($H_2O$) is 5.5. Soil granulometry includes, on average, 74.5% sand, 13.5% clay, and 9.5% silt with an estimated available water capacity (RU) of 70 mm (SODEXAM, 2013).

### 2.2. Plant material

In this study, one medium-cycle of 120 days (IDSA 85) and one short-cycle of 100 days (Nerica 1) varieties were used. Nérica 1 was introduced in Côte d'Ivoire in 1996 and used as resilient to climate risks (Akintayo et al., 2008). For all of these varieties, there are four major growing stages, and each one is characterized by a crop coefficient Kc that determines the stage water requirements (FAO, 1998).

### 2.3. Data collection

Two categories of data were used in this study: climatic and agronomic data. Daily climate data over 37 years (1980 to 2017) were supplied by the SODEXAM weather station in Yamoussoukro (latitude North 6.90; longitude East -5.37). These data from the study area include minimum and maximum temperatures, minimum, maximum and mean relative humidity values, global radiation, mean wind speed, and rainfall amounts.

Agronomic data consist first in soil water capacity (RU), and rhizosphere water holding capacity (RUR) estimated at 70 mm.

### 2.4. Data Analyses

The agro-climatic analysis approach was used in this study to determine the favorable sowing period and the optimal sowing period for rice. The crop year was divided into five (05) day time steps. Each time step constituting a potential sowing date. The favorable and optimal sowing dates are those that ensure the satisfaction of the crop's water requirements (Lhomme and Monteny, 1980).

#### 2.4.1. Determination of the favorable rice sowing period

According to Stern *et al.* (2006), the favorable sowing period is the one during which the probability of appearance of dry sequences longer than ten days is low (≤ 20%). This period ensures water satisfaction for the plantlets' emergence.

The analysis of the probability of occurrence of dry sequences exceeding ten days during the 30 days following sowing allowed to estimate the favorable sowing period.

The software INSTAT + version 3.036, a statistical analysis software of agro-climatological data and agrometeorological simulation model, was used to count, for a given sowing date and over the 37 years of study, the number of dry sequences greater than 10 days during the 30 days following this sowing date. This number, related to the number of years of study (37 years), made it possible to calculate the probabilities of occurrence of dry sequences greater than 10 days during the 30 days following the sowing dates.

The evolution curve of the probability of occurrence of dry sequences greater than 10 days during the 30 days following sowing was obtained by putting the sowing dates on the abscissa and the probabilities of occurrence of dry sequences greater than 10 days during the 30 days following these sowing dates on the ordinate.

**2.4.2. Determination of rice optimal sowing period**

Unlike the favorable sowing period, which ensures that water requirements for plantlet emergence are met, the optimal sowing period ensures, with the maximum probability, that both water requirements for the emergence and those for crop's development and growth (Lhomme and Monteny, 1980), particularly the heading-flowering and maturation stages, are also achieved.

The satisfaction of the water requirements of plantlet emergence corresponds to the minimum probability (Probability ≤ 20%) of occurrence of dry sequences longer than ten days during the 30 days following the sowing. The satisfaction of water requirements during the heading-flowering and maturation stages corresponds to the maximum probability (Probability ≥ 80%) of occurrence of good water supply conditions during these stages. The good water supply conditions for the heading-flowering and maturation stages were determined from the rainfed rice water requirements index I defined by Frère (1987), whose values should be greater than or equal to 95.

Indeed, Frère (1987) developed a method for estimating the index I of satisfaction of crop water needs in countries where water is a limiting factor in rainfed agriculture. Index I express the degree to which the plant's cumulative water requirements have been achieved at a given physiological stage or for the entire growing cycle. It also allows water deficits to be monitored throughout the growing season, considering phenological stages and periods when water availability is most critical for crop development.

The water balance is based on a relatively simple principle. At the beginning of the rainy season, I was assigned the value 100 on the assumption that at sowing time, the water content in the soil is higher than the water requirements of the plants.

I value decreases as soon as water stress occurs. In the event of a water deficit ($D_i$), the I index is reduced by the percentage of this deficit in relation to the total water requirements for the season (TMR).

If ($E_i/D_i$) < 0 then $I_i = I_{i-1} - (\frac{E_i}{D_i} \times 100)/TMR$, with TMR = Kci ×PET (1)

If $0 \leq E_i/D_i \leq 100$ then $I_i = I_{i-1}$. (Frère, 1987)

Kci: crop coefficient of the plant at a phenological stage and a given decade or pentad i (Dancette, 1983); $PET_i$ : potential evapotranspiration of the decade or pentad i and $E_i$: excess water in the soil of the decade or pentad i.

The PET (Potential Evapotranspiration) values for the area were calculated using the Penman-Monteith formula (FAO, 1998; Allen *et al.,* 1998).

In the event of excess water in the soil of more than 100 mm, considered as excess water harmful to the plant, the index will be reduced by three units.

If ($E_i/D_i$) > 100, then $I_i = I_{i-1} - 3$ (Frère, 1987) (2)

Depending on the frequency level, we have cases of excellent (I=100%), good (95≤I≤99), moderate (80≤I≤94), mediocre (60≤I≤79) and poor (50≤I≤59) water supply (Sarr, 2012; Sarr *et al.,* 2012).

Using the method of Frère (1987), the value of the I index of water requirement satisfaction, for a given physiological stage, for a given year and for a given sowing date, was determined. Applied to the duration of the study, which spans 37 years (1980-2017), for a given seeding date, 37 Index I values were obtained. The number of Index I values greater than 95 (I ≥ 95) was then deduced, i.e., the number of times the given stage had its water requirements fully met. Finally, the probability of occurrence of good water supply conditions (I ≥ 95) for the considered stage at the indicated sowing date was calculated by relating this number of Index I values higher than 95 on the number of years of study which is 37.

The evolution curve of the probability of occurrence of good water supply conditions (I ≥ 95) for the physiological stage studied was obtained by putting the sowing dates on the abscissa and the probabilities of occurrence of good water supply conditions (I ≥ 95) for this stage on the ordinates.

The analysis of the evolution, as a function of sowing dates, of the likelihood of dry sequences occurring for more than ten days during the 30 days following sowing, as well as the evolution of the likelihood of good water supply conditions in the heading-flowering and maturation stages enabled to determine the optimal period for the sowing of rainfed rice in the study area.

The optimal sowing period was determined graphically using two approaches. The first one from the intersection of three (03) curves: (i) the evolution curve, as a function of sowing dates, of the likelihood of dry sequences exceeding ten days occurring, 30 days after sowing of rainfed rice, (ii) the evolution curve, as a function of sowing dates, of the likelihood of good water supply conditions (I ≥ 95) of the heading-flowering stage and, (iii) the evolution curve, as a function of sowing dates, of the likelihood of good water supply conditions occurring (I ≥ 95) in the maturation stage.

The second approach is the determination from the intersection of two (02) curves: (i) the evolution curve, as a function of sowing dates, of the probability of occurrence of dry sequences of more than ten days, 30 days after sowing of rainfed rice, and (ii) the evolution curve, as a function of sowing dates, of the probability of occurrence of good water supply conditions (I ≥ 95) of both the heading-flowering and the maturation stages. The latter likelihood is the product of two probabilities by considering that the events related to heading-flowering and maturation stages are independent.

## 3. Results

### 3.1. Favorable period for sowing rainfed rice or period of good water supply conditions for the emergence of rainfed rice plantlets

Figure 2 shows, depending on the sowing dates, the evolution of the probability of occurrence of dry sequences longer than ten days during the 30 days following sowing. The probabilities of occurrence of dry sequences greater than ten days were high (greater than 80%) between November 21 and January 26. They decreased from January 26 and reached zero between April 20 and June 4. They increased slightly from June 4 to July 29 before gradually decreasing to zero between August 18 and October 2. From there, they rapidly increased to a maximum of 100% on November 26.

The analysis of this curve reveals the period from March 1 to October 22 as the favorable sowing period because it corresponds to the period when rainfed rice emergence requirements in the pre-forest zone are satisfied. Indeed, throughout this period, the probability of occurrence of dry sequences longer than ten days remained below 20%.

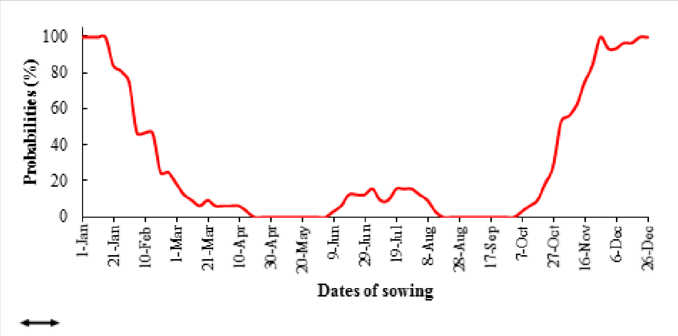


Fig 2. Evolution of the probability of occurrence of dry sequences longer than ten days, 30 days after sowing rainfed rice (1980-2017-time period)

### 3.2. Optimal sowing period for average cycle rainfed rice of 120 days

From the analysis of the evolution of probabilities to obtain enough water supply, we could provide a first approximation of the optimal sowing period. It may go from March 02 to July 20 (Figures 3 and 4). Sowing during this period would allow a good water supply for the rice with probabilities of success ranging from 14% to 90% of the years. However, considering a maximum probability (probability > 80%) of rice growth success over the period 1980-2017, the optimal planting period for rainfed rice of 120 days could be limited

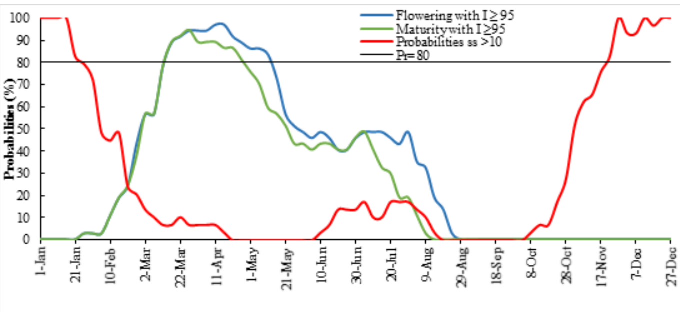


Fig 3. Graphical determination of the optimal sowing period for average cycle rainfed rice by the intersection of the three curves
I: index I of satisfaction of crop water needs at a given physiological stage or for the entire growing cycle; ss: dry sequences

from March 22 to April 26 (Figures 3 and 4). Sowing between March 22 and April 26 will allow a good water supply for 120-day rice variety in more than 80% of the years.

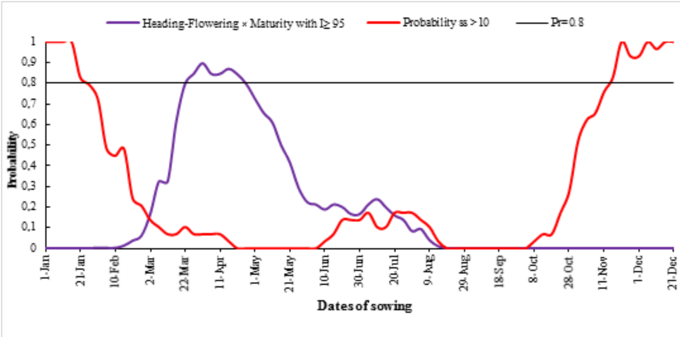


Fig 4. Graphical determination of the optimal sowing period for average rainfed rice by intersecting two curves.
I: index I of satisfaction of crop water needs at a given stage or for the entire growing cycle; ss: dry sequences

### 3.3. Optimal sowing period for short-cycle rainfed rice of 100 days

The intersection between water availability and short-cycle rice requirements allowed us to propose a first approximation of the optimal sowing period. This period ranges from March 02 and September 03 (Figures 5 and 6). Sowing in this period would provide a good water supply for the rice with an annual success rate of between 0 and 95%. However, considering a maximum probability (probability > 80%) of success, the optimal sowing period for rainfed rice of 100 days can be restricted from March 27 to May 11. Sowing during this period will provide a good water supply for rainfed rice of 100 days in more than 80% of cases.

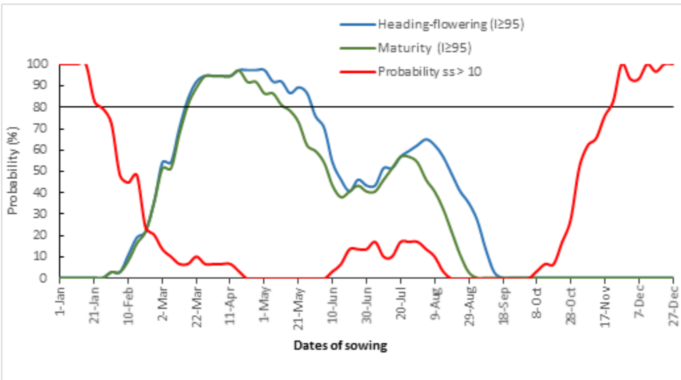


Fig 5. Graphical determination of the optimal sowing period for short cycle rainfed rice by intersecting the three curves.
I: index I of satisfaction of crop water needs at a given stage or for the entire growing cycle; ss: dry sequences

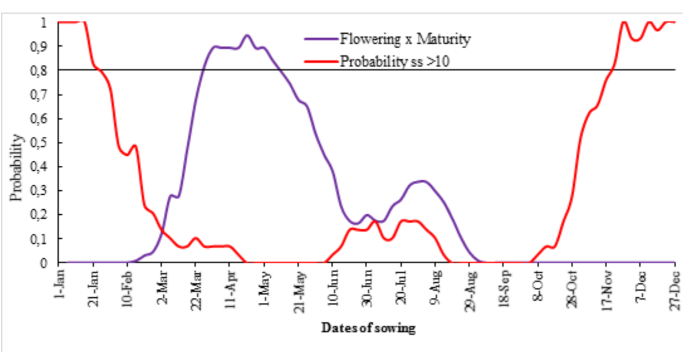


Fig 6. Graphical determination of the optimal sowing period for short cycle rainfed rice by intersecting the two curves

## 4. Discussion

In Côte d'Ivoire, climate change, through its effects on temperatures and rainfall, is aggravating the vulnerability of agriculture, resulting in a complete uncertainty concerning rainfall distribution and evolution. This makes the current cropping periods being completely unsuitable to the new season configuration (Djè, 2014). Diomandé *et al.* (2008) revealed that, in the "V Baoulé region", including the study site, the four-season rainfall regime is gradually shifting into a two-season rainfall regime. Specifically, in the study area, the bimodal rainfall regime has been replaced by a monomodal rainfall regime. As a result, the risk of rainfall deficiency for rainfed crops has increased, and cropping calendars have been disrupted, with a more significant impact on average cycle varieties. The imperative of adapting farming practices to climate change is well established (Somé, 2006). Our results show that, according to the criteria of Stern *et al.* (2006), the favorable sowing period for rainfed rice in the pre-forest zone extends from March 1 to October 22. Considering, also water satisfaction for plantlets' emergence and water satisfaction during heading-flowering and maturity stages, the optimal sowing period for the considered 120-day variety is from March 2 to July 20, with an annual success rate between 14% and 90%. This optimal sowing period should be restricted to March 22 to April 26 when considering an annual success rate of more than 80%. For 100-day rice variety, for an annual success probability between 0% and 95%, the optimal sowing period is from March 2 to September 3. This period should be restricted to March 27 to May 11 when considering an annual success probability greater than 80%.

The optimal sowing period for short cycle rice shown to extend from March 27 to May 11 is included in the period indicated in 2005 by the National Center for Agricultural Research (CNRA), which covers the month of April and the period from June 15 to July 05 (CNRA, 2005). However, for 120-day rice variety, the optimal period determined in the study (from March 22 to April 26), does not include the month of June suggested by the CNRA (CNRA 2005). It appears that the effects of climate change since 2005 have once again disrupted the rainfed rice cropping calendar in the study area. Similar results were obtained by Kouakou *et al.* (2013) in west-central Côte d'Ivoire, where the period from April 11 to 30 is now recommended for 90-day rice planting and from March 1 to April 20 for 105-day rainfed rice.

The narrowness of the identified optimal sowing periods is not favorable to a second crop cycle, neither for the variety of the average length cycle nor for the short-cycle variety. Indeed, in a second growing cycle, plants will not benefit from good water supply conditions with a high probability of success. A possible second crop cycle sown outside the optimal periods identified will be confronted with water supply conditions ranging from average to poor or with a lower probability of success (Probability $< 0.8$), implying a higher risk of failure. Kouakou et al (2013) reached similar results, showing that the second vegetative period of rainfed rice in central western Côte d'Ivoire is short (maximum 2 months 10 days) and could not guarantee water satisfaction of the second rainfed rice cycle, which has a minimum duration of 3 months, regardless of the variety grown. They therefore recommended a single cropping cycle in the year for some localities in this zone. This single cropping cycle should straddle the two vegetative periods, with a sowing taking place at the end of the first vegetative period.

## 5. Conclusion

The study aimed to identify the optimal sowing period for rainfed rice in the Ivorian pre-forest zone. The results showed that the optimal sowing period for 120-day rainfed rice varieties is 35 days from March 22 to April 26, and for 100-day rainfed rice varieties is 45 days from March 27 to May 11. According to our results, rainfed rice farmers in the department of Yamoussoukro should prioritize a single crop cycle and sow average cycle varieties between March 22 and April 26 and short cycle varieties between March 27 and May 11. Considering the high variability of climatic parameters, the present study is timely to propose new adjustments in cropping calendars. In addition to the newly suggested periods, our research considers success rates, which are important to reduce lost risks considering low economic possibilities of small farmers who cannot afford ruined harvests. In this perspective, further climate data modeling could provide a rapid and real-time update of optimal sowing periods.

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